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Musculoskeletal Disorder Risk and Harvester Work Movements in Oil Palm Plantation: A Pilot Study

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ABSTRACT

Oil palm Fresh Fruit Bunches (FFB) harvesting activities pose a potential risk of Musculoskeletal Disorders (MSDs) due to repetitive tasks, manual material handling, and non-neutral working postures. This case study aims to evaluate the ergonomic risk levels associated with FFB harvesting to minimize the MSDs among harvesters. Three assessment methods were employed: Nordic Body Map (NBM) to identify MSD complaints across 27 body regions, Rapid Entire Body Assessment (REBA) to determine overall postural risk, and Material Manual Handling (MMH) analysis to assess biomechanical loading on the L4/L5 spinal segment. The findings indicate that the highest MSD complaints were reported in Lumbago, with an NBM score of 32.73 (low risk). The REBA score of 6 indicated a moderate risk level. MMH analysis revealed compression forces of 1714 N during lifting and 1288 N during load transportation, both below NIOSH AL recommended limits. Although the overall risk level is low to moderate, ergonomic interventions are necessary to prevent potential long-term MSDs.

1. INTRODUCTION

The oil palm harvesting process represents a critical stage in determining the quality of crude palm oil produced. Harvesting is conducted when Fresh Fruit Bunches (FFB) reach physiological maturity, typically occurring approximately three years after field planting, with yields increasing progressively from the seventh to the eighteenth year of cultivation [1]. Harvesting is performed by cutting the FFB using a traditional harvesting tool known as an eggrek. This operation must be carried out carefully to avoid damage to both the fruit bunches and the oil palm trees, thereby preserving oil quality. The harvester's activities of oil palm FFB, including the use of an eggrek and the subsequent lifting and transportation of FFB to the harvest collection point without mechanical assistance, are illustrated in Figure 1.

Figure 1. Harvester activities during the oil palm Fresh Fruit Bunch (FFB) harvesting process: Harvesting, lifting, and transporting

Based on Figure 1, it can be observed that each palm oil FFB weighs between 12 kg and 15 kg. The FFB is carried by the harvester on the right shoulder, with the right hand used to support and secure the load to prevent it from slipping. The harvester's left hand further assists in stabilizing the FFB, while the head provides slight support to the bottom of the load. This support is facilitated using a protective helmet, which helps reduce direct pressure on the harvester's scalp and shoulders. Such working postures pose a significant risk of musculoskeletal and spinal disorders when performed repeatedly over prolonged periods without appropriate ergonomic tools or interventions. Consequently, during the harvesting process, harvesters commonly adopt a hunched body posture. This posture indicates that harvesting activities are conducted without adequate consideration of ergonomic principles. Furthermore, maintaining a standing position for extended durations imposes additional physical strain on harvesters. Overall, these non-ergonomic working postures increase the risk of developing symptoms associated with Musculoskeletal Disorders (MSDs).

MSDs constitute a category of occupational diseases that affect the musculoskeletal system of harvesters when job-related activities are performed repetitively over extended periods [2]. These disorders typically manifest as musculoskeletal conditions involving muscles, bones, nerves, and other supporting body structures, primarily resulting from non-ergonomic working conditions. MSDs pose significant challenges in occupational settings, particularly by increasing health-related compensation costs, reducing work productivity, and diminishing harvesters' overall quality of life [3]. In oil palm harvesting operations, the highest risk of MSDs has been identified during the lifting and transportation of FFB [4]. Consequently, a systematic evaluation of harvesters' postures is essential, especially during the lifting and transportation of FFB to the collection area [5].

The role of ergonomic work factors in mitigating MSDs and ensuring occupational safety and health among oil palm plantation harvesters has been widely recognized in previous research [6-8]. However, the results of the ergonomic assessment in this analysis still have limitations, as the test can only determine the MSDs index score without explaining the conditions and body positions of oil palm harvesters who experience fatigue during the FFB harvesting process. The present research introduces a novel contribution by integrating multiple ergonomic assessment methods to evaluate MSDs conditions among FFB oil palm harvesters. This research adopts a multi-method ergonomic evaluation framework, incorporating the Nordic Body Map (NBM), Rapid Entire Body Assessment (REBA), and Material Manual Handling (MMH) analyses. These methods were applied to assess harvester-reported discomfort, postural loading, movement patterns, and biomechanical body positions associated with handling oil palm FFB during harvesting activities. MSD-related symptom prevalence was assessed using the NBM questionnaire to identify anatomical regions experiencing discomfort or pain [9]. Postural risk levels were assessed using the REBA analysis, which classifies ergonomic risk from low to very high, thereby facilitating the prioritization of ergonomic interventions [10]. Furthermore, an MMH analysis was conducted to evaluate harvesters' physical capacity and determine acceptable load limits for manual handling of oil palm FFB during harvesting operations [11].

This pilot study aims to reduce the risk of MSDs among harvesters during the oil palm FFB harvesting process. Furthermore, it seeks to identify more ergonomic work methods and to reconfigure safe workload limits in accordance with individual physical capacities, thereby improving work effectiveness and efficiency, enhancing workforce productivity, and supporting the overall sustainability of the oil palm plantation industry.

2. METHODOLOGY

Harvesting FFB of oil palm is a series of physical activities that require optimal strength and endurance. These activities relate to the harvester's body position, which involves standing, bending, and moving the eggrek harvesting tool to reach different heights, as well as lifting FFB to the collection point. The lifting and collecting process is performed manually, with consideration for time efficiency. Harvesters lift an average load of 12–15 kg throughout a 6–8-hour harvest [12]. Therefore, the ergonomic postures adopted by harvesters require careful consideration, particularly with respect to the shoulders, neck, back, and feet [13]. Harvester reliability and skill levels play a crucial role in preventing MSDs. The ergonomic evaluation of FFB harvesting comprises four primary components: NBM analysis, REBA analysis, Liliefors Test, and MMH analysis. The overall framework of the ergonomic evaluation is presented in Figure 2.

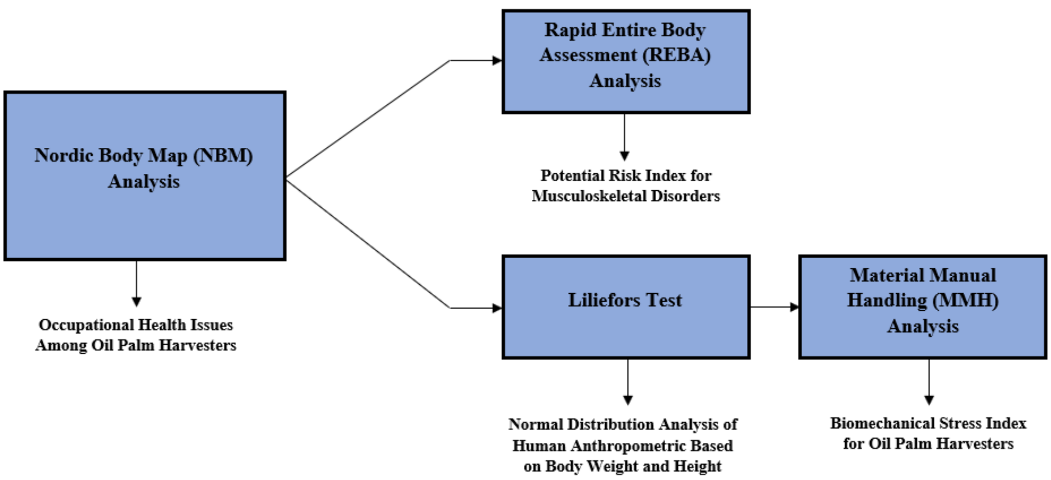
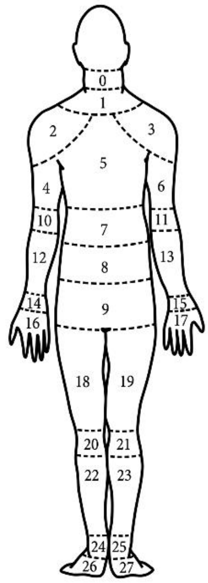


Figure 2. Ergonomic evaluation test

The NBM analysis is used to map harvesters' bodily complaints and pain during oil palm FFB harvesting activities. The NBM data were collected through interviews with harvesters to assess the ergonomic conditions of the body in static anthropometric postures [14]. Interviews were also conducted to determine the harvesters' age, work time, weight, and height. As the purpose of this research is a pilot study, a total of 15 harvesters were interviewed and analyzed using NBM. The use of 15 harvesters is attributed to the limited area of the oil palm plantation and the relatively low number of FFB available for harvesting. The NBM analysis data in Figure 3 indicates the number of body parts experienced by harvesters during the oil palm FFB harvesting activity.

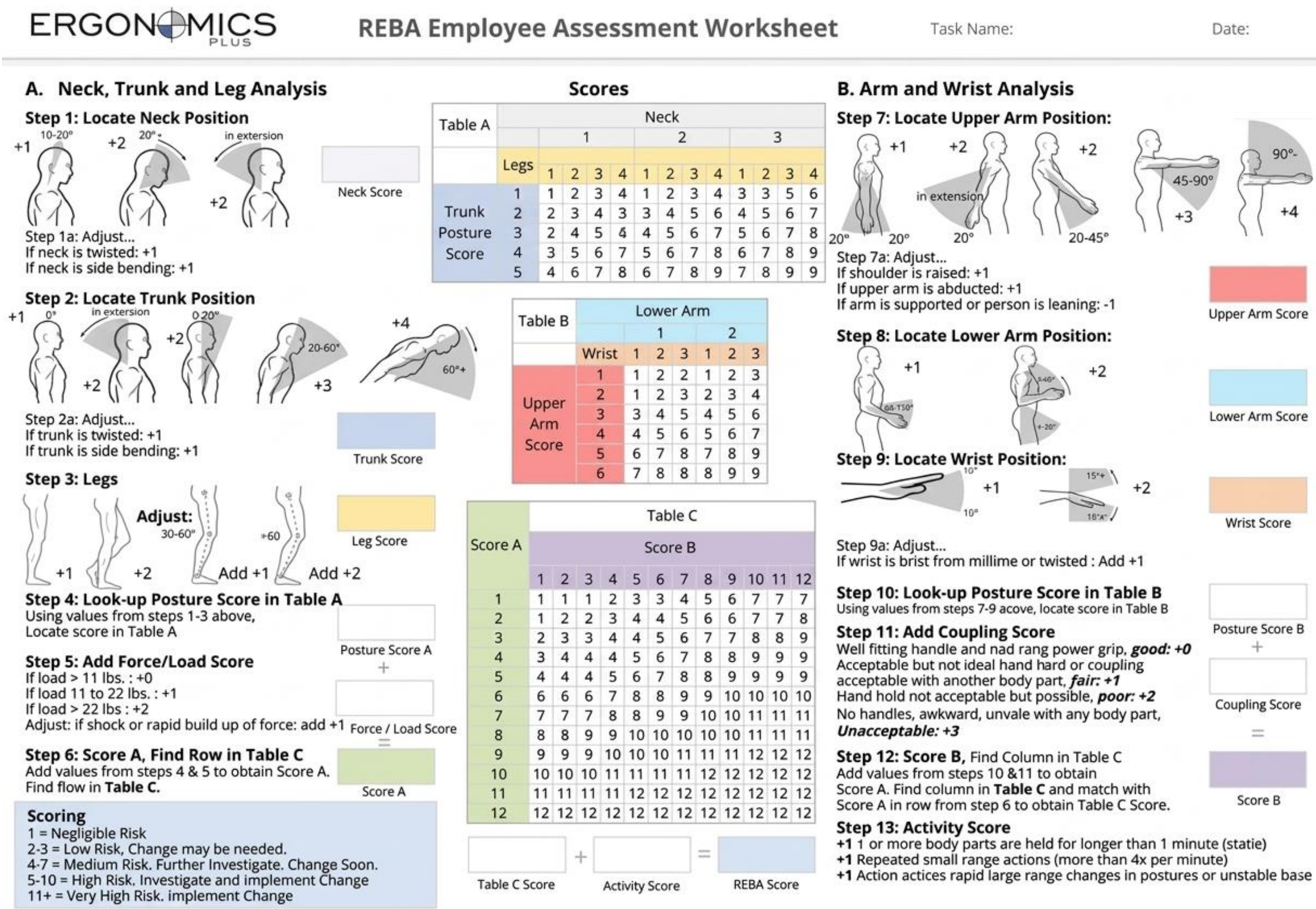
NBM interview results were used to identify harvesters' body regions at the highest risk of MSDs, followed by MSDs risk assessment using REBA analysis. REBA analysis was conducted to assess ergonomic risk levels associated with harvesters' body postures during oil palm FFB harvesting activities [15]. The REBA assessment was performed during the dynamic anthropometric postures [14]. The results show a score for injury risk based on harvester body parts and tasks (Table 1). Data from the NBM analysis identified two at-risk body region groups: Group A (neck, body, and legs) and Group B (upper arms, lower arms, and wrists). Scores from Table A were calculated for Group A and combined with the load score to obtain Score A. Scores from Table B were calculated for Group B and combined with the coupling score to obtain Score B. Scores A and B were then integrated, and the activity score was added to determine the overall REBA score. These groups served as inputs to the REBA analysis, which evaluated risk during the harvesting of oil palm FFB using the eggrek tool. The analysis followed the guidelines provided in the worksheet shown in Figure 4.



No	Pain Area	Pain Level (1-4)			
		1	2	3	4
0	Upper Neck Pain				
1	Lower Neck Pain				
2	Left Shoulder Pain				
3	Right Shoulder Pain				
4	Left Upper Arm Pain				
5	Backache				
6	Right Upper Arm Pain				
7	Lumbago				
8	Buttock Pain				
9	Bottom Pain				
10	Left Elbow Pain				
11	Right Elbow Pain				
12	Left Lower Arm Pain				
13	Right Lower Arm Pain				
14	Left Wrist Pain				
15	Right Wrist Pain				
16	Left Hand Pain				
17	Right Hand Pain				
18	Left Thigh Pain				
19	Right Thigh Pain				
20	Left Knee Pain				
21	Right Knee Pain				
22	Left Calf Pain				
23	Right Calf Pain				
24	Left Ankle Pain				
25	Right Ankle Pain				
26	Left Leg Pain				
27	Right Leg Pain				

1 = no pain
2 = mild pain
3 = moderate pain
4 = severe pain

Figure 3. Nordic Body Map (NBM) analysis [16]



ERGONOMICS PLUS

REBA Employee Assessment Worksheet

Task Name:

Date:

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position

+1 10-20°

+2 20°+

in extension +2

Neck Score

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position

+1 0°

in extension +2

+2 0-20°

20-60° +3

+4 60°+

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Trunk Score

Step 3: Legs

+1 +2

Adjust: 30-60° Add +1 +60 Add +2

Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A

Posture Score A

+

Step 5: Add Force/Load Score
If load > 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs : +2
Adjust: if shock or rapid build up of force: add +1

Force / Load Score

=

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find flow in **Table C.**

Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk, Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
5-10 = High Risk. Investigate and implement Change
11+ = Very High Risk. implement Change

Scores

Table A		Neck											
		1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	3	3	4	5	6	4	5	6	7
	3	2	4	5	4	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B		Lower Arm					
		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	6
	4	4	5	6	5	6	7
	5	6	7	8	7	8	9
	6	7	8	8	8	9	9

Score A	Table C											
	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	4	4	5	6	7	7	8	8	9
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	8	9	9	10	10	11	11	11
8	8	8	9	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:

+1 20° 20°

+2 in extension 20°

+2 20-45°

45-90° +3

90°- +4

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Upper Arm Score

Step 8: Locate Lower Arm Position:

+1 60-110°

+2 0-60° 110°+

Lower Arm Score

Step 9: Locate Wrist Position:

+1 10° 10°

+2 15°+ 15°+

Wrist Score

Step 9a: Adjust...
If wrist is brist from millime or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 acove, locate score in Table B

Posture Score B

+

Step 11: Add Coupling Score
Well fitting handle and nad rang power grip, ***good: +0***
Acceptable but not ideal hand hard or coupling acceptable with another body part, ***fair: +1***
Hand hold not acceptable but possible, ***poor: +2***
No handles, awkward, unvale with any body part, ***Unacceptable: +3***

Coupling Score

=

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain Score A. Find column in **Table C** and match with Score A in row from step 6 to obtain Table C Score.

Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (statie)
+1 Repeated small range actions (more than 4x per minute)
+1 Action actices rapid large range changes in postures or unstable base

Figure 4. Rapid Entire Body Assessment (REBA) analysis worksheet [17]

The results of the REBA analysis for Group and Group B body regions during oil palm FFB harvesting activities were used as the basis for action level assessment, as shown in Table 1.

Table 1. Results of Rapid Entire Body Assessment (REBA) analysis score

Action Level	REBA Score	Risk Level	Action
0	1	Very Low	Still acceptable and does not need to be changed
1	2–3	Low	Changes may be necessary
2	4–7	Moderate	Needs review
3	8–10	High	Repairs will be made immediately
4	11–15	Very High	Changes right now

In addition to the REBA analysis, this research also conducted a Manual Material Handling (MMH) analysis, beginning with a test for data normality using the Liliefors test [18]. The Liliefors test served as an initial step in the MMH analysis, which used interview data from NBM assessment, specifically focusing on harvesters' body weight and height. This procedure was conducted because, in MMH analysis, the influence of harvesters' body weight and height is critical for evaluating physical strength and endurance during the lifting and carrying of oil palm FFB to the collection area. The Liliefors test was conducted based on the following hypothesis formulation for the data [19].

H_0: f(X) = normal

H_1: f(X) ≠ normal

The steps in testing the Liliefors analysis hypothesis include:

(1) Sort the sample data from smallest to largest value
(2) Calculating the mean value from the standard deviation of the data

$$\overline{X} = \frac{\sum x_i}{n} \quad (1)$$

$$\sigma = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n - 1}} \quad (2)$$

where, X: data value; $\bar{X}$: average value; σ: standard deviation.

(3) Arrange the data starting from the smallest value, followed by the respective frequencies, cumulative frequency (F), and calculate the Z value for each data point using the formula

$$Z = \frac{X - \bar{X}}{\sigma} \quad (3)$$

(4) Determine the cumulative probability ($P \leq Z$) using the standard normal distribution table
(5) Calculate the absolute difference between the cumulative relative frequency ($FZ = F/n$) and the cumulative probability ($P \leq Z$) and determine the absolute value
(6) Calculate the value of $S(z)$ using the formula

$$S(Zi) = \frac{data\ numbers \leq x}{n} \quad (4)$$

(7) Determine the maximum value of the absolute difference between $F(z)$ and $S(z)$, written as L_0 or LCalculate = $|F(z) - S(z)|$
(8) Compare the L_0 value with the critical value in the Liliefors table (L_{table})
(9) Hypothesis testing criteria:
- H_0 Rejected ($L_0 > L_{table}$)
- H_0 Accepted ($L_0 \leq L_{table}$)

Therefore, if the L_0 value exceeds the L_{table} value at a 5% significance level, the data are not normally distributed; conversely, if the L_0 value is less than or equal to the L_{table} value, the data are normally distributed.

After conducting the Lilliefors test, the next step was to perform an MMH analysis. The MMH analysis is employed to quantify the magnitude of biomechanical compressive forces acting on the harvesters' body segments, particularly the lumbar region at the L4/L5 spinal level [20]. These compressive forces serve as an indicator of whether the harvesters' activities remain within acceptable safety thresholds for occupational health. The MMH analysis was carried out during the task of lifting and transporting oil palm FFB to the collection point, as illustrated in Figure 5.

(a) (b)

Figure 5. Harvester activities for (a) lifting and (b) transporting Fresh Fruit Bunches (FFB) oil palm manually

This analysis was conducted by developing a harvester model using CATIA V5 software. The developed model was subsequently subjected to MMH analysis to determine the magnitude of compressive biomechanical forces acting on the harvester's body, with particular emphasis on the L4/L5 spinal segment. The results of the REBA and MMH analyses may be utilized as improvement inputs to mitigate ergonomic risks associated with the harvester's posture and to prevent the onset of MSDs symptoms.

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3. RESULTS AND DISCUSSION

3.1 Results and discussion Nordic Body Map

The harvesting of oil palm FFB is a critical activity that directly influences the quality of the harvested produce. Consequently, the involvement of healthy and physically fit harvesters is essential in ensuring effective harvesting operations. Maintaining the physical fitness of harvesters also plays a significant role in reducing the risk of MSDs symptoms associated with oil palm FFB harvesting activities. The NBM questionnaire is employed to identify physical complaints experienced by harvesters and serves as an analytical tool (Table 2) for the prevention of MSD symptoms affecting various body parts during oil palm FFB harvesting.

Table 2. Individual total risk level classification

Score Total	Risk Level	Action
28–49	Low	Corrective action is not required currently
50–70	Moderate	Corrective action may be required in the future
71–90	High	Immediate corrective action is required
91–112	Very High	Immediate comprehensive action is required

Based on the NBM questionnaire data presented in Table 3, MSDs symptoms were reported across multiple anatomical regions among harvesters, with varying levels of severity. Symptom intensity was classified as follows: 1 = no pain, 2 = mild pain, 3 = moderate pain, and 4 = severe pain. The highest prevalence of MSDs symptoms was observed in the lower back (lumbago), with a total score of 26. This region was predominantly affected by pain and muscle tension, likely attributable to non-ergonomic working postures, particularly prolonged body flexion during oil palm FFB harvesting, as well as extended working durations. Additional regions reporting MSDs complaints included the buttocks (score = 25), upper neck (score = 24), left shoulder (score = 24), and right shoulder (score = 23). Analysis of cumulative individual harvester scores yielded a mean value of 32.73. According to the risk classification in Table 2, this value falls within the 28–49 range, corresponding to a low-risk category, thereby suggesting that corrective interventions are not immediately required.

Although the individual scores indicate a low risk level and do not require immediate corrective action, attention should be given to body regions with a pain score of 3, including the upper and lower neck, shoulders, left upper arm, waist, buttocks, right elbow, thighs, knees, right calf, and left ankle. Discomfort in the neck, shoulders, and left upper arm is associated with carrying FFB near the neck and maintaining an extended neck posture during harvesting.

Musculoskeletal discomfort in the waist, buttocks, thighs, and knees is linked to the forward-bending posture adopted when lifting FFB, which imposes considerable load on the lumbar region. Overall, these discomforts are associated with repetitive activities during oil palm FFB collection and transportation over prolonged working periods. Therefore, an ergonomic evaluation of the work process is recommended to mitigate the risk of developing MSDs symptoms.

NBM results indicate that the most affected body regions are the waist, buttocks, upper neck, and both shoulders, consistent with previous findings [21]. Similarly, harvesters at PTPN IV Tanam Itam Ulu engaged in comparable tasks reported MSDs symptoms primarily in the upper and lower neck, back, waist, upper right arm, and bilateral calves [22].

Table 3. Musculoskeletal Disorders (MSDs) symptoms scores of harvesters based on Nordic Body Map (NBM) analysis

No.	Pain Area	The Number of Harvesters															Total Score	Highest Score
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
0	Upper Neck	1	1	1	1	1	1	1	2	3	1	2	1	3	2	3	24	3
1	Lower Neck	1	1	1	1	1	1	1	3	3	2	2	1	1	1	1	21	3
2	Left Shoulder	2	1	1	1	2	1	1	3	2	1	1	3	1	1	3	24	3
3	Right Shoulder	1	1	1	1	1	1	1	3	3	1	1	3	1	3	1	23	3
4	Left Upper Arm	2	1	1	1	1	1	1	2	3	1	1	1	2	1	1	20	3
5	Backache	1	2	1	2	2	1	1	2	2	1	1	1	1	1	2	21	2
6	Right Upper Arm	1	1	1	1	1	1	1	2	1	1	1	1	2	1	1	17	2
7	Lumbago	1	3	1	1	1	1	2	3	2	1	1	1	2	2	3	**26**	3
8	Buttock	1	1	1	1	1	1	1	1	2	3	3	3	2	3	2	25	3
9	Bottom	1	1	1	1	1	1	1	1	2	2	3	2	1	2	2	22	3
10	Left Elbow	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	1
11	Right Elbow	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	17	3
12	Left Lower Arm	2	1	1	1	1	1	1	2	2	1	1	1	1	1	1	18	2
13	Right Lower Arm	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	17	2
14	Left Wrist	1	1	1	1	1	1	1	2	1	1	1	1	2	1	1	17	2
15	Right Wrist	1	1	1	1	1	1	1	2	1	1	1	1	2	1	1	17	2
16	Left Hand	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	16	2
17	Right Hand	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	16	2
18	Left Thigh	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	17	3
19	Right Thigh	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	17	3
20	Left Knee	3	1	1	1	1	1	1	2	2	1	1	1	1	1	1	19	3
21	Right Knee	1	3	3	1	1	1	1	2	2	1	1	1	1	1	1	21	3
22	Left Calf	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	17	2
23	Right Calf	1	3	1	1	1	1	1	2	2	1	1	1	1	1	1	19	3
24	Left Ankle	1	1	1	1	1	1	1	1	1	1	3	1	1	1	1	17	3
25	Right Ankle	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	1
26	Left Leg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	1
27	Right Leg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	1
Individual Score		33	35	30	29	30	28	29	48	51	32	38	35	38	35	37	491	
Average Score									32.73									

3.2 Results and discussion Rapid Entire Body Analysis

Harvester posture data were used to assess the risk of MSDs affecting various body regions during the oil palm harvesting process. Postural measurements were obtained through the analysis of photographic records of harvester activities during the harvesting and transportation of oil palm FFB, as illustrated in Figure 6.

Figure 6 illustrates a harvester performing manual harvesting of oil palm FFB. The harvester adopts a standing posture with both arms raised to direct the cutting tool toward the FFB at an elevated height. Image analysis reveals that the harvester's neck is oriented upward, and the arms are extended overhead for a prolonged duration to support the harvesting activity, which may contribute to muscle fatigue in the neck, shoulders, and back. Furthermore, the uneven ground surface increases the risk of postural instability and loss of balance during the harvesting process.

As illustrated in Figure 6, REBA analysis was performed on the harvester's body postures, which were divided into Group A and Group B. Group A encompassed the neck, body, and legs, whereas Group B comprised the upper arms, lower arms, and wrists. The REBA evaluation was conducted using the worksheet shown in Figure 4.

As illustrated in Figure 7(a), the harvester's neck is inclined backward, with the gaze directed upward at an angle of 45.1° during the harvesting of oil palm FFB using the eggrek tool. This posture deviates from the neutral neck alignment and, if sustained for extended periods, may contribute to fatigue and MSDs. The observed neck angle of 45.1° is assigned a REBA score of 2, as it exceeds a backward inclination of 20°.

As shown in Figure 7(b), the harvester's body demonstrates slight extension (tilted backward) to maintain balance while lifting the eggrek and sustaining an upward gaze, resulting in an angle of 15°. Although this posture is considered moderate, prolonged maintenance may induce discomfort in the lower back musculature. The observed body angle is assigned a REBA score of 2, as it falls within the 0°–20° range.

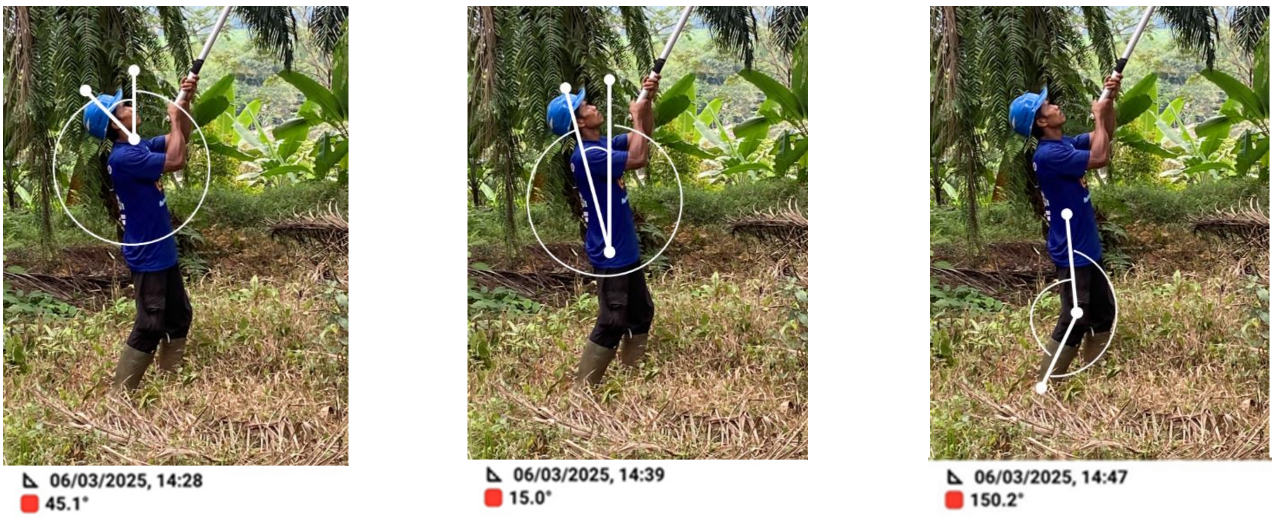
As illustrated in Figure 7(c), the harvester's legs exhibit slight extension to support body weight and maintain balance while elevating the eggrek, resulting in an angle of 150.2°. Prolonged maintenance of this posture without dynamic leg movement may induce stiffness in the thigh and calf musculature. The observed leg angle is assigned a REBA score of 2, as it exceeds 60°.

The combined score was determined based on the angular positions of Group A body segments, namely the neck, body, and legs, each of which was assigned a score of 2. The load score was then determined based on the combined score of the Group A body segments. During the oil palm FFB harvesting process, harvesters handle a load of 7 kg while operating the eggrek; therefore, this load falls within the category of less than 10 kg and is assigned a score of +0.

The REBA analysis was futher extended to evaluate the body postures of harvesters categorized under Group B, as illustrated in Figure 8.

Based on Figure 8(a), it can be explained that the harvester's upper arm position during oil palm FFB harvesting using the eggrek harvesting tool is positioned away from the body. This posture is required to support body weight and maintain balance while maneuvering the eggrek, resulting in an upper-arm angle of 80.5°. Prolonged maintenance of this posture without dynamic movement may increase the risk of muscle stiffness in the upper arm. The measured upper arm angle falls within the +3 score category, as the upper arm is positioned forward at an angle ranging between 45°–90°.

Figure 6. Manual harvesting process of oil palm Fresh Fruit Bunches (FFB)



(a) (b) (c)

Figure 7. Body postures of Group A harvesters: (a) neck, (b) body, and (c) legs

(a) (b) (c)

Figure 8. Body postures of Group B harvesters: (a) upper arms, (b) lower arms, and (c) wrists

Based on Figure 8(b), it can be explained that the harvester's lower arm forms an angle of approximately 90.8°, indicating that the elbow is maintained in a flexible position. This posture contributes to maintaining stability while the eggrek is held upward during the oil palm FFB harvesting process. Although this posture is ergonomically acceptable, careful consideration should be given to the duration of the harvesting activity, as prolonged static positioning necessitates periodic rest to minimize muscle fatigue and reduce the potential risk of MSDs symptoms. The measured lower arm angle falls within the +1 score category, as the lower arm is oriented forward at an angle between 60°–100°.

Based on Figure 8(c), it can be explained that the harvester's wrist is maintained in a slightly flexed position during the oil palm FFB harvesting process using the eggrek, with an inward bend forming an angle of 25.7°. Prolonged maintenance of this posture may increase the risk of tendon stiffness in the wrist; therefore, the provision of adequate rest periods is essential to mitigate the potential development of MSDs symptoms. The measured wrist angle falls within the +2 score category, as the wrist is positioned in flexion or oriented upward at an angle exceeding 15°.

The combined score value, derived from the angular positions of the body segments of Group B—specifically the upper arm (score = 3), lower arm (score = 1), and wrist (score = 2)—is 4.

The coupling or grip score is determined based on the assessment of the body segments of Group B. The grip employed by harvesters during the oil palm FFB harvesting activity is deemed satisfactory, as the eggrek, weighing 7 kg, possesses a diameter that allows for secure handling. Therefore, this condition satisfies the requirements for an optimal grip and is assigned a score of +0.

The body posture score value C represents a combination of the body part scores of Group A (score = 4) and Group B (score = 4) is 4.

The harvester activity score during the oil palm FFB harvesting process was measured based on the harvester's body posture, specifically maintaining a standing position with raised hands to manipulate the eggrek upwards for a duration of 2 to 5 minutes, which was assigned a score of +1. Furthermore, repetitive execution of the activity was also assigned a score of +1. The overall activity scores is +1.

The REBA analysis score is calculated based on the combination of outcomes of the C-table score and the activity score. With a C-table score of 4 and an activity score of 2, the resulting REBA score is 6, corresponding to action level 2, which denotes a moderate risk level and necessitates the implementation of corrective measures in the oil palm FFB harvesting process.

A posture evaluation was conducted using the REBA during the FFB harvesting process, which indicated a moderate risk level. This finding contrasts with several studies on the harvesting process that report a high-risk level [23]. The differences in the REBA evaluation results can be attributed to factors such as the height of the trees and the method used for harvesting FFB.

3.3 Results and discussion Manual Material Handling analysis

Ergonomic risk assessment of harvesting activities using the eggrek oil palm harvesting tool, including lifting and transporting FFB, was performed employing the REBA method in conjunction with MMH analysis.

(a) (b)

Figure 9. Process of (a) lifting and (b) transportation of oil palm Fresh Fruit Bunches (FFB)

Figure 9 illustrates the process of (a) lifting and (b) transporting FFB of oil palm to the collection point. In Figure 9(a), the harvester assumes a pronounced forward-bending posture, with the back and head inclined downward and the legs fully extended. This posture indicates that the lumbar region bears the primary load during FFB lifting, resulting in substantial stress on the lower back and elevating the risk of MSDs in this area. Figure 9(b) illustrates the harvester in a slightly flexed posture, holding the FFB symmetrically above the head with both hands. This activity represents a high level of physical strain due to the weight of the FFB, ranging from 20 to 40 kilograms, imposing considerable stress on the neck, back, and spine. The risk of MSDs increases significantly if these tasks are performed repetitively without appropriate ergonomic support.

Harvester anthropometric data, specifically weight and height, were incorporated to evaluate the alignment of physical workload with individual capacity and to identify potential overloads that could increase the risk of MSDs. The findings from this assessment serve as a basis for optimizing working conditions, including the implementation of harvesting aids or mechanization, to enhance both safety and productivity in oil palm FFB harvesting.

Statistical evaluation was conducted using responses from the NBM questionnaire, which were visualized to facilitate the identification of harvester characteristics from biodata and the severity of complaints in each anatomical region. Required data included age, tenure, height, and weight of the harvesters.

The ages of the oil palm harvesters analyzed ranged from 36 to 45 years, indicating that many harvesters are classified as middle-aged. This age range was selected to mitigate the potential decline in physical capacity and the risk of health-related complications associated with older harvesters. Data on the tenure of oil palm FFB harvesters range from 1 to 5 years. Harvesters with long-term experience are generally more susceptible to muscle and joint fatigue due to repetitive work over extended periods. Conversely, harvesters with limited experience are also at risk of developing MSDs because of unfamiliar muscle conditions and insufficient knowledge of safe FFB harvesting techniques.

The average height of oil palm FFB harvesters is 155–164 cm, classified as medium. Height influences musculoskeletal strain during FFB transport in bent postures: taller harvesters bend below their center of gravity, increasing lower back load, while shorter harvesters bend more to reach the FFB, elevating muscle tension. Ergonomic harvesting techniques are needed to mitigate these risks across different heights. The average body weight of oil palm FFB harvesters is 50–59 kg. This weight range corresponds to an ideal proportion for moderate to heavy physical activity. Body weight is also an important factor influencing muscle strength and joint loading. Underweight individuals may have limited muscular capacity to support heavy workloads, increasing the risk of injury, whereas excess weight can impose additional stress on the joints and spine during FFB harvesting [24]. Therefore, maintaining an ideal body weight is crucial for optimizing endurance and performance under physically demanding conditions.

Table 4. Liliefors test results for weight data

No.	Weight (kg)	Z	F (z)	S (z)	|F(z) – S(z)|
1	48	-1.166795289	0.121646525	0.133333	0.011686808
2	48	-1.166795289	0.121646525	0.133333	0.011686808
3	49	-1.027891088	0.152000531	0.200000	0.047999469
4	50	-0.888986887	0.187005064	0.333333	0.14632827
5	50	-0.888986887	0.187005064	0.333333	0.14632827
6	53	-0.472274284	0.318365512	0.400000	0.081634488
7	54	-0.333370083	0.369427472	0.466667	0.097239195
8	55	-0.194465881	0.422905554	0.600000	0.177094446
9	55	-0.194465881	0.422905554	0.600000	0.177094446
10	59	0.361150923	0.641006686	0.666667	0.02565998
11	60	0.500055124	0.691481868	0.733333	0.041851465
12	65	1.194576129	0.88387366	0.933333	0.049459674
13	65	1.194576129	0.88387366	0.933333	0.049459674
14	65	1.194576129	0.88387366	0.933333	0.049459674
15	70	1.889097134	0.970560593	1.000000	0.029439407

Table 5. Liliefors test results for height data

No.	Height (cm)	Z	F (z)	S (z)	|F(z) – S(z)|
1	153	-1.184679428	0.118072110	0.066667	0.051405443
2	155	-0.921417333	0.178416291	0.133333	0.045082958
3	156	-0.789786285	0.214826295	0.266667	0.051840372
4	156	-0.789786285	0.214826295	0.266667	0.051840372
5	157	-0.658155238	0.255219192	0.400000	0.144780808
6	157	-0.658155238	0.255219192	0.400000	0.144780808
7	158	-0.52652419	0.299262025	0.466667	0.167404642
8	160	-0.263262095	0.396174287	0.600000	0.203825713
9	160	-0.263262095	0.396174287	0.600000	0.203825713
10	163	0.131631048	0.552361937	0.666667	0.11430473
11	167	0.658155238	0.744780808	0.800000	0.055219192
12	167	0.658155238	0.744780808	0.800000	0.055219192
13	168	0.789786285	0.785173705	0.866667	0.081492962
14	173	1.447941523	0.926183297	0.933333	0.007150036
15	180	2.369358856	0.991090523	1.000000	0.008909477

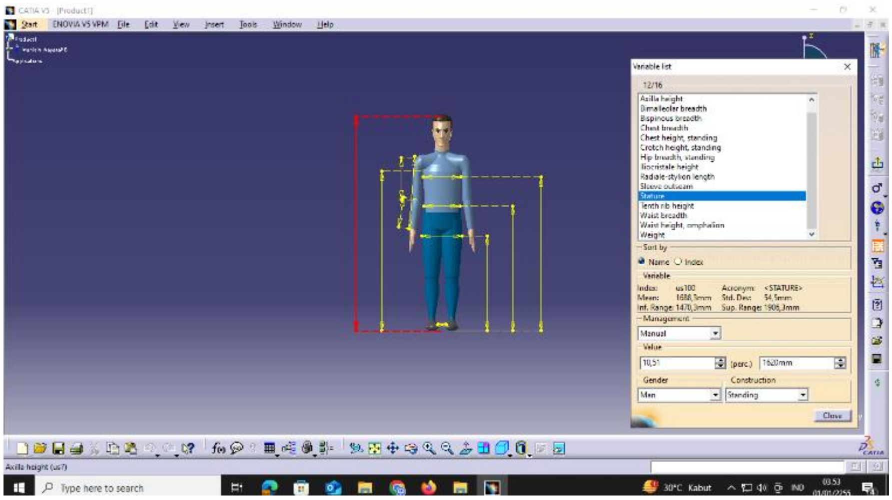
The MMH analysis involved lifting oil palm FFB from the ground and transporting it to the collection point was analysed to determine the biomechanical stress imposed on harvesters using CATIA software. The initial step of analysis entailed a comprehensive assessment of harvesters' anthropometric data, specifically weight and height, which were examined for normality using the Liliefors test, as summarized in Tables 4 and 5.

Based on the data presented in Tables 4 and 5, the Liliefors normality test results indicate that the statistic for harvesters' weight is 0.20383, and the harvesters' height is 0.17709. Both values are lower than the range of the Liliefors test table value of 0.22. Accordingly, since the calculated L values are smaller than the L_{table} value, the weight and height data can be assumed to follow a normal distribution. Based on these data, the mean body weight and height of oil palm FFB harvesters are 56.4 kg and 162 cm, respectively. These mean anthropometric values were subsequently employed as baseline input parameters for the MMH analysis conducted using CATIA software, as shown in Figure 10.

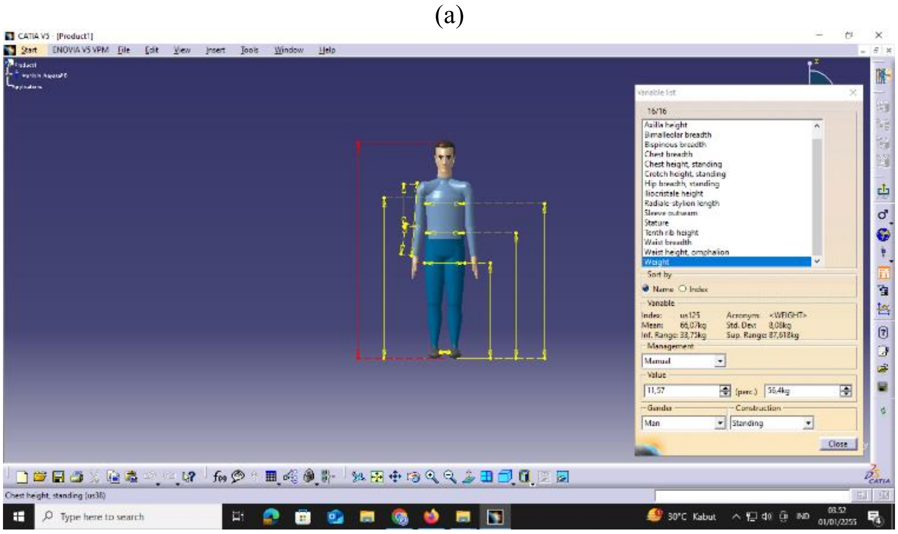
Following the input of the harvester's anthropometric data, a work posture model was constructed to represent the activity of lifting oil palm FFB to determine the MMH analysis, which is associated with the biomechanical risk in the L4/L5 spine segment, as illustrated in Figure 11. Figure 11 shows the calculated compression force, referred to as the Compression Limits of 1714 N, generated by the harvester's bending posture during the lifting activity. The compression force indicates the magnitude of the vertical resistive load imposed on the lower spinal segment, especially in the intervertebral disc between L4 and L5 vertebrae. In addition, the Joint Shear Limits are presented, indicating a posterior shear force (backward) of 2N, which is a horizontal force that also provides a load on the spinal segment.

Subsequently, the harvester's working posture during the activity of transporting oil palm FFB to the collection point was evaluated to assess the MMH analysis associated with this activity. The biomechanical risk assessment of the L4/L5 spine segment indicated a compression force of 1288 N and a posterior shear force of 22 N. These values indicate the amount of vertical and horizontal pressure transmitted to the lower spinal vertebrae, especially in the intervertebral section between L4 and L5, as illustrated in Figure 12.

Based on the ergonomic standard values from NIOSH AL (National Institute for Occupational Safety and Health) implemented in the CATIA software, as shown in Figure 13, the safe threshold limit for compression force at the L4/L5 segment is ≤ 3433 N. This indicates that the compression force experienced by harvesters during the lifting and transportation of oil palm FFB remains within the safe category. However, this condition still needs to be considered in relation to the frequency of lifting oil palm FFB, duration of work, and more appropriate lifting techniques to prevent the risk of cumulative MSDs symptoms.



(a)



(b)

Figure 10. CATIA data input for (a) height and (b) weight

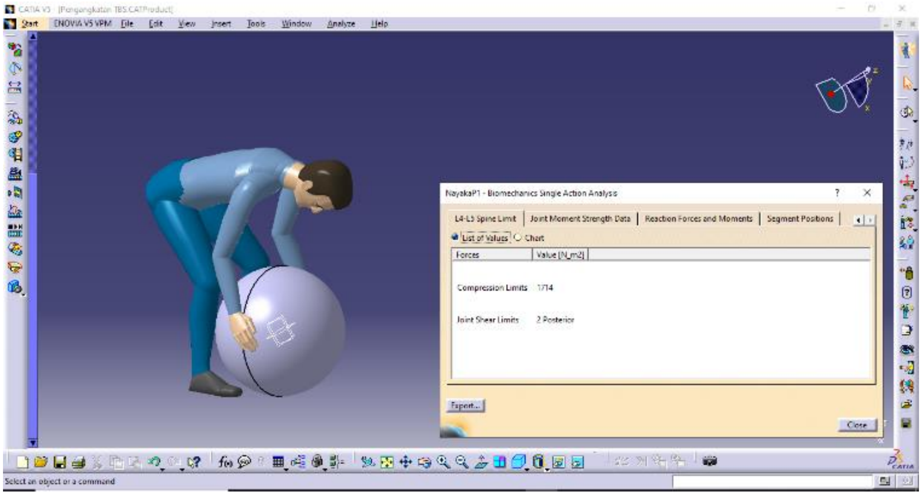


Figure 11. L4/L5 compression force during the palm oil Fresh Fruit Bunches (FFB) lifting process

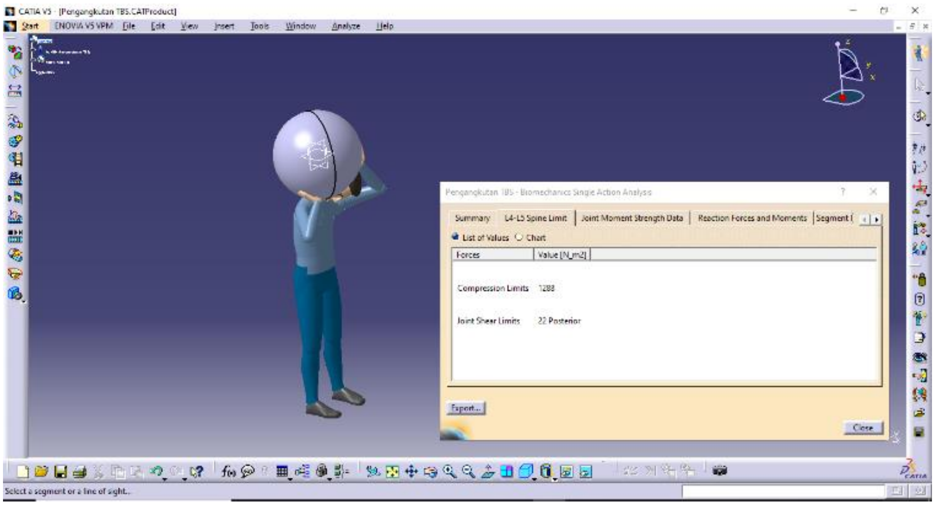


Figure 12. L4/L5 compression force during the oil palm Fresh Fruit Bunches (FFB) transportation process

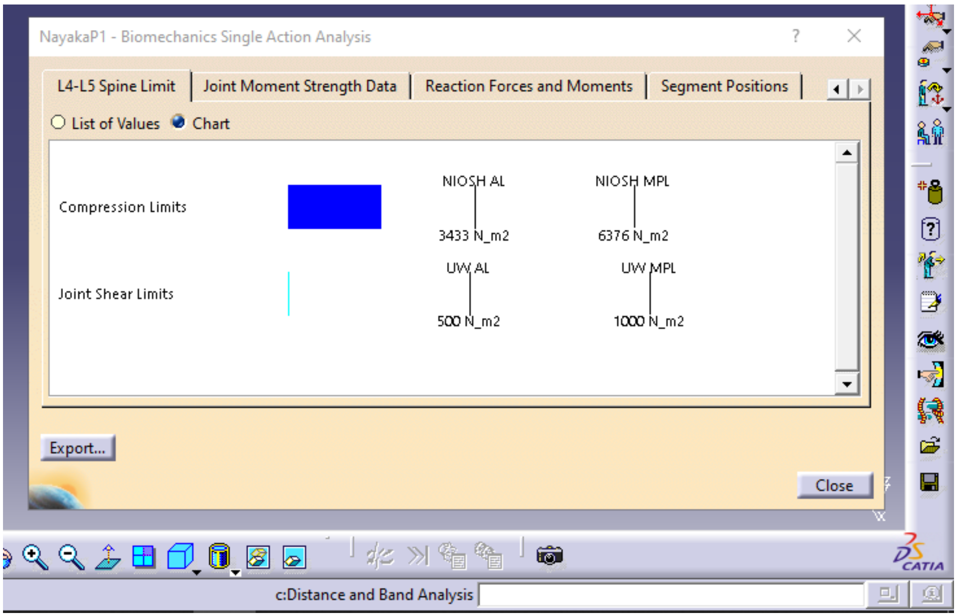


Figure 13. NIOSH AL standard biomechanical risk limits (L4/L5 compression force)

Based on the results of the biomechanical analysis of the two activities, significant biomechanical pressure was obtained. This pressure is felt in the lower spine, especially in the L4/L5 segments, which indicates that both values have a compression force still below the safe threshold according to the NIOSH AL standard (3433 N), which includes the potential for cumulative loads and muscle fatigue due to high work frequencies, which remain ergonomic risk factors that need serious attention.

The biomechanical stress associated with MMH, as assessed by CATIA, is below the standards set by the National Institute for Occupational Safety and Health (NIOSH). However, the same study indicates that the results for all tasks performed by harvesters in oil palm plantations exceed the NIOSH standards, with L5-S1 compression forces surpassing 3,400 N [6]. The difference of results depends on the harvester posture and the load of FFB.

The pressure values at L4/L5 are influenced by the lifting angle, body weight, the distance of the load from the hip, and abdominal pressure, which helps reduce the load on the lumbar spine. In this study, the lifting values were below the safety threshold, supported by the body posture during the lifting of FFB, specifically the close distance between the FFB and the hip, as well as the angle formed between the back and the horizontal axis [25].

NIOSH provides guidelines for performing manual handling activities. Factors such as the distance between the body and the object, the destination point of the lifted object, the coupling of the object, the frequency of lifting, and the asymmetry angle influence the safe lifting limits [26]. Therefore, in this case, although the compression force on L4/L5 remains within the safe limit, attention should be given to the lifting posture of FFB in accordance with the factors mentioned above.

Therefore, as an improvement effort to reduce ergonomic risks and prevent MSDs, ergonomic-based interventions need to be carried out, such as improving the work system, namely rotating work by switching harvesters from heavy activities to lighter activities periodically to reduce certain body loads for harvesters, considering harvester recruitment by limiting the maximum age of harvesters to no more than 40 years. In addition, providing ergonomic training and correct work postures so that harvesters understand how to harvest FFB more safely and not overload their bodies. Then, providing harvesting aids in the form of FFB containers and transporters to collection points reduces direct biomechanical pressure on the harvester's body. This can prevent potential injuries or complaints to the musculoskeletal system. Providing tools to assist in harvesting oil palm FFB is also a strategic step in supporting a more productive, safe, and ergonomic work system and can be an innovative solution to improve workforce sustainability in the oil palm plantation sector.

4. CONCLUSIONS

The results of ergonomic conditions for harvesters in oil palm FFB harvesting activities can be determined through NBM analysis, REBA analysis, and MMH analysis. Based on the results of the NBM analysis, it can be concluded that the condition of the harvester's body parts with the highest level of complaints is in the waist, buttocks, upper neck, left shoulder, and right shoulder. The body parts of harvesters who experience fatigue are related to age factors and length of work, which can cause complaints of MSDs symptoms to increase. In addition, the results of the REBA analysis on harvester activities during oil palm FFB harvesting activities also showed a high score, namely a score of 6, which is included in the moderate risk category. This indicates that the body posture of harvesters needs to be reviewed and improved, as it is at risk of causing MSDs complaints if performed repeatedly and over a prolonged period. The results of the MMH analysis also showed the biomechanical pressure compression forces on the L4/L5 segment of the harvester's spine during the process of lifting oil palm FFB (1714 N) and transporting oil palm FFB (1288 N). Although both compression forces are still below the safe limit of the compression force value set by NIOSH AL (3433 N), if repeated over a long period, they can have a cumulative impact on MSDs symptoms. Although this is a pilot study, the methods used can analyze the potential for MSDs among oil palm harvesters. Further research with a larger sample size is necessary to gather more reliable data.

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STATEMENT ON THE USE OF GENERATIVE ARTIFICIAL INTELLIGENCE

The authors declare that artificial intelligence technologies were used in the creation of this work. Grammarly (https://www.grammarly.com) is used to check the grammar structure of sentences, and Quillbot (https://quillbot.com) is used to check the sentence paraphrase.

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