Journal of Oil Palm Research
DOI: https://doi.org/10.21894/jopr.2024.0045

A BIOMECHANICAL ANALYSIS ON WORK-RELATED MUSCULOSKELETAL DISORDERS USING A MECHANISED CHAINSAW FOR OIL PALM HARVESTING

UMESH GANESH[1]; ZAIDI MOHD RIPIN[1]; WAN MOHD AMRI WAN MAMAT ALI[1]; YEO YING HENG[1]; MITCHELLE LAW JYY JINN[1]; JEEVINTHIRAN KARUNAGARAN[1] and MOHAMAD IKHWAN ZAINI RIDZWAN[1*]

ABSTRACT

The demanding nature of harvesting, which requires high cutting force, often leads to extensive physical exertion and fatigue. This study investigates the potential of utilising a pole-mounted mechanised chainsaw to minimise the pulling effort required to overcome friction forces during oil palm harvesting. The powered chainsaw demonstrates a mean peak cutting force of 677.57 ± 337.83 N, with a corresponding Rapid Entire Body Assessment (REBA) score averaging 8.11 ± 1.41. The mean 5th lumbar vertebra and 1st sacral vertebra (L5-S1) compression and shear forces were 808.63 ± 63.84 N and 528.16 ± 190.98 N, respectively, both below the safety threshold. Mechanised tools reduce muscle activation and pain scores across various muscle groups. Peak muscle activation measured less than 65% for the right biceps, and mean values were below 30% for all muscle parts. The mean peak pain score was 6 for the right and left biceps, and the right anterior deltoid, while the mean peak value was consistently less than 4 for all muscle parts. The tool processes one frond every 25 s, potentially handling 20 to 30 FFBs/hr. This study suggests that mechanised tools have the potential to enhance worker well-being and efficiency in oil palm harvesting.

Keywords: hand-force, mechanised harvesting tool, oil palm ergonomics, oil palm harvesting, work-related musculoskeletal disorders (WMSDs).

Received: 2 February 2024; **Accepted:** 9 July 2024**; Published online:** 19 September 2024.

INTRODUCTION

The oil palm, which originated from West Africa, has been cultivated as a primary food crop for approximately 5000 years. Today, it is grown in 43 countries worldwide, with Malaysia being one of the prominent producers (Kushairi *et al.*, 2017). The expansion of oil palm plantations has been driven by its versatile applications, including the widespread use of palm oil biodiesel as an alternative energy source. Furthermore, the increasing demand for vegetable oils, fuelled by dietary and industrial needs, has further propelled the growth of the oil palm industry (Oyedeji *et al.*, 2020). In 2016, the oil palm plantation sector employed 429 351 field workers, and this figure continued to rise in subsequent years (Abdullah *et al.*, 2023).

Despite the rapid growth of oil palm production, traditional harvesting methods involving long sickles and chisels are still prevalent, necessitating a considerable workforce (Teo *et al.*, 2023). Harvesters are required to exert significant hand forces for frond cutting, leading to extensive physical exertion and potential fatigue (Abdullah *et al.*, 2023). The manual application of cutting forces and repeated attempts are essential in the actual palm environment, contributing to the physical strain experienced by the harvesters, as highlighted

[1] Neurorehabilitation Engineering and Assistance Systems Research, School of Mechanical Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.

* *Corresponding author e-mail: mikhwanr@usm.my*

in the study by Saibani *et al.* (2015). Harvesters face challenges associated with uncomfortable working positions and repetitive cutting motions (Tumit *et al.,* 2021), including a 30° neck extension, 90° shoulder flexion, 31° shoulder extension, 45° back flexion, 20° back extension, 120° elbow flexion, 90° hip flexion, 90° knee flexion and 20° ankle flexion. These factors contribute to an increased risk of work-related musculoskeletal disorders (WMSDs), encompassing high physical exertion, awkward postures, and repetitive movements (Tumit *et al.,* 2021).

Previous studies consistently report a high prevalence of lower back and upper back pain among oil palm plantation workers, attributed to spinal loads, inducing vertebral stress (Henry *et al.,* 2015). The lumbar region, particularly L5-S1, experienced the most compression forces. Body pain may result from work-related musculoskeletal disorders (WMSDs), which are common among palm harvesters (Ahmad and Yahya, 1998a; Bhuanantanondh *et al.,* 2021). Most studies assessing the risk of WMSDs among palm workers employ an indirect measurement and qualitative approach, by utilising ergonomic assessment tools such as rapid upper limb assessment (RULA), rapid entire body assessment (REBA), and OVAKO working posture analysis system (OWAS), based on video recording and interviews (Abdullah *et al.,* 2023; Nawi *et al.,* 2016; Ng *et al.,* 2015).

Mechanisation and automation in oil palm harvesting have been the focus of research and development to address the WMSD issues and improve labour productivity in oil palm harvesting (Aljawadi *et al.*, 2018). Various methods and technologies have been proposed to improve the efficiency and safety of the harvesting process (Hamsi *et al.,* 2020). The advantage of the chainsaw over readily available tools like CANTAS™ and Ckat™, lies in its cutting mechanism. While CANTAS™ and Ckat™ utilise motorised sickles and chisels mounted inside a vibrating mechanism, which can be effective for harvesting fresh fruit bunches (FFBs), the chainsaw, however, introduces a different approach. Another study that will possibly eliminate the risks associated with oil palm harvesting is by developing and evaluating the performance of an oil palm harvesting robot (Oyedeji *et al.,* 2022). By employing a material-removing cutting method, specifically with a chainsaw, this study aims to address a specific challenge and minimise the pulling effort during harvesting. Unlike the vibrating sickles and chisels, the chainsaw's cutting action involves removing material more directly, thus potentially reducing the resistance encountered during the cutting process. This change in approach may offer potential advantages in terms of efficiency, ease of use, and safety during oil palm harvesting operations.

A narrow wedge angle in cutting tools such as sickles, increases the friction force, and demands a larger pulling force to overcome resistance to cut the fronds. Chainsaws, however, have wider wedge angles, which reduce the pulling force needed to enhance penetration and reduce binding, thus making them more efficient for cutting thicker fronds with less manual effort. This study represents the first comprehensive investigation into the effectiveness of the chainsaw as a cutting tool in oil palm harvesting. By examining the muscle activity, working postural angles, hand force exertion, lower back forces, ergonomic risks, and body pain, this study aims to provide valuable insights into the potential benefits of this innovative approach for oil palm harvesting.

MATERIALS AND METHODS

Area

The average height of oil palm trees in the study area ranged from 2.5-3.0 m, which shows the suitability of the developed mechanised electric-chain saw in the harvesting process. The study was conducted at Universiti Sains Malaysia's (USM) Engineering Campus in Nibong Tebal, Penang, located at GPS coordinates 5°08'47.7"N; 100°29'27.9"E.

Participants

Ten male students from USM were recruited (age = 23.8 ± 1.17 years old; height = 169.90 ± 6.48 cm; weight = 66.6 ± 9.56 kg). The male gender was chosen because they were predominantly involved in the oil palm harvesting activities (Abdullah *et al.,* 2023; Mehraban *et al.,* 2022). The inclusion criteria of this study included: Individuals who had no health issues and major surgery, as well as consent and compliance with all aspects of the study protocol. The participants were briefed on the experimental protocol, demonstrated the harvesting process, and conducted a trial before data recording. They were equipped with safety helmets and other necessary safety measures. The study was approved by the Human Research Ethics Committee USM (JEPeM) (JEPeM Code: USM/JEPeM/21100665). All participants signed an informed consent document before the study.

Surface Electromyography (EMG)

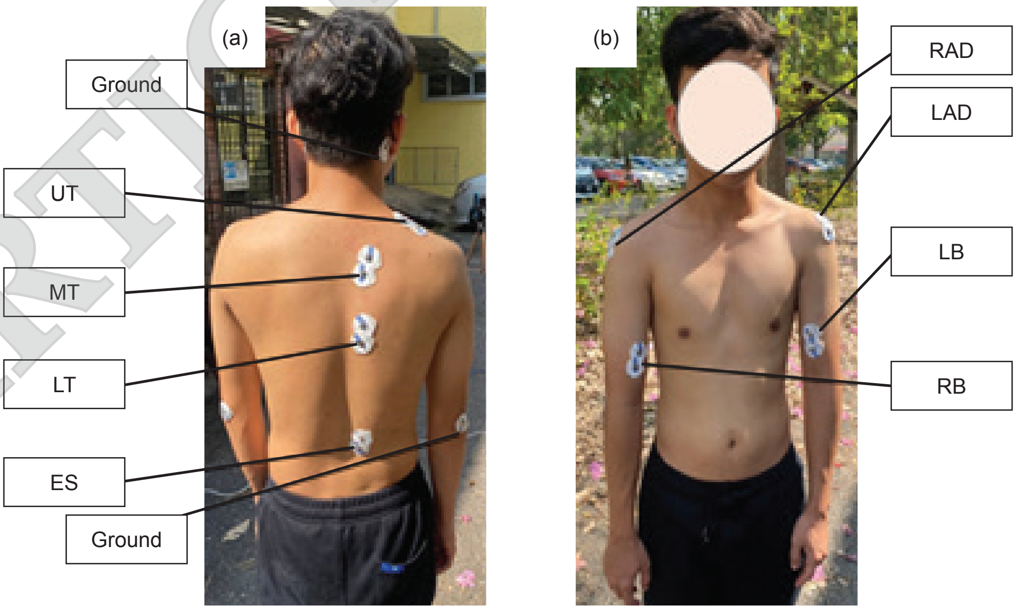
The muscle activation patterns of the participants were measured using surface electromyography (EMG) from iMotions 9.0 software (iMotions, Copenhagen, Denmark). The surface electrodes used were 24 mm diameter disposable Ag/AgCl, as used in previous studies by Pelaez *et al.* (2020) and Tang (2023). Then, the electrodes were placed in bipolar configurations on the right and left biceps brachii (RB, LB), right and left anterior deltoid (RAD, LAD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and erector spinae (ES), as done in the previous study by Abdullah *et al.* (2023). All participants were coincidentally dominant on the right side. The placement of the electrodes (*Figure 1*) is based on the guidelines provided in the surface EMG for the non-invasive assessment of muscle (SENIAM). The participants carried out maximum voluntary isometric contractions (MVIC) tests, as done by Christova *et al.* (1999), and determining their maximum muscle activation at a sampling rate of 1024 Hz, as studied by Burns *et al.* (2010a; 2010b), Chan *et al.* (2022), Manjarres-Triana *et al.* (2023) and Reza *et al.* (2013).

Posture Angle (OpenCap)

OpenCap is a specialised software designed for measuring postural angles. This open-source, markerless, web-based application can estimate 3-dimensional kinematics from videos captured by two separate smartphones (Lima *et al.*, 2023). Posture angles were assessed using two iPhone operating system (iOS) devices (iPhone SE 2020) in conjunction with the OpenCap system. The devices were securely mounted on tripods and strategically placed to obtain a field of view that encompasses the entire experimental area. Following that, calibration was performed using an appropriately sized checker box. During the calibration, to ease the OpenCap system in detecting and calibrating posture, participants were instructed to stand in a neutral posture, where the OpenCap model scaled the participant size, height, and shape. Following a successful calibration, the OpenCap software can be used for the recording process as conducted by Uhlrich *et al.* (2022).

Mechanised Cordless Chainsaw Cutting Tool and Measurement of Cutting Forces

A mini cordless chainsaw (brand: Santino), was fixed to the top of a pole (*Figure 2*). The chainsaw provides a maximum power of 66.6 W, a chain speed ranging from 3000-3700 rpm, and was powered by lithium batteries with a total capacity of 20 000 mAh. Modifications were made to the battery housing and Direct Current (DC) motor wiring on the cordless chainsaw. A control and monitoring panel (*Figure 2d*) for the DC motor was developed, featuring displays for voltage and current, a DC speed controller, an on/off switch, a battery indicator, and storage of batteries. The total cost for developing the prototype was RM250, which includes items such as the chainsaw machine, pole, lithium battery, DC controller, on/off switch, battery indicator, voltage/current indicator, and wires. It is important to note that this cost pertains only to developing the prototype, and the actual cost analysis may vary.



Note: RB - right bicep; LB - left bicep; RAD - right anterior deltoid; LAD - left anterior deltoid; UT - upper trapezius; MT - middle trapezius; LT - lower trapezius; ES - erector spinae.

Figure 1. *EMG electrode placement to the muscle parts: (a) Back, and (b) front and legend box.*

A load cell (S-Type S9M load cell (HBM, Germany)) was attached to the pole, approximately 2.19 m from the top. The length of the pole was approximately 2.50 m and weighed around 7.5 kg. For ease of operation, the control panel was placed at the base of the pole. The load cell was linked to the HX711 load cell receiver, which was then connected to an Arduino Mega, a microcontroller. Arduino was used to record and process the data. For accuracy, the load cell was calibrated by erecting the cutting tool vertically and adjusting the readings to zero to eliminate the reading coming from the weight of the parts, ahead of the load cell (Abdullah *et al.*, 2023; Latha *et al.*, 2017).

Field Setup for Experiment

For the experiment, a suitable oil palm tree measuring between 2.5 and 3.0 m in height was selected. The iMotion software, OpenCap system, and load cell were connected to one computer to synchronise all collected data (*Figure 3*).

Data Collection, Processing and Statistical Analysis

After participants completed the MVIC test and once calibrated with the OpenCap software, they were instructed to perform the harvesting process by using the mechanised chainsaw. Participants were instructed to perform five trials to ensure sufficient data points for robust statistical analysis. The data collection begins simultaneously for iMotion, OpenCap and load cell. Participants were instructed to turn on the chainsaw to initiate the frond-cutting task. Each participant completed five repetitions of the frond-cutting task, with recordings paused between cuts. Subsequently, participants completed a pain level form similar to Abdullah *et al.* (2023) based on the muscles involved.

This study aimed to assess how mechanised tools affect hand force, posture, and muscle activation during harvesting. A total of 50 trials were conducted involving 10 participants. In some trials, the posture angles could not be recorded in the OpenCap software, due to the poor connectivity between the smartphone and the server because, there was no real-time indicator that indicated data loss. Eventually, the data from the 19 trials contributed by six participants were included in the analysis.

The collected data, iMotion EMG recordings, OpenCap posture angles, and load cell readings, were later exported. For hand force values, the load cell data was tabulated to visualise maximum mean, and standard deviations (SD). Muscle activation data, comprising raw MVIC test data and

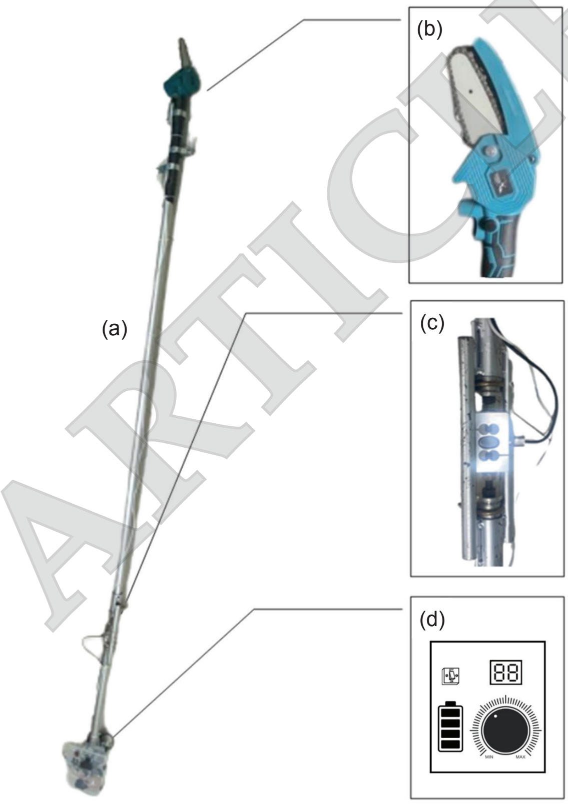


Figure 2. (a) Prototype in detailed view, (b) chainsaw, (c) load cell, and (d) schematic diagram of the control panel.

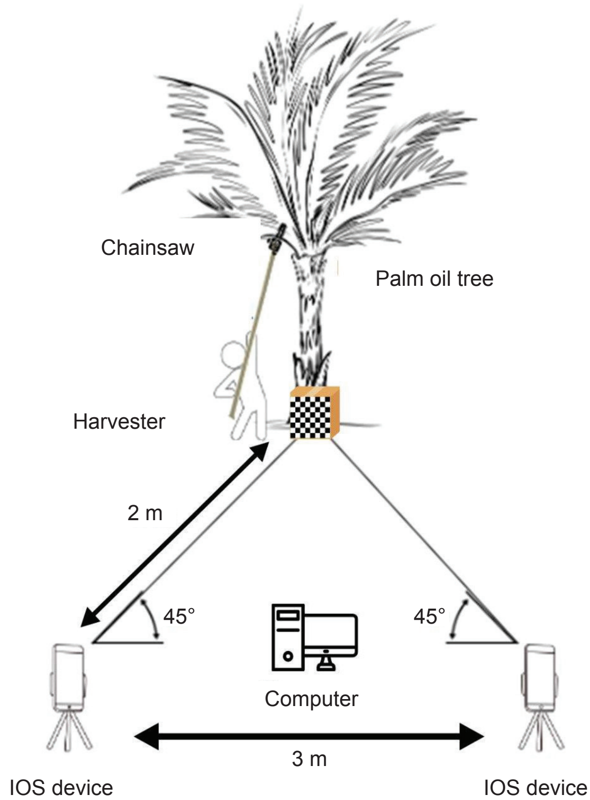


Figure 3. Field experiment setup.

raw task data during the harvesting process, were exported from the iMotion software in millivolts (mV) into an Excel file for each participant. The normalised muscle activation was then calculated as a percentage and tabulated.

Kinematics data from OpenCap were exported and tabulated for each body part. These kinematics data identified critical movements during the harvesting process. By using hand force values and kinematics data, the spinal loading at L5-S1 (compression and shear forces) was calculated using the 3-Dimension Static Strength Prediction Software (3DSSPS) (Ghezelbash *et al.*, 2020). Additionally, the REBA score was determined for each participant. The REBA score ranged from 1 to 15 levels, divided into 5 risk levels as recorded in the study by Law *et al.* (2022). Pain levels during the harvesting process were assessed using a standardised questionnaire administered to participants immediately after task completion as done by Abdullah *et al.* (2023).

The collected data on hand force, muscle activation, and joint angles were analysed using descriptive statistical methods such as mean and SD. The REBA score and spinal loadings (compression and shear force) at L5-S1 were determined based on the hand force and joint angles of each participant. Descriptive statistical methods were then applied to determine the mean and SD for these variables. To explore the relationship between muscle activation and pain score, a correlation analysis was conducted using Spearman's correlation. The correlation analysis was performed using the IBM SPSS Statistics software.

RESULTS AND DISCUSSION

Hand Force, Total REBA Score and Spinal Loadings

The mean peak hand forces, total REBA scores, and lower back forces at L5-S1 across different trials (*Table 1*). The mean value of peak hand forces was 677.57 ± 337.83 N, with a range between 190 N and 1386.03 N. The REBA score data provides valuable insights into the ergonomic risk associated with tasks performed by the subjects. The mean REBA score from all trials recorded was 8.11 ± 1.41. The scores ranged from 6 to 10, indicating varying levels of risk for musculoskeletal disorders. The L5-S1 disc loads were quantified to investigate the forces exerted on the spine of the subjects during the palm harvesting activities. The mean compression and shear forces for all participants were 808.63 ± 63.84 N and 528.16 ± 190.98 N, respectively.

A graphical representation illustrates the continuous hand force pattern observed in one of the participants during the execution of the harvesting task, using the mechanised chainsaw (*Figure 4*). The peak value was the maximum pulling force applied by the participant to cut the targeted frond.

TABLE 1. MEAN AND STANDARD DEVIATION (SD) FOR PEAK HAND FORCES, TOTAL REBA SCORE AND LOWER BACK FORCE

	Hand force (N)	Total REBA score	Compression force (N)	Shear force (N)
Range	192.29-1386.03	6.00-10.00	700.00-870.00	290.00-750.00
Mean (SD)	677.57 (337.83)	8.11 (1.41)	808.63 (63.84)	528.16 (190.98)

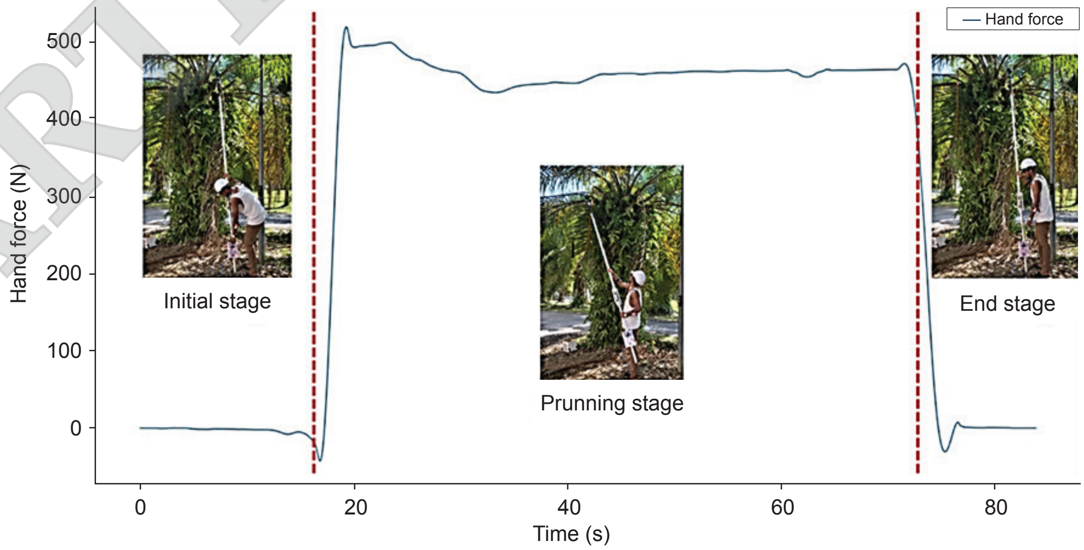


Figure 4. Hand force pattern during the experiment.

Muscle Activation

Various muscle groups were examined to assess the physical effort involved in the harvesting process (*Figure 5*). The EMG activation was considered moderately activated, with the mean peak value for all muscles being less than 30% MVIC. Notably, the muscles RB, LB, LAD, and LT exhibited the highest mean peak activation levels, emphasising their significant role in the harvesting process by generating force and executing repetitive movements during harvesting. The mean peak muscle activation is considered the maximum value in the box plot graph (*Figure 5*), outliers may negatively bias the entire result of an analysis.

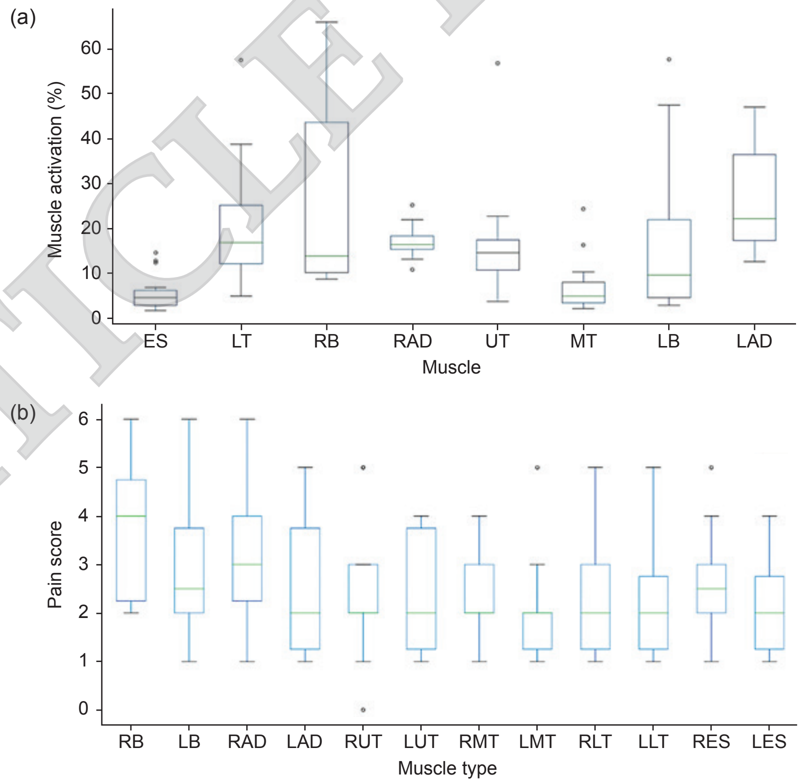
Body Pain Score

After harvesting, the pain score was recorded by questionnaire form, and the result of questionnaires was plotted in a box-plot graph (*Figure 5*). The questionnaire form was prepared based on the EMG electrode placement to correlate the muscle activation and pain score. The pain score was measured using a scale of 0 (lowest) to 10 (highest). The peak value obtained was 6 for the right bicep, left bicep, and right anterior deltoid. The mean pain scores for every muscle show less than 4, which was considered a moderated pain rate by the participants.

The Spearman correlation (*Table 2*) indicates a high degree of significance for all muscles when comparing measured EMG values and self-reported pain scores, except for the upper trapezius, which shows a moderate correlation. It is concluded that there is a linear relationship between muscle activation measured using EMG with the body pain scores. There is mostly a moderate Spearman correlation between the two variables ($p<0.05$). The grading standards followed a previous study by Yan *et al.* (2019). The significant correlation suggests a robust relationship between the two variables.

TABLE 2. CORRELATION BETWEEN EMG DATA AND PAIN SCORE

Muscle	Correlation Rs	*p*-value
Right Bicep (RB)	-0.626	0.004
Left Bicep (LB)	-0.488	0.034
Right Anterior Deltoid (RAD)	-0.459	0.048
Left Anterior Deltoid (LAD)	0.696	0.001
Upper Trapezius (UT)	0.450	0.053
Middle Trapezius (MT)	-0.606	0.006
Lower Trapezius (LT)	0.596	0.007
Erector Spinae (ES)	0.520	0.023



Note: RB - right bicep; LB - left bicep; RAD - right anterior deltoid; LAD - left anterior deltoid; RUT - right upper trapezius; LUT - left upper trapezius; RMT - right middle trapezius; LMT - left middle trapezius; RLT - right lower trapezius; LLT - left lower trapezius; RES - right erector spinae; LES - left erector spinae.

Figure 5. (a) Average maximum muscle activation, and (b)reported body pain score in all muscle regions.

Body Posture

The posture angles were captured and obtained during the harvesting process. A comprehensive understanding of these angles was derived from mean and SD values observed across the participants (*Table 3*).

On the right side, the hip exhibited a slight adduction angle of 4.66° ± 4.16° and a moderate external rotation angle of 16.93° ± 6.18°. The knee displayed a slight flexion angle of 7.55° ± 4.98° and a stable standing position angle of 0.13° ± 0.09°.

Transitioning to the left side, the hip demonstrated a moderate flexion angle of 12.85° ± 4.10°, a slight adduction angle of 8.46° ± 2.67°, and a moderate external rotation angle of 8.22° ± 4.39°. Similarly, the left knee displayed slight flexion at 5.95° ± 4.07° and a stable position angle of 0.10° ± 0.07°. On the right side, the shoulder angles indicated a moderate external rotation of 16.93° ± 6.18° and a flexion angle of 15.57° ± 4.30°. The abduction angle was measured at 4.66° ± 4.16°. In contrast, the left shoulder exhibited a moderate external rotation of 8.22° ± 4.39°, a flexion angle of 12.85° ± 4.10°, and an abduction angle of 8.46° ± 2.67°.

Analysis of lumbar angles unveiled a moderate extension angle of 9.32° ± 2.82°, a slight lateral bending angle of 9.37° ± 2.14°, and a moderate rotation angle of 15.12° ± 3.16°. These intricate kinematic body posture angles offer comprehensive insights into the joint angles and movements crucial for oil palm harvesting.

The mechanised chainsaw demonstrated a mean peak cutting force of 677.57 ± 337.83 N, representing a reduction of 57.67% compared to the mean cutting force of the traditional sickle (1601.23 ± 424.26 N) (Abdullah *et al.*, 2023). The elimination of the need for additional pulling force, typical of material removal cutting processes, contributes to the substantial reduction in hand force observed when using a mechanised chainsaw.

In a previous laboratory study (Ahmad *et al.*, 2020), a sickle cutter with an actuator delivered a force of 12.2 kg/cm² (1196411 N/m²), whereas in the field experiment with a mechanised chainsaw, a mean peak specific cutting force of 9.38 kg/cm² was obtained, representing a reduction of about 30% when considering an average frond cross-sectional area of approximately 35.82 cm² (Ahmad and Yahya, 1998a). While these results highlight the advantages of the mechanised tool, it is essential to acknowledge other potential influencing factors such as frond moisture, frond maturity, and cutting angles, as identified by (Ahmad and Yahya, 1998b; Ahmad *et al.*, 2020), which should be considered to optimise the harvesting methods.

The wedge angle (α), which is crucial in frond cutting with tools like sickles, plays a key role in dictating the force (F) needed for the cutting process to overcome the friction force (Fr) over the normal force (N) (*Figure 6*). A smaller wedge angle, found in traditional sickles, demands a greater pulling force. In contrast, chainsaws make a wider wedge angle, reducing the pulling force required to cut fronds. This broader angle facilitates penetration and minimises the binding problem, where the wedge gets stuck in the frond. The wedge angle is a critical factor influencing the pulling force: Smaller angles demand more force, while larger angles, as seen in chainsaws, require less force for effective cutting.

The REBA score data reveals varying levels of ergonomic risk associated with tasks performed by participants. The mean REBA score of this study, 8.11 ± 1.41, was lower than that of a previous study using traditional harvesting tools, which

TABLE 3. JOINT ANGLE DURING FIELD EXPERIMENT FROM 19 TRIALS

Articulation	Posture angle [Mean (SD)] (°)			
	Lateral bend	Axial rotation	Flexion	Extension
Pelvis	12.00 (5.23)	4.99 (2.10)	35.93 (11.45)	35.93 (11.45)
	Lumbar bending	Lumbar rotation	Flexion	Extension
Lumbar	9.37 (2.14)	15.12 (3.16)	-	9.32 (2.82)
	Flexion	Abduction	Adduction	
Right shoulder	16.93 (6.18)	15.57 (4.30)	4.66 (4.16)	
Left shoulder	8.22 (4.39)	12.85 (4.10)	8.46 (2.67)	
	Ulnar deviation	Radial deviation	Flexion	Extension
Right knee	-	-	7.55 (4.98)	0.13 (0.09)
Left knee	-	-	5.95 (4.07)	0.10 (0.07)
Right wrist	8.82 (4.79)	-	-	-
Left wrist	-	9.51 (2.96)	-	-

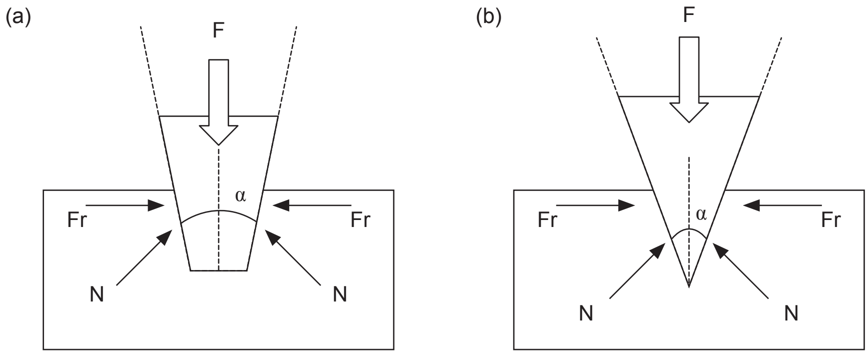


Figure 6. Wedge angle comparison between (a) chainsaw, and (b) sickle.

reported a score of 10.30 ± 1.16 (Abdullah *et al.*, 2023). The use of manual or traditional harvesting tools in harvesting oil palm FFBs exposes workers to musculoskeletal disorders (Shuib *et al.*, 2020). Immediate action, such as providing ergonomics training for workers, should be highly considered to solve this problem (Nawi *et al.*, 2016). The adoption of mechanised harvesting methods can improve workers' productivity and reduce ergonomic risks, leading to a better REBA score (Azaman *et al.*, 2022).

The mean compression and shear forces at the L5-S1 joint across all participants were approximately 808.63 ± 63.84 N, (range from 700 N to 870 N) and 528.16 ± 190.98 N, (range from 290 N to 750 N), respectively, both of which were lower than the NIOSH safety limits (Afshari *et al.*, 2018). The current study demonstrates a substantial reduction in both compression and shear forces by approximately 67.56% and 63.52% when compared to the previous study by Abdullah *et al.* (2023) who reported a mean compression and shear forces of 2493.20 ± 1349.48 N and 1446.10 ± 411.00 N, respectively. Research has shown that using ergonomic cutting tools can reduce lower back force during oil palm harvesting activities (Selamat *et al.*, 2023).

The usage of specific harvesting tools, such as the chisel, pole, and loading spike has been found to further contribute to WMSDs (Mohamaddan *et al.*, 2021). In terms of muscle activation, it is evident that the right bicep and lower anterior deltoid muscles display the highest mean peak activation levels. The left trapezius muscle also exhibits significant mean peak activation, indicating its involvement in generating force and facilitating repetitive movements during harvesting.

This study found that muscle activation levels at various muscle locations were reduced for all participants compared to previous studies employing traditional harvesting methods (Abdullah *et al.*, 2023). The right bicep experienced a reduction of 61.4%, the left bicep decreased by 73.4%, the upper trapezius saw a reduction of 69.1%, the middle trapezius experienced a reduction of 85.9% and the erector spinae showed the highest reduction of 89.0%. In terms of pain scores, reductions of 35.7%, 45.4%, 40.5%, 45.5% and 47.5% were observed in the right bicep, left bicep, upper trapezius, middle trapezius, and erector spinae, respectively. These percentage of reductions highlighted the significant ergonomic advantages associated with the use of mechanised chainsaws in oil palm harvesting.

The decrease in muscle activation levels suggests a considerable reduction in the physical strain experienced by workers during the harvesting process (Selamat *et al.*, 2023). The reduction in muscle activation supports the adoption of mechanised tools for oil palm harvesting activities. The evolution of mechanisation in oil palm harvesting has shown a reduction in muscle strain and pain levels among oil palm harvesters (Mohamad, 2022; Selamat *et al.*, 2023). By incorporating these ergonomic devices and mechanised tools, the physical stress and risk factors associated with the manual handling of materials can be minimised, thereby reducing work-related muscle disorders (Rahman *et al.*, 2017).

Previous studies found that workers are exposed to various postural problems, with the latter emphasising the need for immediate action to address these issues (Nawi *et al.*, 2013). The OpenCap software analysed the posture involved in kinematic details, thereby providing a comprehensive understanding of joint angles and movements during the oil palm harvesting activities.

On the right side, the hip exhibited a slight adduction angle and a moderate external rotation angle, suggesting a posture that involves a degree of inward movement and external rotation. The knee displayed a slight flexion angle with a stable position, reflecting a balanced stance, while the ankle angle indicated slight dorsiflexion, contributing to a stable footing. Moving to the left side, the hip demonstrated a moderate flexion angle, coupled with a slight adduction and external rotation angle. These angles suggest a posture involving a more flexed and rotated position on the left side, potentially influenced by the nature of the harvesting task.

The lumbar angles revealed a moderate extension angle, indicating a slight backward tilt, as a stabilising mechanism during the harvesting process. Additionally, a slight lateral bending angle and a moderate rotation angle suggest a meticulous movement in the lumbar region, contributing to the dynamic nature of the task. This further emphasises the prevalence of unsafe postures, particularly in the upper body, highlighting the imperative for interventions to mitigate these risks. Research by Ng *et al.* (2015) added to this by identifying specific risk factors for musculoskeletal disorders, including awkward postures, and the need for further investigation into the dynamic of work activities.

The efficiency comparison between the traditional manual sickle, CANTAS™, and mechanised electric chainsaw is an essential aspect to be addressed comprehensively. Initial data suggests that the manual sickle can harvest approximately 50 FFBs/hr, while CANTAS™ achieves around 75 FFBs/hr (Muhamad and Aziz, 2018). In contrast, the mechanised electric chainsaw prototype currently processes one frond every 25 s, potentially handling approximately 20-30 FFBs/hr. This estimate is based on the average time required for various tasks: Searching for a mature palm oil tree (40.73 s), cutting two fronds (50 s), and cutting one mature FFB (60.26 s) (Saibani *et al*. 2015). However, further investigation is necessary to determine the actual effectiveness of the electric chainsaw in the oil palm plantation.

This paper attempts to measure the harvesters' hand forces during oil palm harvesting activities under actual field conditions, employing the mechanised chainsaw as the oil palm harvesting tool. Unlike simulated scenarios in a laboratory setup, this approach measures the forces required for cutting palm fronds with a mechanised chainsaw in the field. Furthermore, these findings not only contribute to valuable insights but also serve to complement and address the identified limitations. This unique approach adds depth to the understanding of ergonomic challenges faced by workers in the oil palm industry. Employing students for testing provides insights into muscle activation variations compared to experienced harvesters, enhancing our understanding of biomechanical responses to the new tool. Testing with students allows for the assessment of the new tool's functionality and biomechanical implications before field deployment, informing potential ergonomic refinements for real harvesters.

There are several recommendations aimed at enhancing the effectiveness and applicability of future research activities in the context of oil palm harvesting. Firstly, it is suggested to increase the sample size and recruit experienced oil palm harvesters to gather feedback on performance, preference, and productivity compared to traditional tools. For the joint angle measurement, the connectivity issues of the smartphone and OpenCap server should be resolved to enable the data capturing successfully. Furthermore, ensuring signal stability for Shimmer and iMotion devices is crucial for improving the reliability of EMG data. The implementation of these recommendations is expected to boost research on motorised saws, leading to enhanced efficiency relevant to the challenges in oil palm harvesting.

CONCLUSION

The mechanised chainsaw cutting tool demonstrates a 57.67% reduction in cutting force compared to traditional sickles. Moreover, the analysis of worker safety metrics reveals a consistent pattern of lower ergonomic risk for participants utilising mechanised chainsaws. The mean REBA score of 8.11 ± 1.41 with reductions in muscle activation levels, ranging from 35.7% to 89.0%, emphasises the considerable decrease in physical strain experienced by workers during the harvesting activity. Pain scores similarly exhibit reductions, ranging from 40.5% to 47.5%, further supporting the potential ergonomic benefits of mechanised chainsaws in oil palm harvesting. Additionally, the compression and shear forces at the L5-S1 level demonstrate reductions of approximately 67.56% and 63.52% respectively, indicating a positive impact on lower back health. These findings collectively highlight the comprehensive advantages of adopting mechanised tools in promoting both worker well-being and operational efficiency in oil palm harvesting.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Sains Malaysia (1001/PMEKANIK/8023046) for the funding allocated for the study.

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