Journal of Oil Palm Research Vol. 37 (4) December 2025 p. 581-597
DOI: https://doi.org/10.21894/jopr.2024.0048

PREVALENCE OF WORK-RELATED MUSCULOSKELETAL DISORDERS (WMSDs) AND RECENT INITIATIVES TO ADDRESS THEM IN THE OIL PALM INDUSTRY: A SYSTEMATIC REVIEW

'UMAR MOHAMAD NOOR[1] and MOHAMAD IKHWAN ZAINI RIDZWAN[1]*

ABSTRACT

This systematic review investigates the prevalence of work-related musculoskeletal disorders (WMSDs) within the oil palm industry, where the incidence is high due to the widespread use of manual tools, despite the availability of intervention tools in the market. The objectives of this review are twofold: To identify and summarise studies focusing on WMSDs prevalence in oil palm plantation work, and to examine research related to biomechanical evaluations and the design of intervention tools aimed at addressing WMSDs. A comprehensive search of databases including Web of Science, Scopus, PubMed, and ScienceDirect was conducted, covering articles published from 2013 to 2023. From the initial pool of 245 articles identified, a rigorous selection process yielded 27 studies meeting the inclusion criteria for this review. The majority of these studies were conducted in Malaysia (22 studies), with additional contributions from Thailand (2 studies), Colombia (2 studies) and Indonesia (1 study). In conclusion, WMSDs prevalence remains alarmingly high in oil palm plantation works. However, promising approaches utilising modern tools such as inertial measurement units (IMU) and electromyography (EMG) for direct measurement, as well as sophisticated human musculoskeletal model simulation in software like AnyBody, have been explored in some studies, indicating avenues for future intervention strategies.

Keywords: ergonomics, harvesters, intervention tools, MSDs, occupational health.

Received: 14 March 2024**; Accepted:** 15 August 2024**; Published online:** 17 October 2024.

INTRODUCTION

The oil palm industry is one of the most promising agricultural industries. It serves as the source of many important products ranging from palm oil, palm kernel oil and is also used in the making of various products such as soap, margarine and ice cream. Since 2005, Indonesia has emerged as the largest producer of palm oil, with oil production reaching 15.6 million tonnes and increasing up to 28.5 million tonnes by 2012 (Murphy, 2014). In 2017, Indonesia contributed about 50% of the worldwide palm oil production (Shigetomi et al., 2020). By 2020, Indonesia followed by Malaysia were the two highest producers of palm oil (Shigetomi et al., 2020). When compared to soybean and rapeseed, oil palm stands out as the most efficient crop, yielding the highest oil-based hydrocarbons (Murphy, 2014; Sibhatu, 2023). In short, in terms of oil produced per hectare planted, it is the most productive crop (Rahman et al., 2016; Sibhatu, 2023). Oil palm cultivation is therefore profitable to plantation owners, but this may be different for oil palm workers who do not have farms (Shigetomi et al., 2020).

Comparing oil palm planted area in Malaysia from 2021 to 2023, a decrease of 1.1% and 0.4% respectively in two consecutive years resulted in the reduction of the oil palm planted area from

[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*

5.74-5.65 million hectares (Malaysian Palm Oil board [MPOB], 2023, 2024). The reduction of 1.1% planted area from 2021-2022 was attributed to the MPOB license renewal procedures upgrade and adherence to the Malaysian Standard for Sustainable Palm Oil Production (MSPO) (Parveez et al., 2023). The slight decrease in the planted area (0.4%) from 2022-2023 was, to a certain extent, due to replanting preparation (MPOB, 2024). In managing such a vast area, the sustainability aspect of the oil palm industry should be a focus to ensure the industry's survival and prosperity. This effort should begin at the oil palm plantation itself, by taking care of the manual workers involved in oil palm fronds pruning, oil palm fresh fruit bunches (FFB) harvesting, FFB loading, oil palm loose fruits (LF) collection and many other tasks, as they are vulnerable to the harsh physical and mental demands of the work. Malaysia had been dependent on foreign labour, hence the post-effect of COVID-19 which resulted in the reduction of imported labour had seriously affected productivity (Parveez et al., 2023), with the lasting consequences still experienced by the industry, as indicated by only a slight growth in FFB yield (1.9%) in 2023 compared to 2022, despite the recovering of manpower supply (Parveez et al., 2024). This signalled the need to hasten mechanisation and automation, to reduce labour requirements (Parveez et al., 2023).

Traditionally, to harvest FFB, harvesters must adopt a stooping posture and use a chisel during early harvesting when the oil palm tree is under 3 m (Ng et al., 2013a). Stooping posture was characterised by trunk flexion adopted by the harvesters, to avoid contact with the oil palm fronds, as the fronds were shorter in height compared to the harvesters and hence acted as obstacles during harvesting activity. On the other hand, for tall oil palm trees, harvesters must tilt their heads upward in search of ripe FFBs and maintain this position throughout the harvesting motion (Ng et al., 2013a). Coupled with heavy tools such as traditional sickles/poles and chisels, the repetitive motions involved in these activities can result in injury or disorder to the musculoskeletal system of oil palm workers. The manual methods of FFB harvesting, FFB loading, and LF collection using traditional tools such as a sickle, chisel, and sharp metal skew are still used nowadays, as indicated in a study by Bhuanantanondh et al., (2021). This was due to the new technology not being widely adopted (Saibani et al., 2015).

Some of the inventions made for the frond pruning and FFB cutting tasks were the motorised cutter, while FFB loading task was the mechanical grabber attached to a tractor-trailer, whereas for LF collection task was the use of a vacuum-suction machine. Based on a study by Mohiddin and Pebrian (2021), the degree and capacity of mechanisation in oil palm plantations in Malaysia were explored, using 2013 survey data from the MPOB, which involved 4,541 estates. Mechanisation degree, expressed in percentage, is the ratio of plantation areas utilising machines, to the entirety of plantation areas (Mohiddin & Pebrian, 2021). On the other hand, mechanisation capacity, also expressed in percentage, is the ratio of machines availability multiplied with their working capacity and frequency of usage, to the total yearly yield from the whole operations (Mohiddin & Pebrian, 2021). Motorised cutters showed 2.36% of mechanisation degree and 18.52% of mechanisation capacity. Besides, the infield collection incorporating both FFB loading and LF collection; by using the motorcycle-trailer, tractor-trailer, tractor-trailer with grabber, three-wheel cart, vacuum (LF collection) and other tools, showed the mechanisation degree of 29.66% and mechanisation capacity of 12.81% (Mohiddin & Pebrian, 2021). This finding shed light on the opportunity and responsibility, to devise mechanised tools related to FFB harvesting activities in providing essential mechanisation needs for the oil palm plantation works. Considering the fact of the various tools' availability and usage, one of the focuses of this systematic review is to review studies on intervention tools, only if they incorporate biomechanics or ergonomics or risk evaluations of the human body. This will ensure the safety and suitability of the inventions to the targeted user, especially in prolonged usage.

The agriculture industry is synonymous with work-related musculoskeletal disorders (WMSDs) issues, showing 60%-80% WMSDs prevalence for farmers in Africa, America, East Asia and South Asia in previous studies, highlighted by Akbar et al. (2023). One of the effects of musculoskeletal disorders (MSDs) was the decrease in productivity of the oil palm plantation (Oktaviannoor et al., 2015). Thus, increasing working hours only resulted in decreasing work efficiency for farmers who suffered from MSDs (Prommawai et al., 2019). From the systematic review by Akbar et al. (2023), the prevalence of WMSDs was very high among farmers in the Southeast Asia Region (80.10%), with prevalence as high as 88.39% in Malaysia, 81.27% in Indonesia and 78.31% in Thailand. The only two included studies from Malaysia were related to oil palm workers (Akbar et al., 2023), hence it could be said that the prevalence of WMSDs for farmers in Malaysia were those of oil palm workers. Agriculture-related study was scarce in Indonesia, despite the importance of the agricultural sector to the country (Widyanti, 2018).

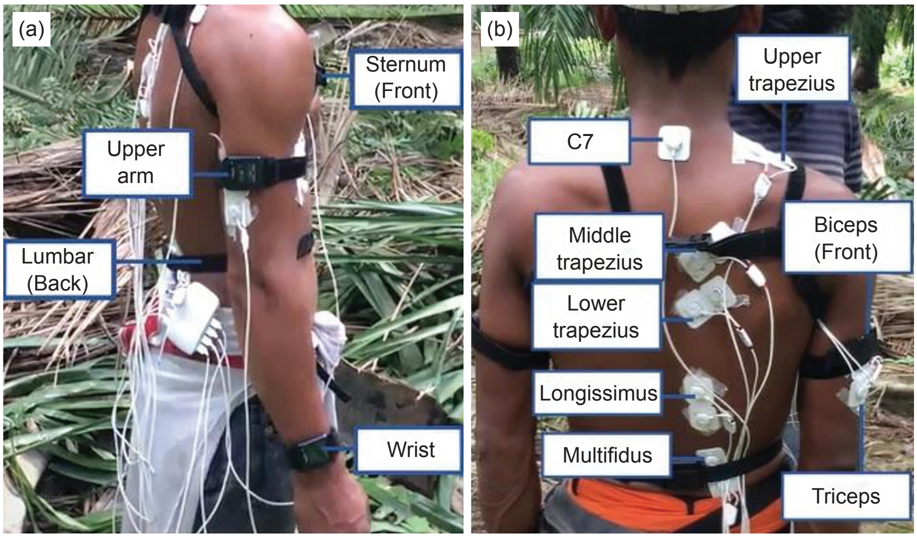
To the best of our knowledge, only two systematic reviews have closely addressed the prevalence of WMSDs in the oil palm industry; Akbar et al. (2023) and Myzabella et al. (2019). Firstly, Myzabella et al. (2019) conducted a systematic review focusing on occupational health and safety in the oil palm industry, including WMSDs, albeit limited to studies up to 2018. However, they overlooked the technological aspect utilised by researchers to assess biomechanical aspects of oil palm works, for instance, the use of inertial measurement unit (IMU) and electromyography (EMG) as shown in *Figure 1*. Magnetic-inertial measurement units (MIMU) or IMUs have also been used in an industrial context, with 20 studies focusing on risk assessment (using MIMU/IMU) included, and four of them combining the usage of MIMU/IMU with EMG technology, as listed by Digo et al. (2022). The 20 studies were from the year 2014-2022 (Digo et al., 2022). Secondly, Akbar et al. (2023) specifically reviewed the prevalence of WMSDs among farmers of various agricultural backgrounds, also encompassing oil palm workers in some studies, in Southeast Asia, from 2015 to 2022, though excluding certain study types such as experimental, case-control and cohort studies from their analysis. Thus, there is a need for a comprehensive systematic review to identify and summarise current findings and efforts aimed at addressing oil palm work issues, particularly WMSDs, with a focus on enhancing the work environment for oil palm workers. This review encompasses a wide range of sources, including journal and conference articles, and considers various study designs, such as experimental, simulation, cross-sectional, observational and survey studies.

MATERIALS AND METHODS

This systematic review was performed based on Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines. Relevant articles were identified by searching four databases, Web of Science, Scopus, PubMed and ScienceDirect. The search was restricted to articles published between 1 January 2013 and 31 December 2023. This time frame was selected because the articles of interest were primarily from the most recent 10 years. This was done to highlight current issues in WMSDs and the methods used to address them, with the anticipation of incorporating more modern tools.

The use of Boolean operators (OR, AND) had to be limited because ScienceDirect database only allowed a maximum of eight Boolean operators. Additionally, truncation of word searches was not available in certain databases. In light of these limitations, preliminary searches were conducted with various combinations of keywords. Ultimately, the final set of keywords was chosen for its effectiveness in retrieving relevant papers from all four databases. These keywords consisted of a single line of common words describing oil palm works, WMSD issues faced by the oil palm workers, and interventions designed to address these issues. The keywords used were (oil palm worker OR oil palm harvester OR oil palm harvesting OR oil palm FFB) AND (work-related musculoskeletal disorders OR WMSDs OR ergonomic OR intervention OR tool).

Additionally, the result from ScienceDirect was further refined to only four publication titles, namely: 1) Procedia Engineering, 2) International Journal of Industrial Ergonomics, 3) Results in Engineering and 4) Applied Ergonomics. The subject area was also refined to only Engineering. These were done to limit the search to only relevant studies.



Source: Teo et al. (2021).

Figure 1. (a) IMU Sensor placement, and (b) EMG sensor placement on the harvester's body.

Inclusion and Exclusion Criteria and Evaluation of Articles

Inclusion criteria encompassed quantitative data articles addressing WMSDs, biomechanics related to oil palm activities, or interventions with proper data. This review focused exclusively on oil palm plantation workers. Only articles published between 1 January 2013 to 31 December 2023, were considered. Exclusion criteria were applied to systematic review articles, qualitative data studies, time and motion studies, production studies, research on oil palm mill workers and studies not directly addressing WMSDs or biomechanical evaluation.

The process of article selection and elimination is outlined in *Figure 2*. Critical Appraisal Skills Programme Programme (CASP) (CASP, 2019) checklists were used to assess the quality of selected papers included in this systematic review. All developments including search terms, inclusion and exclusion criteria and quality appraisal of included papers were discussed with M.I.Z.R.

RESULTS AND DISCUSSION

The database search resulted in 245 papers, all of which underwent screening based on title and abstract as shown in *Figure 2*. Among these, 71 articles were selected by excluding 174 articles not related to oil palm or WMSDs. Duplicate articles, which were the same articles but retrieved from different databases, were then removed, resulting in the elimination of 26 papers. The removal process commenced after title and abstract screening, as this systematic review was conducted manually without specific systematic review software. A total of 45 full-text articles were evaluated, and after excluding 18 articles based on the exclusion criteria, 27 articles remained for analysis.

All articles included in this systematic review are listed in *Table 1* and *2*. Out of the 27 articles, 22 were from Malaysia, two from Thailand, two from Colombia, and one from Indonesia. As stated in the inclusion criteria, only articles published between 2013 and 2023 were considered. The distribution of articles by publication year was as

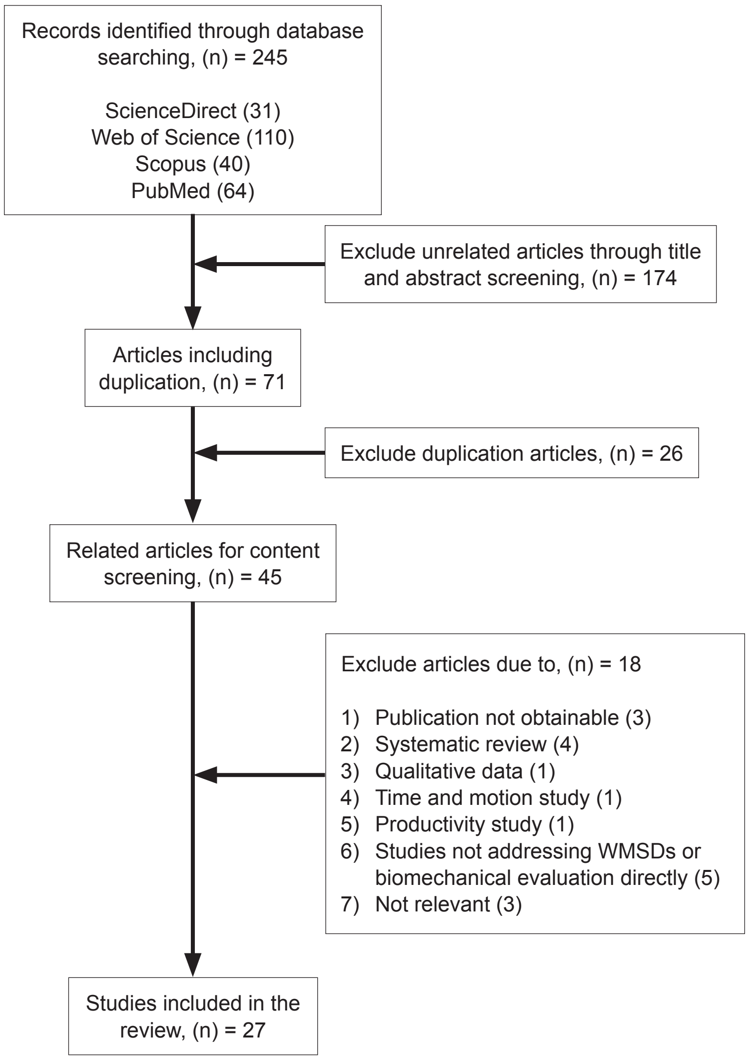


Figure 2. Systematic review study selection flowchart.

follows: Three in 2013, two in 2014, three in 2016, one in 2017, three in 2018, three in 2020, seven in 2021, one in 2022 and four in 2023. No articles from 2015 and 2019 were included in this systematic review.

The critical appraisal of selected articles using the CASP Randomised Controlled Trial (RCT) checklist (18 articles) is presented in *Table 1*. One article scored 7 (maximum score is 11), 12 articles scored between 4 and 6 and five articles scored between 1 and 3. Evaluation using the CASP Cohort checklist (nine articles) is depicted in *Table 2*, where one article scored 11 (maximum score is 12), one scored 8, two scored 7 and five ranged from 4-6. Low CASP scores were primarily attributed to the strict criteria of the RCT checklist, especially for experimental (nine studies) and simulation (eight studies) studies, wherein none of the studies were randomised. Marks were also deducted as the RCT checklist was intended for intervention studies. Cross-sectional (six studies), observational (two studies), and survey (one study) studies were evaluated using the CASP Cohort checklist, given its similarity to cohort studies, which are observational. It is worth noting that, in contrast to a cross-sectional study where results were obtained instantly during that specific time of study, a cohort study was employed to study certain effects over time.

TABLE 1. ARTICLES RATED USING RCT CASP CHECKLIST

Article No.	Author	Location	Year	Participant(s)	Measurement tool(s)	Main result(s)	CASP score
1	Mohamaddan et al.	Malaysia	2021	30 male FFB harvesters	CATIA V5R20 and AnyBody software	RULA score of 7 for works using pole, chisel and loading spike	4
2	Abdullah et al.	Malaysia	2023	10 male harvesters	S-Type Load cell, force plate, IMU, and EMG	Maximum cutting force of 1,601.23 ± 424.26 and 420.80 ± 96.00 N for sickle and chisel respectively	6
3	Chan et al.	Malaysia	2022	6 male FFB harvesters	IMU, EMG, and OpenSim	The highest average peak joint moment was during back lateral bending to the right (19.02 Nm/kg), back flexion (13.69 Nm/kg) and dominant shoulder extension (5.98 Nm/kg)	4
4	Teo et al.	Malaysia	2021	8 FFB harvesters and 8 LF collectors	IMU, EMG	Peak muscle activities during FFB harvesting and LF collection were all higher than 50%, for all muscles (upper trapezius, middle trapezius, lower trapezius, longissimus, multifidus, biceps and triceps).	4
5	Ahmad et al.	Malaysia	2023	4 workers (only 2 harvesters)	Noise meter and vibration test equipment	Noise level of 60 dB. Magnitude of vibration at the pole and throttle of 1.3 and 0.8 m/s^2 respectively	5
6	Jelani et al.	Malaysia	2018	6 workers (only 2 harvesters)	Vibration test equipment	Vibration level of 0.6 and 0.4 m/s^2 at throttle and pole respectively	6
7	Tumit et al.	Malaysia	2021	20 male harvesters	Quintic biomechanics system	Greater range of harvesting movements at initial posture in the support shoulder by participants in the age group of 40-49 (90.4°) and 30-39 (86.0°) compared to 20-29 (63.6°)	5
8	Harith et al.	Malaysia	2021	10 non-experienced male participants	EMG and survey form	Mean %MVC showed significant reduction when using exoskeleton: Left and right deltoids for 43.2% and 31.3% respectively and left biceps for 51.8% reduction	6

TABLE 1. ARTICLES RATED USING RCT CASP CHECKLIST (continued)

Article No.	Author	Location	Year	Participant(s)	Measurement tool(s)	Main result(s)	CASP score
9	Ahmad et al.	Malaysia	2020	(unclear number*) oil palm harvester	Load cell	Maximum cutting force of 300.2 N using a magnetic actuator oil palm cutter, in a lab experiment	5
10	Parra-Ruiz et al.	Colombia	2018	4 oil palm harvesters	SolidWorks and Siemens PLM software	OWAS score of 1 using a new simulated tool and a score of 4 using traditional sickle	3
11	Rahman et al.	Malaysia	2016	(unclear number*) oil palm harvester	AnyBody Technology software	The maximum force of 15.12 N to triceps lateral head (LH), 11.30 N to extensor carpi ulnaris, 6.89 N to deltoideus scapular and 4.51 N to trapezius clavicular	1
12	Nawi et al.	Malaysia	2013	1 harvester, 1 loader	Video recorder	Highest REBA score of 13 for FFB harvesting and 10 for FFB loading	3
13	Rahman et al.	Malaysia	2017	(unclear number*) oil palm worker	AnyBody Technology software	Biceps muscle required 3.50×10^2, 2.91×10^{-1} and 4.02×10^3 N, to move the pole, chisel and loading spike respectively	2
14	Sabri et al.	Indonesia	2020	(unclear number*) operator	Not stated	The maximum human energy needed to operate the intervention tool was 250.2 N.m	1
15	Parra et al.	Colombia	2018	(unclear number*) oil palm harvester	Video recorder, Kinovea, and JACK Siemens software	Maximum back compression of 8,385 and 440 N when using a conventional sickle and new intervention respectively	4
16	Teo et al.	Malaysia	2023	8 male harvesters	IMU and EMG	The first muscle synergy was contributed by the upper trapezius (activated during 20% to 60% harvesting movement), the second synergy was contributed by the longissimus and multifidus (activated during 10%-25% harvesting movement), and the third synergy was contributed by the biceps (activated during 20%-70% harvesting movement),	4
17	Chan et al.	Malaysia	2023	6 male harvesters	IMU and OpenSim software	Reduction in average peak muscle activation and peak muscle force for most muscles when exotendon was applied, by up to 49.22% and 82.00% respectively	5
18	Mohamaddan et al.	Malaysia	2021	30 male harvesters	Digital video camera, survey, CATIA and AnyBody software	The highest leg mean muscle force of 96.83 N at the left gastrocnemius medialis (loading spike) 82.19 N at the right gastrocnemius medialis (chisel) and 79.06 N at the left gastrocnemius medialis (pole)	4

Note: *Unclear number of participants, due to the author not stating it or due to participant was not necessary for a simulation-type or lab experimental study.

TABLE 2. ARTICLES RATED USING COHORT CASP CHECKLIST

Article No.	Author	Location	Year	Participant(s)	Measurement tool(s)	Main result(s)	CASP score
19	Bhuanantanondh et al.	Thailand	2021	334 oil palm harvesting workers	Questionnaire (Thai-JCQ-54 and modified standardized Nordic questionnaire)	The highest 12-month MSDs prevalence was lower back (59.0%), shoulder (37.1%) and neck (27.2%)	11
20	Deros et al.	Malaysia	2016	70 male oil palm workers	Ergo Fellow 2.0 software and Modified Nordic questionnaire	Upper and lower back pain was experienced by 87.1% and 94.3% of workers respectively	6
21	Ng et al.	Malaysia	2013b	143 harvesters	Questionnaire (Nordic musculoskeletal questionnaire)	The highest MSD prevalence for the past 12 months was for the lower back (58.0%), knee (45.5%) and shoulder (32.9%)	7
22	Yusoff et al.	Malaysia	2014	273 male harvesters	SolidWorks and CATIA software and questionnaire	RULA score of 7 for 51.6% of harvesters, a score of 5 or 6 for 45.1% of harvesters and a score of 3 or 4 for 3.3% of harvesters	5
23	Mongkonkansai et al.	Thailand	2020	50 workers	Questionnaire and REBA	The highest MSD prevalence after 1 year was lower right arm (76%), upper right arm (76%), right shoulder (74%), lower back (74%) and right hand (70%)	7
24	Mokhtar et al.	Malaysia	2013	6 FFB harvesters and 1 truck driver	Questionnaire and video recorder	RULA final score of 7 for 83% (5 out of 6) harvesters	5
25	Deros et al.	Malaysia	2014	3 FFB harvesters	Video camera and Digital Human Modelling Software (DHMS)	Final RULA score of 7 for all harvesters	4
26	Rozadi and Fatin	Malaysia	2021	40 oil palm workers	Questionnaire	Common pain faced by workers were shoulder (36 workers), neck (33 workers) and lower back (34 workers)	6
27	Nawi et al.	Malaysia	2016	88 male oil palm workers	Nordic musculoskeletal questionnaire and video camera	Body parts with the highest pain complaints were the lower back (99%), upper back (85%) and shoulder (77%)	8

WMSDs Prevalence

There were six articles included in this systematic review focusing on WMSDs prevalence among oil palm workers. The WMSDs prevalence was quantified using questionnaires, answered by the respondents. A study by Bhuanantanondh et al. (2021) found that the body region with the highest 12 months MSDs prevalence was the lower back (59.0%), shoulder (37.1%) and neck (27.2%). This finding was comparable with a study by Ng et al. (2013b) where the lower back (58.0%), shoulder (32.9%) and neck (32.2%) were three of the highest body regions affected over the past 12 months. This was supported by findings by Rozadi and Fatin (2021) and Nawi et al. (2016), with both studies showing a high prevalence of pain in the lower back, shoulder and neck (74.0% and higher). A study by Deros et al. (2016) only reported the prevalence of lower and upper back pain, at 87.1% and 94.3% respectively. The lower back pain prevalence of 87.1% was comparable to the finding of 85.0% by Rozadi and Fatin (2021). The reported 12 months MSDs prevalence for any body parts was very high, which ranged from 78.0%-93.0% (Bhuanantanondh et al., 2021; Mongkonkansai et al., 2020; Ng et al., 2013b).

Postural Risk Assessment

There were three types of postural risk assessment tools employed by 10 studies included in this systematic review, which were Rapid Upper Limb Assessment (RULA) (5 studies), Rapid Entire Body Assessment (REBA) (4 studies) and Ovako Working Posture Analysis System (OWAS) (1 study) as listed in *Table 3*.

RULA. Two studies (Deros et al., 2014; Mohamaddan et al., 2021b) used CATIA P3 and CATIA V5R20 software respectively for the RULA analysis. For loading spike, a RULA score of 7 was obtained in the study by Mohamaddan et al. (2021b). Both Deros et al. (2014) and Mohamaddan et al. (2021a) obtained RULA scores of 7 for harvesting activities using a pole. Harvesting by using a chisel, on the other hand, also resulted in a RULA score of 7 (Mohamaddan et al., 2021b) and was similarly obtained for 51.6% of the respondents in a study by Yusoff et al. (2014). The other 45.1% obtained scores of 5 or 6 and 3.3% obtained scores of 3 or 4. Also, 5 out of 6 (83.0%) subjects obtained a RULA score of 7 when using a pole or a chisel (Mokhtar et al., 2013). As most of the findings showed a maximum final RULA score of 7, several investigations and changes were required immediately for all the tasks involving poles, chisels and loading spikes (Deros et al., 2014; Mohamaddan et al., 2021b; Yusoff et al., 2014). Finally, an intervention tool simulated design, which was a design of a chisel with added front and back handles for hand placement, managed to reduce the final RULA score to 3 (Yusoff et al., 2014).

In a study by Tumit et al. (2021), only Section A of RULA (arm and wrist) was used to analyse the risks associated with age and initial shoulder placement. Findings showed that during the tool placement phase in targeting a specific FFB, a higher risk of MSDs at the support shoulder was experienced by 40-49 years old harvesters, compared to those of 20-29 years old.

REBA. An automated REBA tool from Xsens was used by Abdullah et al. (2023), while the Ergo Fellow 2.0 software was used by Deros et al. (2016) in evaluating postures using the REBA risk assessment tool.

The average peak REBA scores obtained for the fronds pruning tasks using sickle and chisel were 10.30 ± 1.16 and 11.00 ± 1.05 respectively (Abdullah et al., 2023), whereas less score was obtained by

TABLE 3. RISK ASSESSMENT TOOL, METHOD AND EQUIPMENT/SOFTWARE USED

Article No.	Author (yr)	Risk assessment tool	Method	Equipment/software
7	Tumit et al. (2021)	RULA (Section A)	Manual	Quintic Biomechanics system
18	Mohamaddan et al. (2021b)	RULA	Simulation	CATIA V5R20
22	Yusoff et al. (2014)	RULA	Simulation	CATIA
24	Mokhtar et al. (2013)	RULA	Manual	Video recording
25	Deros et al. (2014)	RULA	Simulation	CATIA P3
2	Abdullah et al. (2023)	REBA	Simulation	Xsens automated REBA tool
12	Nawi et al. (2013)	REBA	Manual	Video recording
20	Deros et al. (2016)	REBA	Simulation	Ergo Fellow 2.0 software
23	Mongkonkansai et al. (2020)	REBA	Not stated/manual	Not stated/no
10	Parra-Ruiz et al. (2018)	OWAS	Simulation	Jack Siemens

Deros et al. (2016) when harvesting FFB (5) and highest score was obtained by Nawi et al. (2013) when harvesting FFB using sickle and chisel (both 13, respectively). The FFB loading task, on the other hand, showed a very high score of 12 (Deros et al., 2016) and a high score of 10 (Nawi et al., 2013) and was also labelled as high risk (8-10 score) by Mongkonkansai et al. (2020). Nevertheless, investigation and implementation of change should be done quickly for frond pruning, FFB harvesting and FFB loading tasks.

OWAS. Only one study implemented OWAS, which was a study by Parra-Ruiz et al. (2018). The maximum simulated OWAS score (4) was obtained when a traditional sickle was used, whereas, with the new simulated intervention cutting tool, a minimum OWAS score (1) could be obtained. Hence, immediate corrective actions were required for the traditional sickle.

Muscle Force and Joint Moment

AnyBody modelling software was used by four studies (Mohamaddan et al., 2021a, 2021b; Rahman et al., 2016, 2017) to obtain muscle force, while OpenSim was used by one study (Chan et al., 2022).

The highest simulated mean muscle force when the loading spike was used, in the upper part of the human body, was at the left triceps (16.36 N), left biceps (10.55 N), and right biceps (Mohamaddan et al., 2021b). For the chisel, the highest simulated mean muscle forces were at the left triceps (14.24 N), right triceps (14.23 N) and both right and left biceps (12.00 N). For the sickle, the highest simulated mean muscle forces were at the left triceps (15.06 N), both right and left biceps (13.00 N), and right triceps (9.25 N). Compared to the sickle from the simulated result by Rahman et al. (2016), the maximum reaction force of the left triceps lateral head, (15.12 N) and right triceps lateral head (9.93 N) were both close in magnitude. The highest reaction force was at flexor carpi ulnaris (15.61 N) (Rahman et al., 2016). For the lower part of the human body, the highest mean muscle forces were at the left gastrocnemius medialis (96.83 N) when using a loading spike, right gastrocnemius medialis (82.19 N) when using a chisel, and at the left gastrocnemius medialis (79.06 N) when using a pole (Mohamaddan et al., 2021a).

To move the pole vertically, the chisel horizontally and the loading spike vertically, the required biceps muscle forces were 350.000, 0.291, and 4,020.000 N respectively (Rahman et al., 2017). Finally, a simulation by Chan et al. (2022) showed the joint moments that would potentially lead to MSDs were back flexion and back rotation, with the average peak joint moments of 13.69 and 5.23 Nm/kg.

Muscle Activation

All muscles (biceps brachii, middle deltoid, upper and middle trapezius) were reported to be highly activated [>50% maximal voluntary contraction (MVC)] in tasks related to oil palm fronds pruning using sickle and chisel except for erector spinae in certain tasks (Abdullah et al., 2023). This was similar to a study by Chan et al. (2022) showing an average normalised peak muscle activation of more than 50% for every muscle (longissimus, multifidus, biceps, triceps, rectus abdominis, iliocostalis, external oblique, internal oblique and latissimus dorsi) for optimal forces of reserve actuator of 30 and 50 N. Also, similar findings by Teo et al. (2021), peak muscle activities during FFB harvesting and LF collection, for all muscles (upper trapezius, middle trapezius, lower trapezius, longissimus, multifidus, biceps and triceps) were all higher than 50%.

Muscle synergies in oil palm harvesting activity were studied by Teo et al. (2023), showing three muscle synergies, the first one being synergy contributed by upper trapezius, the second synergy contributed by longissimus and multifidus (both are lower back muscles) and the third and last synergy was contributed by biceps.

Next, to test for the efficacy of an intervention tool prototype, an upper limb exoskeleton tailored for oil palm FFB harvesting activity in a preliminary study by Harith et al. (2021), a comparison of muscle activity was done in a simulated harvesting environment to mimic the real-life FFB harvesting experience. By wearing the exoskeleton, muscle activity for all simulated tasks of pole raising, tugging, and carrying decreased. A significant reduction was observed for mean %MVC in left and right deltoids and left biceps (43.2%, 31.3% and 51.8% respectively) during pole tugging. Besides, a significant reduction of mean %MVC was also found in the left and right biceps and right deltoids (25.8%, 35.6% and 47.0% respectively).

Besides, a simulated intervention, which was a passive exotendon assistive device to support rectus abdominis, longissimus and iliocostalis was studied in a simulation by Chan et al. (2023), showing reduction of the most value of average peak muscle activation, average peak muscle force and average normalised peak joint moment. However, the relationship between the longissimus and rectus abdominis should be addressed cautiously, as some workload from the longissimus would be transferred to the rectus abdominis (Chan et al. 2023).

Spinal Loadings

The limits proposed by the National Institute of Occupational Safety and Health (NIOSH) for compressive and shear forces at L5-S1 disc were 3,400 and 1,000 N respectively. The compressive and shear forces to L5-S1 disc during harvesting activities were estimated by Abdullah et al. (2023) and Parra et al. (2018) using 3D Static Strength Prediction Programme (3DSSPP) and JACK Siemens software respectively. Estimated 2,981.40 ± 761.20 N of compressive force and 505.30 ± 90.22 N of shear force were reported for pruning activity using a chisel while 2,493.20 ± 1,349.48 N of compressive force and 1,446.10 ± 411.00 N of shear force were reported for pruning activity using sickle (Abdullah et al., 2023). The simulated result by Parra et al. (2018) for compressive force was a maximum of 8,385 N when using sickle, which far exceeded the 3,400 N safety limit. The proposed simulated intervention Cutting System however managed to reduce the compressive force to 440 N, which was far below the safety limit.

Noise and Vibration

Noise and vibration of mechanised harvesting tools should be quantified and made sure to fall below the safe limit to prevent oil palm workers from developing WMSDs.

Studies on the design of mechanised intervention tools such as experiments done on the Cantas Evo (Jelani et al., 2018), Cantas Elektro (Ahmad et al., 2023) and magnetic oil palm cutter prototype (Ahmad et al., 2020) incorporated important measurements such as hand-arm vibration (HAV). Cantas Evo was a superior version of Cantas (the earlier version of the mechanised cutting tool) with a new design of cutting head, pole, pole gripper and shaft guider. Cantas Elektro, on the other hand, is a battery-powered version of Cantas. The magnetic oil palm cutter was a prototype of a cutting tool using a magnetic actuator and incorporating a counter shear attachment to the design. All three interventions had a vibration level below the threshold level of 2.50 m/s^2. The vibration at the pole and throttle for Cantas Evo was 0.60 and 0.40 m/s^2 (Jelani et al., 2018), Cantas Elektro was 1.30 and 0.80 m/s^2 (Ahmad et al., 2023), while the magnetic oil palm cutter was at 1.20 m/s^2 (Ahmad et al., 2020). Also, the noise level of Cantas Elektro was measured to be 60 dB, lower than the maximum noise limit of 85 dB recommended by NIOSH (Ahmad et al., 2023).

Cutting Force and Human Energy

In a lab experiment done by Ahmad et al. (2020), the maximum cutting force required by a magnetic actuator cutting tool to cut frond samples was 300.2 N. On the other hand, the maximum cutting force of 1601.23 ± 424.26 and 420.80 ± 96.00 N were obtained by using a sickle and chisel respectively, to cut oil palm fronds in the field (Abdullah et al., 2023).

The calculated human energy to operate a mechanised intervention tool in a study by Sabri et al. (2020) was 250.2 N.m, which was categorised as a very light job. Besides, the proper distance between the operator and the oil palm tree was suggested, whereby for a 5 m tall tree, a 4 m distance between the operator and the tree was considered ideal to moderate the force, tension, and deflection exerted on the tools.

Intervention Tools

In this systematic review, there were nine studies related to interventions in oil palm activities, with a total of eight different interventions (two articles referred to the same intervention (Parra et al., 2018; Parra-Ruiz et al., 2018). One study was on the simulated design of a hand handle for the chisel (Yusoff et al., 2014), one preliminary study on an exoskeleton prototype (Harith et al., 2021), one study on a simulated new Cutting System (Parra et al., 2018; Parra-Ruiz et al. 2018), one study on simulated passive exotendon assistive device (Chan et al., 2023) and four studies on mechanised tools (Ahmad et al., 2020, 2023; Jelani et al., 2018; Sabri et al., 2020).

Extensive Review

This study aimed to conduct a thorough review of research on the prevalence of WMSDs among workers in oil palm plantations and to assess interventions designed to alleviate these issues through biomechanical evaluation or the design of intervention tools. By synthesising current study efforts, tools, and interventions, this study aimed to provide valuable insights into addressing WMSDs in the occupational setting.

The findings of the six studies highlighted the high prevalence of WMSDs among oil palm workers, emphasising the substantial risk posed by these tasks (Bhuanantanondh et al., 2021; Deros et al., 2016; Mongkonkansai et al., 2020; Nawi et al., 2016; Ng et al., 2013b; Rozadi & Fatin, 2021). The lower back, shoulder and neck were identified as the most commonly affected body parts. However, the specific body regions experiencing pain and WMSDs risk varied among workers, depending on their tasks, such as FFB harvesting, collecting, loading, LF collecting, or other plantation activities. For example, FFB and LF collectors faced a 3.98 times higher risk compared to FFB cutters in developing lower back MSDs (Bhuanantanondh et al., 2021). This was due to the need for FFB collectors to lift heavy FFBs, weighing up to 50 kg, in a forward bending and twisted posture, while

LF collectors had to adopt a stooping posture with arms to gather the scattered LF (Ng et al., 2013a).

Regarding shoulder MSDs, FFB cutters, and collectors faced a 2.51 times higher risk compared to LF collectors (Bhuanantanondh et al., 2021). This is because FFB cutters are required to lift their arm above the shoulder level to harvest from tall trees using a sickle, and employing a forceful pulling motion to cut the FFB. In contrast, the FFB collectors lift the FFB using a loading spike and then transfer the load onto their shoulders before transporting it to a wheelbarrow. Furthermore, the risk of developing neck MSDs was 4.82 times higher for FFB cutters compared to LF collectors (Bhuanantanondh et al., 2021). This discrepancy arises from the fact that FFB cutters must frequently tilt their heads upwards during the search for ripe FFB and throughout the cutting activity (Ng et al., 2013b).

A cross-sectional study by Ng et al. (2015) involving 446 male respondents showed that the FFB cutters and collectors had to work daily for about 7 hr and 50 min including resting time, with 75% of them normally working overtime. Hence, it was not a surprise that during the 12 months time the prevalence of WMSDs was high for oil palm harvesters (86%) (Ng et al., 2015). The harvesters in the study by Mokhtar et al. (2013) on the other hand, only worked for 6 hr, with a break-time of 1 hr.

By identifying the underlying reasons for absence from work, such as physical and psychological job demands and financial conditions (for instance sick pay availableness), effective policies can further be introduced (Coggon et al., 2013). The prevalence rate ratio (PRR) for the risk factors associated with extended sickness leave by office workers, nurses and other workers was 1.43 [95% confidence interval (CI) 1.24 to 1.65] for pressure at work (Coggon et al., 2013).

In the broader sense of the agriculture sector, WMDSs were experienced by workers in this sector due to the similar working conditions such as working manually, repetitive movements, the need for a certain level of force to execute the task, design of the agriculture tools and vibration produced from the tools (Kaewdok et al., 2021). In a study by Nankongnab et al. (2019) involving vegetable, rice, sugarcane and fruit farmers, the 3-month time MSDs showed more pain experienced by organic farmers than conventional farmers. The reason was speculated due to the organic farmers had to spend more time taking care of the plants, such as manual weeding (Nankongnab et al., 2019). Besides, rice farmers also experienced MSDs to the shoulder (76.1%) and lower back (74.9%) (Widyanti, 2018). The common practices similar to oil palm activities were the use of manual tools in manual plowing tasks (hoe for plowing and sickle for FFB harvesting), and flexed trunk posture during grass cutting, rice planting and harvesting for rice farming; and LF collection for oil palm harvesting. Various assessment tools were also implemented in this study such as the use of ergonomic checkpoints, Nordic body map questionnaire, REBA, RULA and 3DSSPP (Widyanti, 2018). On the other hand, in a study assessing WMSDs among mango-harvesting farmers in Thailand, besides similar usage of assessment tools such as REBA and RULA, tools such as Rating of Perceived Exertion (RPE) with Borg CR-10 and Fatigue Effective Index (FEI) with Power Superposition Theorem were also used. Shoulder, upper arm and lower back were the three body regions most reported for WMSDs, with percentages of 100.00%, 100.00% and 71.43% respectively (total of 14 mango-harvesting farmers). Again, manual tools were used to harvest the mango, similar condition to FFB harvesting. Next, a study on sugarcane farmers in Thailand showed a 74.29% MSDs prevalence, with the highest prevalence being that of the shoulder (53.50%) and lower back MSDs (53.12%) (Prommawai et al., 2019). Finally, a study by Saksorngmuang et al. (2020) on rubber farmers in Thailand showed a 12-month MSD prevalence of 87.70%, also with the highest prevalence at the lower back (36.80%) and shoulder (28.90%). The rubber farmers also had to use manual tools, specifically a tapping knife, to harvest latex from the rubber tree.

RULA was used for the evaluation of risk to upper body parts (McAtamney & Corlett, 1993), REBA for whole body evaluation (Hignett & McAtamney, 2000), while OWAS (Karhu et al., 1977) focused on back and upper limbs and lower limbs posture in terms of posture loadings and external load (Kee, 2022). Also, OWAS does not categorise the body into right and left parts in the assessment, as opposed to REBA and RULA which assess one side at one particular moment (Kee, 2022). Nelfiyanti et al. (2022) used all three tools namely RULA, REBA and OWAS in assessing risk to chassis assembly workers and obtained similar risk level results between them. In a comparison study by Kee (2021), OWAS produced significantly lower results than RULA statistically (p<0.01), from the Wilcoxon signed-rank test. Similarly, OWAS underestimated the result compared to REBA (Kee, 2021). Finally, Kee (2021, 2022) concluded that among the three tools, RULA might be the best to examine postural loading and MSDs due to work. In terms of oil palm plantation work studies, most researchers used RULA and REBA. Thus, both results could be used and compared for each specific task, as it was expected for RULA and REBA to have similar results, due to the rate of agreement between both (Kee, 2022).

High muscle activations have been observed across various muscle groups during frond pruning (Abdullah et al., 2023), FFB harvesting (Chan et al., 2022) and LF collection (Teo et al., 2021), indicating increased energy requirements to meet the demanding physical demands tasks, ultimately elevating the risk of WMSDs (Kodom-Wiredu, 2019). Simulated human musculoskeletal model analysis (HMMA) assists in identifying muscles exerting higher forces during oil palm activities, enabling targeted interventions to alleviate the muscle load. Prolonged and repetitive tasks involving more than 20 motion patterns per minute with tools like poles, chisels and loading spikes can induce fatigue, underscoring the importance of adequate rest intervals between tasks for energy recovery (Mohamaddan et al., 2021b).

Both experienced and inexperienced harvesters face risks of WMSDs due to their harvesting techniques. Inexperienced harvesters often lack the necessary technique and strength required for oil palm activities, while experienced harvesters may not consistently apply the correct method of handling the cutting tools and executing harvesting motions (Tumit et al., 2021). A study by Deros et al. (2016), highlighted that despite 81.0% of respondents being aware of the proper techniques for handling and lifting, only 17.1% practised them. This discrepancy was attributed to the perceived inefficiency and discomfort associated with adhering to correct techniques, leading to prolonged task completion times. In terms of age, no correlation was found between the age of palm farmers with MSDs prevalence in Pt. X oil palm plantation in South Kalimantan (Oktaviannoor et al., 2015). However, generally, MSDs prevalence increases among older participants (Palmer & Goodson, 2015).

The analysis of spinal loadings revealed that while the mean compressive and shear forces for the chisel and the compressive force for the sickle remained within safety limits, the peak compressive force for both tools exceeded the safety limit (Abdullah et al., 2023). Moreover, the mean shear force for the sickle surpassed the safety limit. These findings raise concerns regarding the potential for lower back pain, particularly among harvesters using the sickle, given the elevated mean shear force at the L5-S1 disc, exacerbated by the prevalent trunk twisting posture adopted during harvesting activities.

The use of traditional tools such as sickles, chisels and loading spikes poses a significant risk of WMSDs, necessitating the need for interventions. For instance, the redesigned chisel by Yusoff et al. (2014) reduced RULA scores by minimising bending posture, while the Cutting System by Parra-Ruiz et al. (2018) alleviated spinal loadings and lowering OWAS scores.

Among the four studies on mechanised tools, three of them (Ahmad et al., 2020, 2023; Jelani et al., 2018) assessed the vibration level of the cutting tools namely Cantas Evo, Cantas Elektro and a prototype of magnetic oil palm cutter, with all of them were under the safety limit of 2.5 m/s^2, meaning they were safe to be used in a working period of 8 hr. As the operators would use the mechanised tools throughout the day, the vibration level should be kept to a minimum, for a more comfortable usage and to preserve their endurance (Ahmad et al., 2023). Besides, as the cutting tool would be the load that the FFB harvesters had to carry throughout the day, the optimum weight should also be considered. For comparison, a 6.00 m traditional pole only weighed 4.0 kg, whereas a 6.21 m Cantas Evo weighed 9.0 kg, a 2.50 m Cantas Elektro weighed 7.0 kg and a 5.00 m magnetic oil palm cutter weighed 6.3 kg (Ahmad et al., 2020, 2023; Jelani et al., 2018). From a time-motion study by Saibani et al. (2015), the time taken to adjust the cutting pole, cut the frond and finally cut the FFB was 23.36, 51.30 and 60.26 s. Next, the time taken to load the FFB into a wheelbarrow was 34.25 s, while LF collection took 77.49 s (Saibani et al., 2015). Hence, any interventions aimed at increasing productivity should always take a shorter time. Next, to attract stakeholders, employers and employees to adopt the new mechanised tools compared to traditional tools, the cost-effectiveness analysis should be included in the study, for them to make calculated decisions, as done by Ahmad et al. (2023) and Jelani et al. (2018).

In terms of mechanisation, the early 1960s marked its earliest adoption into oil palm plantations in Malaysia (Azwan et al., 2016), with Malaysia leading the research and development (R&D) in the oil palm industry (as a whole), for over 100 years (Parveez et al., 2024). However, up to now, FFB harvesting, FFB loading and LF collection were still done manually using traditional tools. Only certain tasks such as transportation of FFB from plantations to oil palm mills for processing, were done using a large capacity tractor, due to the large amount of FFB needed to be moved out, whereby fertilising and herbicide/insecticide spraying were done with a smaller tractor (Azwan et al., 2016). The rejection of interventions by the workers was due to extra time needed to familiarise themselves with the new tools, fear due to injury experience, insufficient information and training on the tools and health risks imposed by the machines, while some of the concerns by the plantation managers were on the decreased productivity and significant upkeep expenses (Nawi et al., 2015).

The WMSDs prevalence in oil palm plantation tasks such as FFB harvesting, FFB loading and LF collection were very high, with lower back, shoulder and neck being the three most affected body parts. This condition would persist, as long as the use of manual tools such as sickle, chisel and sharp metal skews are still prevalent. In terms of postural risk assessment, the use of

IMU would provide the best representation and a more accurate workers' posture, compared to manual determination from video recording by ergonomists. The postural angle obtained from IMU can then be used to evaluate risk, whether using REBA for whole body assessment or RULA, if the area of interest is only the upper part of the human body. EMG would provide data on muscle activity, hence the effort needed for a worker to complete a certain task can be determined. Hence, the types of interventions should be focused, when the intervention is intended to change the posture adopted by the workers, IMU should be used. If the new intervention was targeting to reduce muscle effort in accomplishing certain movements, EMG should be used. AnyBody and OpenSim software are two useful tools to estimate specific muscle forces, where the data can be used to design the exoskeleton to assist specific muscle locations. The intervention had to be devised specifically with regards to the nature of an oil palm tree and the location of FFB such as the tree height and canopy arrangement of fronds, that must be cleared to get access to the FFB which is hidden by the oil palm fronds for harvesting purpose (Ng et al., 2013a). Scattered loose fruits, that originated from the outer parts of FFBs had to be collected too, due to their higher level of oil content compared to those in the inner part (Khalid et al., 2021). Besides, the concern over anthropometric data, where the design of the tools was only ergonomically suited for users from the origin country and also not suited for women, was raised by Kaewdok et al. (2021). Hence, an intervention design should follow the anthropometric data of targeted workers, using data for male populations in works mostly done by males, and both male and female data for works done by both genders. Height and grip measurements should also be considered. Finally, a mechanised cutting tool should be robust enough, maintainable and follow NIOSH specifications, so as not to induce other harm to the users, such as risk of excessive noise and vibration. Cost analysis and return on investment should be calculated, for the new tool or intervention to become more attractive and plausible for adoption.

Limitations of this systematic review were the inclusion and exclusion criteria mainly focused on only systematic review and did not take into consideration the possibility of conducting meta-analysis. Hence, new inclusion and exclusion criteria had to be determined for meta-analysis. Besides, this systematic review only covered articles in a period of 10 years, from 2013-2023. Hence, earlier WMSDs prevalence and interventions made were not discussed. However, this systematic review managed to serve its purpose in highlighting the WMSDs prevalence in oil palm workers, methods and tools used in biomechanical evaluations and interventions proposed to reduce the risk of WMSDs.

CONCLUSION

A high prevalence of WMSDs was observed in oil palm plantation works. However, the WMSDs prevalence could only be quantified for Malaysia and Thailand, as prevalence studies were only conducted in these countries. Modern tools such as SolidWorks, CATIA, AnyBody and OpenSim software were employed in designing, measuring postural risk assessment, and building and interacting with human musculoskeletal models, respectively. IMU and EMG were extensively used in biomechanical evaluation studies to examine postural risk and quantify muscle activations. Some of the less common studies focused on muscle synergies and exotendon. Many interventions were designed, with one of the first of its kind in the scene of oil palm works being the exoskeleton prototype. The research gap, which would be very beneficial once filled in is the lack of comparison between an intervention tool and a traditional manual tool in every aspect such as in terms of postural risk assessments, muscle activations, muscle forces needed, productivity, training needed and cost. Hence, the biggest concern would be to design a new intervention that would be attractive enough to be adopted, with its main purpose still intact, to reduce WMDSs risk in FFB harvesting activities.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Sains Malaysia (USM) for the success of this systematic review. The author was funded by Graduate Fellowship USM (GFUSM).

REFERENCES

Abdullah, N. A., Shaberi, M. N. M., Nordin, M. N. A., Ripin, Z. M., Razali, M. F., Ali, W. M. A. W. M., Awang, B., & Ridzwan, M. I. Z. (2023). Field measurement of hand forces of palm oil harvesters and evaluating the risk of work-related musculoskeletal disorders (WMSDs) through biomechanical analysis. *International Journal of Industrial Ergonomics*, *96*, 103468. https://doi.org/10.1016/j.ergon.2023.103468

Ahmad, M. R., Jamaludin, N., Jelani, A. R., Bakri, A., & Shuib, A. (2020). The effect of design parameters on the force and energy requirement for cutting oil palm fronds using magnetic force.

Jurnal Teknologi (Science and Engineering), *82*(4), 141–150. https://doi.org/10.11113/jt.v82.14236

Ahmad, M. R., Radzi, M. K. F. M., Ramli, A. S., Bakri, M. A. M., Azaman, M. I. H., Ibrahim, A., Faudzi, A. A. M., Muhamed, A. A., & Zakariah, H. (2023). Evaluation and comparison of the ergonomics, performance and economics of battery-powered and engine-powered palm oil harvesting tools: Cantas elektro. *Jurnal Kejuruteraan*, *35*(4), 811–821. https://doi.org/10.17576/jkukm-2023-35(4)-03

Akbar, K. A., Try, P., Viwattanakulvanid, P., & Kallawicha, K. (2023). Work-related musculoskeletal disorders among farmers in the southeast asia region: A systematic review. *Safety and Health at Work*, *14*(3), 243–249. https://doi.org/10.1016/j.shaw.2023.05.001

Azwan, M. B., Norasikin, A. L., Abd Rahim, S., Norman, K., & Salmah, J. (2016). Analysis of energy utilisation in Malaysian oil palm mechanisation operation. *Journal of Oil Palm Research*, *28*(4), 485–495. https://doi.org/10.21894/jopr.2016.2804.10

Bhuanantanondh, P., Buchholz, B., Arphorn, S., Kongtip, P., & Woskie, S. (2021). The prevalence of and risk factors associated with musculoskeletal disorders in Thai oil palm harvesting workers: A cross-sectional study. *International Journal of Environmental Research and Public Health*, *18*(10), 5474. https://doi.org/10.3390/ijerph18105474

Boriboonsuksri, P., Taptagaporn, S., & Kaewdok, T. (2022). Ergonomic task analysis for prioritization of work-related musculoskeletal disorders among mango-harvesting farmers. *Safety*, *8*(1), 6. https://doi.org/10.3390/safety8010006

Chan, Y. S., Teo, Y. X., Gouwanda, D., Nurzaman, S. G., & Gopalai, A. A. (2023). Simulation of passive exotendon assistive device for agricultural harvesting task. *Physical and Engineering Sciences in Medicine*, *46*(4), 1375–1386. https://doi.org/10.1007/s13246-023-01305-9

Chan, Y. S., Teo, Y. X., Gouwanda, D., Nurzaman, S. G., Gopalai, A. A., & Thannirmalai, S. (2022). Musculoskeletal modelling and simulation of oil palm fresh fruit bunch harvesting. *Scientific Reports*, *12*(1), 8010. https://doi.org/10.1038/s41598-022-12088-6

Coggon, D., Ntani, G., Vargas-Prada, S., Martinez, J. M., Serra, C., Benavides, F. G., & Palmer, K. T. (2013). International variation in absence from work attributed to musculoskeletal illness: Findings from the CUPID study. *Occupational and Environmental Medicine*, *70*(8), 575–584. https://doi.org/10.1136/oemed-2012-101316

Critical Appraisal Skills Programme (CASP). (2019). *Critical Appraisal Skills Programme appraisal tools*. Retrieved February 29, 2024 from https://casp-uk.net/casp-tools-checklists/

Deros, B. M., Khamis, N. K., Mohamad, D., Kabilmiharbi, N., & Daruis, D. D. I. (2014). Investigation of oil palm harvesters' postures using RULA analysis. In *2014 IEEE International Conference on Biomedical Engineering and Sciences (IECBES)* (pp. 287–290). IEEE.

Deros, B. M., Ali, M. H., Mohamad, D., & Daruis, D. D. I. (2016). Ergonomic risk assessment on oil palm industry workers. *Iranian Journal of Public Health*, *45*(1), 44–51.

Digo, E., Pastorelli, S., & Gastaldi, L. (2022). A narrative review on wearable inertial sensors for human motion tracking in industrial scenarios. *Robotics*, *11*(6), 138. https://doi.org/10.3390/robotics11060138

Harith, H. H., Mohd, M. F., & Sowat, S. N. (2021). A preliminary investigation on upper limb exoskeleton assistance for simulated agricultural tasks. *Applied Ergonomics*, *95*, 103455. https://doi.org/10.1016/j.apergo.2021.103455

Hignett, S., & McAtamney, L. (2000). Rapid entire body assessment (REBA). *Applied Ergonomics*, *31*(2), 201–205. https://doi.org/10.1016/S0003-6870(99)00039-3

Jelani, A. R., Ahmad, M. R., Azaman, M. I. H., Gono, Y., Mohamed, Z., Sukawai, S., Aduka, A., Aziz, A., Bakri, A., Mohamed, A., Selamat, M. B., Ismail, A., Deraman, M. S., Shuib, A. R., Kamarudin, N., & Kushairi, A. (2018). Development and evaluation of a new generation oil palm motorised cutter (Cantas Evo). *Journal of Oil Palm Research*, *30*(2), 276–288. https://doi.org/10.21894/jopr.2018.0015

Kaewdok, T., Sirisawasd, S., & Taptagaporn, S. (2021). Agricultural risk factors related musculoskeletal disorders among older farmers in Pathum Thani Province, Thailand. *Journal of Agromedicine*, *26*(2), 185–192. https://doi.org/10.1080/1059924X.2020.1795029

Karhu, O., Kansi, P., & Kuorinka, I. (1977). Correcting working postures in industry: A practical method for analysis. *Applied Ergonomics*, *8*(4), 199–201. https://doi.org/10.1016/0003-6870(77)90164-8

Kee, D. (2021). Comparison of OWAS, RULA and REBA for assessing potential work-related musculoskeletal disorders. *International Journal of Industrial Ergonomics*, *83*, 103140. https://doi.org/10.1016/j.ergon.2021.103140

Kee, D. (2022). Systematic comparison of OWAS, RULA, and REBA based on a literature review. *International Journal of Environmental Research and Public Health*, *19*(1), 595. https://doi.org/10.3390/ijerph19010595

Khalid, M. R., Shuib, A., & Kamarudin, N. (2021). Mechanising oil palm loose fruits collection - A review. *Journal of Oil Palm Research*, *33*(1), 1–20. https://doi.org/10.21894/jopr.2020.0069

Kodom-Wiredu, J. K. (2019). Work demand, stress and work-related musculoskeletal disorders among emergency workers. *International Journal of Workplace Health Management*, *12*(2), 85–98. https://doi.org/10.1108/IJWHM-08-2018-0111

Malaysian Palm Oil Board (MPOB). (2023). *Overview of the Malaysian oil palm industry 2022*.

Malaysian Palm Oil Board (MPOB). (2024). *Overview of the Malaysian oil palm industry in 2023*.

McAtamney, L., & Corlett, E. N. (1993). RULA: A survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics*, *24*(2), 91–99. https://doi.org/10.1016/0003-6870(93)90080-S

Mohamaddan, S., Munot, M. A., Tanjong, S. J., Dawal, S. Z. M., Case, K., & Hanafusa, A. (2021a). Investigation of the usage of oil palm harvesting tools on work related musculoskeletal disorders of lower limb. In *2021 IEEE 3rd Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS)* (pp. 41–44). IEEE.

Mohamaddan, S., Rahman, M. A., Munot, M. A., Tanjong, S. J., Deros, B. M., Dawal, S. Z. M., & Case, K. (2021b). Investigation of oil palm harvesting tools design and technique on work-related musculoskeletal disorders of the upper body. *International Journal of Industrial Ergonomics*, *86*, 103226. https://doi.org/10.1016/j.ergon.2021.103226

Mohiddin, D. N. A., & Pebrian, D. E. (2021). Exploring mechanization degree and capacity in Malaysia's oil palm plantations. *Agricultural Engineering International: CIGR Journal*, *23*(2), 220–228.

Mokhtar, M. M., Deros, B. M., & Sukadarin, E. H. (2013). Evaluation of musculoskeletal disorders prevalence during oil palm fresh fruit bunches harvesting using RULA. In *2nd International Conference on Ergonomics (ICE 2013)* (pp. 110–115).

Mongkonkansai, J., Thanapop, C., Madardam, U., Cheka, A., Epong, A., & Arwae, A. (2020). Factors related to musculoskeletal disorders in quality control palm workers at palm purchasing establishments in Sichon District, Nakhon Si Thammarat, Thailand. *Annals of Agricultural and Environmental Medicine*, *27*(2), 207–210. https://doi.org/10.26444/aaem/122254

Murphy, D. J. (2014). The future of oil palm as a major global crop: Opportunities and challenges. *Journal of Oil Palm Research*, *26*(1), 1–24.

Myzabella, N., Fritschi, L., Merdith, N., El-Zaemey, S., Chih, H., & Reid, A. (2019). Occupational health and safety in the palm oil industry: A systematic review. *International Journal of Occupational and Environmental Medicine*, *10*(4), 159–173. https://doi.org/10.15171/ijoem.2019.1576

Nawi, N. S. M., Deros, B. M., & Nordin, N. (2013). Assessment of oil palm fresh fruit bunches harvesters working postures using REBA. In *2nd International Conference on Ergonomics (ICE 2013)* (pp. 122–127).

Nawi, N. S. M., Deros, B. M., Ab Rahman, M. N., Nordin, N., & Sukadarin, E. H. (2015). Mechanized tools and technovation machinery in palm oil plantation: Utilization or rejection? In *International Symposium on Advancement in Ergonomics & Safety 2015/ Lean & Six Sigma Symposium 2015* (pp. 1–6).

Nawi, N. S. M., Deros, B. M., Ab Rahman, M. N., Sukadarin, E. H., & Nordin, N. (2016). Malaysian oil palm workers are in pain: Hazards identification and ergonomics related problems. *Malaysian Journal of Public Health Medicine*, *16*(Suppl. 1), 50–57.

Nelfiyanti, Mohamed, N., & Rashid, M. F. F. A. (2022). Analysis of measurement and calculation of MSD complaint of chassis assembly workers using OWAS, RULA and REBA method. *International Journal of Automotive and Mechanical Engineering*, *19*(2), 9681–9692. https://doi.org/10.15282/ijame.19.2.2022.05.0747

Ng, Y. G., Bahri, M. T. S., Syah, M. Y. I., Mori, I., & Hashim, Z. (2013a). Ergonomics observation: Harvesting tasks at oil palm plantation. *Journal of Occupational Health*, *55*(5), 405–414. https://doi.org/10.1539/joh.13-0017-FS

Ng, Y. G., Tamrin, S. B. M., Yik, W. M., Yusoff, I. S. M., & Mori, I. (2013b). The prevalence of musculoskeletal disorder and association with productivity loss: A preliminary study among labour intensive manual harvesting activities in oil palm plantation. *Industrial Health*, *52*(1), 78–85. https://doi.org/10.2486/indhealth.2013-0017

Ng, Y. G., Tamrin, S. B. M., Yusoff, I. S. M., Hashim, Z., Deros, B. M. D., Abu Bakar, S., & How, V. (2015). Risk factors of musculoskeletal disorders among oil palm fruit harvesters during early harvesting stage. *Annals of Agricultural and Environmental Medicine*, *22*(2), 286–292. https://doi.org/10.5604/12321966.1152101

Oktaviannoor, H., Helmi, Z. N., & Setyaningrum, R. (2015). Correlation between age and period of working with the musculoskeletal disorders complaints on palm farmers in Pt. X. *Asian Journal of Epidemiology*, *8*(3), 78–83. https://doi.org/10.3923/aje.2015.78.83

Palmer, K. T., & Goodson, N. (2015). Ageing, musculoskeletal health and work. *Best Practice and Research: Clinical Rheumatology*, *29*(3), 3 91–404. https://doi.org/10.1016/j.berh.2015.03.004

Parra, L., Quintero, L., & Maradei, F. (2018). Decreasing the load on the lower back with an ergonomic cutting tool for harvesting oil palm bunches. *DYNA (Colombia)*, *85*(207), 214–220. https://doi.org/10.15446/dyna.v85n207.69836

Parra-Ruiz, L., Quintero-Medina, J., & Maradei, F. (2018). Design of a cutting tool for oil-palm bunches. *UIS Ingenierías*, *17*(1), 59–67. https://doi.org/10.18273/revuin.v17n1-2018006

Parveez, G. K. A., Abd Rasid, O., Ahmad, M. N., Taib, H. M., Bakri, M. A. M., Hafid, S. R. A., Ismail, T. N. M. T., Loh, S. K., Abdullah, M. O., Zakaria, K., & Idris, Z. (2023). Oil palm economic performance in Malaysia and R&D progress in 2022. *Journal of Oil Palm Research*, *35*(2), 193–216. https://doi.org/10.21894/jopr.2023.0028

Parveez, G. K. A., Leow, S., Kamil, N. N., Madihah, A. Z., Ithnin, M., Ng, M. H., Yusof, Y. A., & Idris, Z. (2024). Oil palm economic performance in Malaysia and R&D progress in 2023. *Journal of Oil Palm Research*, *36*(2), 171–186. https://doi.org/10.21894/jopr.2024.0037

Prommawai, N., Laohasiriwong, W., & Nilvarangkul, K. (2019). Musculoskeletal disorders and quality of life of sugarcane farmers in the northeast of Thailand: A cross-sectional analytical study. *Journal of Clinical and Diagnostic Research*, *13*(6), 11–15. https://doi.org/10.7860/JCDR/2019/41844.12924

Rahman, A., Mohamaddan, S., Majid, N. A. A., Munot, M. A., Yusuf, M., Ngie, D. C. S., & Deros, B. M. (2016). Investigation of human arm musculoskeletal model using aluminium pole in palm oil harvesting process. In *2016 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES)* (pp. 394–399). IEEE.

Rahman, A., Mohamaddan, S., Majid, N. A. A., Andrew-Munot, M., Razali, N. T., Deros, B. M., & Bakri, S. R. A. (2017). Simple arm muscle model for oil palm harvesting process. In *9th International Unimas STEM Engineering Conference - Innovative Solutions for Engineering and Technology Challenges (ENCON)* (p. 02015).

Rozadi, R., & Fatin, K. (2021). The analysis of ergonomic risk factors effecting health problem on workers from harvesting activity in oil palm plantation. In *IOP Conference Series: Earth and Environmental Science* (p. 012008).

Sabri, M., Nasution, A. F., & Hasan, S. (2020). Innovation of fresh fruit bunches (FFB) harvesting tools, using environmentally friendly electronic mechanical system. In *2nd International Conference on Industrial and Manufacturing Engineering (ICI&ME)* (p. 012001).

Saibani, N., Muhamed, A. A., Maliami, M. F., & Ahmad, R. (2015). Time and motion studies of manual harvesting methods for oil palm fruit bunches: A Malaysian case study. *Jurnal Teknologi*, *74*(3), 77–83.

Saksorngmuang, P., Kaewboonchoo, O., Ratchneewan, R. O. S. S., & Boonyamalik, P. (2020). Working hazards and health problems among rubber farmers in Thailand. *Walailak Journal of Science and Technology*, *17*(3), 222–236.

Shigetomi, Y., Ishimura, Y., & Yamamoto, Y. (2020). Trends in global dependency on the Indonesian palm oil and resultant environmental impacts. *Scientific Reports*, *10*(1), 20624. https://doi.org/10.1038/s41598-020-77458-4

Sibhatu, K. T. (2023). Oil palm boom: Its socioeconomic use and abuse. *Frontiers in Sustainable Food Systems*, *7*, 1083022. https://doi.org/10.3389/fsufs.2023.1083022

Teo, Y. X., Chan, Y. S., Gouwanda, D., Gopalai, A. A., Nurzaman, S. G., & Thannirmalai, S. (2021).

Quantification of muscles activations and joints range of motions during oil palm fresh fruit bunch harvesting and loose fruit collection. *Scientific Reports*, *11*(1), 15020. https://doi.org/10.1038/s41598-021-94268-4

Teo, Y. X., Chan, Y. S., Nurzaman, S. G., Gouwanda, D., & Gopalai, A. A. (2023). Investigation of muscle synergies and their consistency among fresh fruit bunches manual harvesters in a real-life oil palm industry. *International Journal of Industrial Ergonomics*, *97*, 103499. https://doi.org/10.1016/j.ergon.2023.103499

Tumit, N. P., Rambely, A. S., & Deros, B. M. (2021). The effects of age and initial shoulder posture on the upper limb range of harvesting movements among oil palm harvesters. *Applied Sciences*, *11*(21), 10280. https://doi.org/10.3390/app112110280

Widyanti, A. (2018). Ergonomic checkpoint in agriculture, postural analysis, and prevalence of work musculoskeletal symptoms among Indonesian farmers: Road to safety and health in agriculture. *Jurnal Teknik Industri*, *20*(1), 1–10. https://doi.org/10.9744/jti.20.1.1-10

Yusoff, I. S. M., Tamrin, S. B. M., Said, A. M., Ng, Y. G., & Ippei, M. (2014). Oil palm workers: Designing ergonomics harvesting tool using user centered design approach to reducing awkward body posture by CATIA simulation. *Iranian Journal of Public Health*, *43*(Suppl. 3), 72–80.