Malaysian Journal of Ergonomics (MJEr)
Volume 1 Issue 1 2024 [1-10]

Addressing Labour Ergonomics through Automation in Oil Palm Plantation Activities: A Necessity for Sustainable Agriculture

Azuwir Mohd Nor, Mohd Sazli Saad, Mohamad Ezral Baharudin, Mohd Zakimi Zakaria,

Dynamics Modeling and Control Systems Research Group
Faculty of Mechanical Engineering and Technology
Universiti Malaysia Perlis
Email: azuwir@unimap.edu.my

ABSTRACT

A key element of the potential of robotics is understanding how effective automation can improve labour-intensive jobs while also considering worker ergonomics. These sectors often depend on manual labour, which exposes employees to considerable ergonomic stress, especially musculoskeletal disorders (MSDs) that can result from repetitive and physically demanding activities like harvesting, pruning, and lifting heavy items. By coordinating automation tools such as harvesters, unloaders, and driverless carts with the various manual tasks that workers perform, we can significantly lower safety risks. The main objective of introducing automation is to reduce the physical strain on workers, which not only aims to alleviate MSD-related health problems but also helps to lessen worker fatigue. Effectively integrating artificial intelligence (AI) and big data analytics will improve workforce efficiency, making the Brightfield industry stronger. Transitioning from manual tasks to automated solutions is just the initial step toward enhancing production in this field. By tackling these ergonomic issues through automation, this paper highlights the dual advantages of promoting worker health and increasing productivity in the industry.

Keywords: Automation, Ergonomic, Oil palm plantation, worker health.

1. INTRODUCTION

Ergonomic challenges for oil palm plantation workers arise from the fact that the tasks of harvesting, manuring, and spraying are highly labour intensive and dangerous. Exposure to awkward postures, repetitive motions, and heavy lifting employs those in these tasks at risk for musculoskeletal disorders (MSDs). Most harvester work is arduous, as shown in Figure 1, because of manual handling with tools and Fresh Fruit Bunches (FFBs). Long-term trauma, usually comprising work in the lower back and upper body, result from repetitions and contractions such as cutting and lifting FFBs, whose common problems are backache and shoulder strain [1], [2].

Figure 1. Harvesting of FBB [2]

While some of these tasks have been automated, many still require significant manual labour on smallholder farms and plantations, where ergonomic hazards remain a constant concern. In addition, the demanding environmental conditions that are harsh in terms of heat and humidity serve to increase physical strain leading to accelerated fatigue and a higher injury rate. Low level of mechanization forced postures and exposure of work in uncomfortable environment make plantation workers highly susceptible to developing chronic MSDs [3], [4].

Therefore, solving these ergonomic problems by improving tool design and incorporating more mechanization is still an urgent area for reducing the burden on this industry. Using ergonomics theory such as human-cantered design, we can improve the posture of these workers that use these tools and pay attention to their welfare. Use of lightweight and adjustable tools for harvesting will enable more ergonomically sound jobs, allowing workers to avoid leaning over or reaching excessively.

There is a growing need for greater mechanization due to the resource constraints that small-holder farmers face. These farmers understand that mechanization can help reduce their dependence on manual labour, streamline their farming processes, and accelerate operations. While it may not be ideal for every farming situation, their main focus is on successfully harvesting their crops, no matter the challenges. By allowing workers to delegate certain tasks to machines, like sprayers or harvesters, they can minimize physical strain. This shift can lead to higher productivity in less time, ultimately benefiting the long-term well-being of the workforce and lowering the economic costs tied to labour.

2. ERGONOMIC CHALLENGES

The physically demanding oil palm plantation industry presents workers with various ergonomic challenges. Tasks such as farming, applying manure to trees, or using pest control machinery often involve repetitive movements and awkward body postures, which can lead to pain over time. This type of work can physically exhaust the core muscles. Many of these activities place significant strain on the upper body and lower back. Addressing these ergonomic issues is crucial not only for the health of the workers but also for enhancing productivity.

2.1 Musculoskeletal Disorders (MSDs) in Plantation Work

Musculoskeletal disorders (MSDs) generally are very common among oil palm workers, mostly due to repetitive and strenuous tasks. Studies have shown that the harvesting of fresh fruit bunches (FFBs) exposes the workers to shoulder, back, and wrist injuries [5]. The major reasons which contribute to MSDs include:

2.1.1 Repetitive Movements:

Repetitive motion activities significantly contribute to the onset of musculoskeletal disorders (MSD) in oil palm plantation work. The actions involved in tasks like harvesting fresh fruit bunches (FFBs) include repetitive cuts, utilizing long tools while maintaining awkward postures. Frequent twisting, bending, and reaching overhead impose substantial strain on joints and muscles, particularly in the lower back, shoulders, and arms. Workers engage in these same static motions repeatedly, resulting in overuse injuries in the shoulder, arm, and lower back areas. [6].

Workers who frequently lift heavy objects or carry substantial loads, such as moving fresh fruit bunches (FFBs), experience increased strain on their backs over time, which can lead to chronic back pain. Figure 2 shows wheelbarrow with FFB pushed by worker. If tasks are repetitive and workers are constantly compelled to carry out the same tasks continuously without any breaks or suffering without ergonomic tools, the risk of MSDs increases. Tools are often badly designed

and are not mechanized, which means that workers need to do the bulk of the work manually, and excessive strain is placed on the same muscle groups, leading to wear and tear [1], [7].

Figure 2. Worker pushing heavy load [4].

2.1.2 Awkward Postures:

The awkwardness of reaching up to cut FFBs or having to bend and collect FFBs for too long also requires that people adopt awkward postures that can result in long term harm and damage to the spine, and shoulders [5], [8]. Main factors that lead to awkward postures are outlined below:

2.1.2.1 Reaching and Overhead Work:

Workers cutting FFBs, as shown in Figure 3, may need to extend their arms upward for long periods, sometimes using tools like long poles. Such overextension strains the shoulder and neck muscles. Repeated overhead work puts a person at an increased risk of muscle fatigue and can lead to cumulative trauma disorders of the upper body, including shoulder impingement and neck pain. [9].

Figure 3. Worker cutting FFB [6]

2.1.2.2 Bending and Stooping:

Tending to fallen fruit requires a lot of bending and stooping, which can put significant strain on the lower back of the worker. The various bent positions adopted during harvesting can create excessive pressure on the lumbar area, increasing the risk of disc herniation or chronic lower back pain. Additionally, the twisting and bending involved in the harvesting process can further heighten these risks, making the work not only physically demanding but also potentially harmful

to the lower back. [9]. These repetitive awkward postures create conditions for further injury, and without proper ergonomic interventions or mechanization, these risks are prevalent in plantation work

2.2 Other Health Concerns

In addition to musculoskeletal disorders, workers are also worried about physical exhaustion from long hours of demanding manual labour, which negatively impacts both their performance and overall health. Another significant concern is heat stress, particularly in tropical environments where extended exposure to high temperatures can exacerbate existing health issues and result in heat exhaustion or even heat stroke. The combined effects of repetitive tasks, awkward postures, and heavy lifting during plantation work heighten the risk of chronic fatigue and long-term health problems, ultimately affecting worker efficiency and well-being.

2.2.1 Physical Exhaustion:

Working on a plantation is extremely exhausting, which can lead to significant fatigue and a higher likelihood of accidents and injuries due to a loss of alertness [10]. These tasks demand continuous effort from workers in hot and humid conditions, which can quickly lead to exhaustion. Prolonged exertion without sufficient recovery time results in both physical and mental fatigue, reducing alertness. A tired worker is more likely to make mistakes, respond more slowly, and have decreased coordination, all of which increases the risk of accidents and injuries. This heightened risk is particularly concerning environments where machinery and hazardous chemicals are present, as it could lead to very serious consequences for the worker [11].

2.2.2 Heat Stress:

Many labourers face tough weather conditions, especially those working in fields, construction sites, or plantations, where high temperatures and humidity are common. These environments can result in heat stress, a situation where the body struggles to cool itself effectively, leading to symptoms like excessive sweating, dizziness, and muscle cramps. Prolonged exposure without proper hydration increases the risk of dehydration, which can impair both physical and mental performance. If not addressed, these issues can escalate into serious heat-related illnesses such as heat exhaustion or heat stroke, posing significant health risks for workers [12].

2.2.3 Cumulative Physical Toll

All that manual labour, repetitive motion, and strenuous activity really takes a toll on the body, particularly on the back, joints, and muscles. Over time, these repetitive strains can result in work-related musculoskeletal disorders (WMSDs) like chronic back pain, tendonitis, and carpal tunnel syndrome, which gradually diminish a worker's physical abilities and lead to pain and disability. This lack of movement and work capacity not only holds us back but can also contribute to more serious, chronic health issues such as arthritis and cardiovascular disease. Ongoing stress can ultimately result in a lower quality of life, making everyday tasks and maintaining a job in the future feel like an even greater challenge [13].

3. Potential of Automation

The new age of automation technologies plays a crucial role in addressing ergonomic issues that are prevalent in many labour-intensive industries, such as oil palm plantations, where workers often must repeat the same tedious and strenuous tasks. Exoskeletons and wearable sensor systems are designed not only to enhance human performance but also to monitor posture and exertion in real time, helping to alleviate ergonomic stresses on the body. Automation and robotics not only reduce the need for manual labour but also take on many hazardous tasks, such

as lifting heavy objects and performing repetitive movements, which are major contributors to musculoskeletal disorders (MSDs) and physical fatigue. Additionally, these technologies can create a safer workplace by allowing humans to focus on more cognitive tasks while machines handle the more dangerous physical work. Here's how these innovations can enhance workers' health:

3.1 Exoskeletons:

Exoskeletons help relieve some of the physical toll taken on workers because they provide mechanical assistance while lifting heavy objects and during repetitive movements. This minimizes the ergonomic risk factors of MSDs, especially during prolonged static work or lifting [14]. In oil palm plantations, harvesting fresh fruit bunches (FFB) and other strenuous jobs involve carrying heavy load and working in awkward postures for prolonged periods, therefore it carries a high risk of musculoskeletal disorders (MSDs). This strain can be relieved by exoskeletons because they provide mechanical assistance to the body when lifting and repeating movements, particularly in the lower back, shoulders, and arms. This ergonomic technology doesn't just cut muscular exertion but also keeps the user in a more ergonomic posture while performing strenuous tasks, thereby lowering the incidence of workplace MSDs. The use of exoskeletons would be especially helpful in jobs requiring prolonged stances or lifting such as fruit bunch gathering and manuring [15], [16]

Workers often report severe body aches and muscle fatigue due to the awkward positions they must maintain and the long hours of manual labour. Some even claim this has led to permanent damage to their spines and shoulders. The situation is worsened by a lack of adequate safety investments. Figure 4 depicts an experiment aimed at developing a lightweight hybrid exoskeleton designed to reduce muscle strain during palm oil harvesting. This exoskeleton uses an iso-elasticity method and a DC linear motor to compensate for gravitational and muscular torque. Research shows that the hybrid exoskeleton reduced muscle strain by 23%, while the passive version achieved a 16% reduction. If companies adopted this technology for their workers, it could significantly alleviate pain and enhance overall safety. [17]

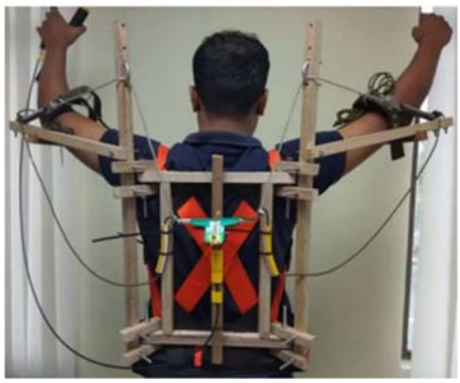

Figure 4. Study of passive exoskeleton for oil palm harvesting [17].

3.2 Wearable Sensors:

Wearable devices track the movements and postures of workers in real time, providing alerts for potentially dangerous actions before they lead to injury. Thus, immediate ergonomic adjustments can be implemented to enhance worker safety [14]. In oil palm plantations, workers frequently engage in repetitive and physically demanding tasks such as harvesting, which often involve awkward postures and the lifting of heavy loads. Wearable sensors prove to be extremely beneficial in this context, as they can track the workers' movements and postures in real-time. These sensors are capable of identifying hazardous movements, such as improper lifting

techniques or ergonomically incorrect positions, which are known to contribute to musculoskeletal disorders (MSDs). This technology enables immediate ergonomic interventions, allowing for adjustments in work practices or tools to enhance worker safety and reduce the risk of injury. Additionally, these data-driven approaches can help refine job performance and mitigate potential health issues for plantation labourers in the future [18], [19].

3.3 Artificial Intelligence (AI) & Computer Vision:

Ergonomic risks are assessed by systems that analyze the posture and movements of workers, providing insights on how to modify the workplace and tools for improved safety. Additionally, automation helps eliminate repetitive, high-risk tasks, thereby reducing the likelihood of injuries. AI-driven systems, particularly when integrated with computer vision, can evaluate the postures and movements of workers in oil palm plantations and identify ergonomic risks in real-time. With this information, plantation managers can redesign workplaces, tools, or methods to alleviate the physical strain on workers. The implementation of automation, whether through mechanical tools or self-propelled vehicles, can also lessen the need for manual labour in these hazardous, repetitive tasks, further decreasing the risk of injury for plantation workers [18], [19].

3.4 Robotic Automation:

Robots are taking on repetitive and physically demanding tasks such as material handling, which helps to reduce the risk of repetitive strain injuries and overexertion. This shift not only enhances ergonomics but also boosts overall productivity [20]. This not only enhances the health and safety of workers by reducing injuries but also boosts productivity. Harvesting oil palm plantations is crucial for obtaining fresh fruit bunches with high oil content, which leads to maximum profit. Mechanization is essential in the harvesting process, making the task significantly easier. In the past, wheelbarrows were used for this purpose as they could navigate various surfaces and inclines without causing pollution. However, they demanded considerable effort from workers when fully loaded. To address this, buffalo carts were introduced to lessen the workers' burden, lower costs, and expedite the harvesting process. Over time, innovations led to the development of mechanical buffaloes (such as Badang and Rhyno) that improved efficiency, reduced labour costs, and increased productivity in the plantation sector [21]. Another study involved a 6WD with 4WS transporter with a grabber to facilitate FFB loading and an elevated discharge system to minimize labour as shown in Figure 5 [22].

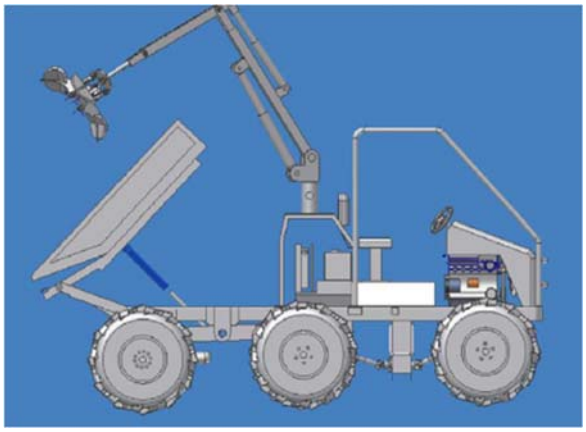

Figure 5. The transporter with FFB grabber [22].

4. Implementation and Barriers

Small oil palm farmers face numerous financial and technological challenges when it comes to adopting automation. The significant initial investment required for automation, coupled with limited access to capital, often makes it unfeasible for them to make such investments. Furthermore, many farmers lack the technical expertise needed to install and maintain these systems effectively. The small size of their farms also hinders their ability to benefit from economies of scale, rendering automation less cost-effective for smallholders.

4.1 High Initial Costs:

Automated machinery and technology require significant upfront investment. Smallholders often do not have the capital or access to capital to purchase or upkeep these technologies [23]. The significant startup costs associated with automated machinery and advanced equipment pose a major challenge for oil palm plantations, especially for smallholder farmers. Many of the essential technologies needed to boost productivity and reduce labour demands require substantial initial investment, which smallholders often cannot afford. This issue is further exacerbated by their limited access to credit or loans for purchasing or maintaining these technologies. Additionally, without sufficient capital, they struggle to benefit from economies of scale, making it difficult to compete with larger plantations that can more easily implement modern machinery [24], [25].

4.2 Economies of Scale:

Automation is cheaper, but only on a large-scale (i. e. large plantations) because the increased yield and efficiency more than compensates for the initial cost. Small-scale farmers, for example, have very little land and cannot afford to pay for automation that may not give the same return on investment as a large-scale farmer [26]. Speaking of oil palm plantations, the economics of scale play a huge role in determining the viability and use of automation technology. Economies of scale are a big factor in large plantations because they can spread fixed costs over a large output which allows them to have lower unit costs of production. With larger operations the high upfront cost of automated machinery becomes worth it because they can achieve greater efficiency and productivity gains and thus become more profitable overall. On the other hand, small farmers have different problems; they don't have much land to farm and probably don't even produce enough yield to cover the large expenses of automation. This gap though makes it hard for smallholders to invest in new technology because the return on investment is not as great as it would be for their larger counterparts. As a result, the small farmers may continue to rely on intensive labour methods, which would keep them at a competitive disadvantage and unsustainable compared to the larger, more automated plantations that are taking over the market [27].

4.3 Lack of Technological Access and Knowledge:

A lot of small farmers don't have the know-how or knowledge to automate. They have a hard time getting the more complex equipment and learning how to apply it to their farming operations [23]. Small farmers are often poor and lack the capital to invest in new equipment (drones, precision agriculture) that could potentially increase their productivity and sustainability. That and the fact that even when technology is there, many of these farmers are not well versed in the technical know-how to apply the technology to the best of its use. This lack of know-how can be attributed to the lack of training programs, extension services and information on best practices in automation [28]. They do not have the skills or the equipment to compete against these larger plantations that have the use of technology to make their operations much more efficient and productive, thereby making it impossible for the small farmers to survive in the competitive oil palm industry [29]

4.4 Infrastructure and Support:

Rural infrastructure is also a problem, for example, bad roads and lack of access to technology providers make it difficult for the small farmer to adopt automation [24]. Many smallholders operate in regions where the roads are poorly developed, making it difficult to transport their goods. This isolation keeps them away from markets and technology providers. Additionally, the lack of physical connectivity hinders their access to modern farming equipment and automated systems that could boost productivity and efficiency. Without proper infrastructure, maintaining and repairing these machines becomes a significant challenge, discouraging farmers from adopting automation. Consequently, smaller farmers find themselves at a disadvantage compared to larger plantations that can leverage their superior infrastructure to implement more advanced farming techniques and expand their operations more effectively [30].

5. Conclusion

Automation is transforming the way we approach health and sustainability in oil palm plantations. By reducing the amount of physical labour required from workers, automation helps minimize injuries and health issues associated with repetitive tasks. Additionally, mechanization enhances operational efficiency, enabling plantations to make better use of resources while lessening their environmental footprint. Automated systems can support precision agriculture, allowing for the optimization of inputs like water and fertilizers, which boosts sustainability and reduces the ecological impact of oil palm cultivation. This advancement can also lead to increased productivity and profitability, helping smallholders thrive in a competitive market while adhering to environmental and social governance standards. Ultimately, automation is essential for fostering a healthier workforce and a more sustainable oil palm industry.

REFERENCES

[1] S. Mohamaddan *et al.*, "Investigation of oil palm harvesting tools design and technique on work-related musculoskeletal disorders of the upper body," *Int J Ind Ergon*, vol. 86, p. 103226, Nov. 2021, doi: 10.1016/J.ERGON.2021.103226.

[2] N. S. M. Nawi, B. Md Deros, and N. Norani, "Assessment of Oil Palm Fresh Fruit Bunches Harvesters Working Postures Using Reba," *Advanced Engineering Forum*, vol. 10, pp. 122–127, Dec. 2013, doi: 10.4028/WWW.SCIENTIFIC.NET/AEF.10.122.

[3] Y. G. Ng, M. T. S. Bahri, M. Y. I. Irwan Syah, I. Mori, and Z. Hashim, "Ergonomics Observation: Harvesting Tasks at Oil Palm Plantation," *J Occup Health*, vol. 55, no. 5, pp. 405–414, 2013, doi: 10.1539/JOH.13-0017-FS.

[4] N. Syazwani Mohd Nawi *et al.*, "Ergonomic risk assessment of manual handling tools by oil palm collectors and loaders," 2016. [Online]. Available: https://www.researchgate.net/publication/303368559

[5] P. Bhuanantanondh, B. Buchholz, S. Arphorn, P. Kongtip, and S. Woskie, "The Prevalence of and Risk Factors Associated with Musculoskeletal Disorders in Thai Oil Palm Harvesting Workers: A Cross-Sectional Study," *Int J Environ Res Public Health*, vol. 18, no. 10, p. 5474, May 2021, doi: 10.3390/IJERPH18105474.

[6] M. M. Mokhtar, B. Md Deros, and E. H. Sukadarin, "Evaluation of Musculoskeletal Disorders Prevalence during Oil Palm Fresh Fruit Bunches Harvesting Using RULA," *Advanced Engineering Forum*, vol. 10, pp. 110–115, Dec. 2013, doi: 10.4028/WWW.SCIENTIFIC.NET/AEF.10.110.

[7] E. H. Sukadarin, B. Md Deros, N. S. Mohd Nawi, J. A. Ghani, A. R. Ismail, and J. Zakaria, "Back Pain and the Observed Factors among Oil Palm Workers," *International Journal of Engineering Technology and Sciences*, vol. 3, no. 1, pp. 70–78, Jun. 2016, doi: 10.15282/ijets.5.2016.1.9.1048.

[8] Y. G. Ng, S. B. M. Tamrin, W. M. Yik, I. S. M. Yusoff, and I. Mori, "The Prevalence of Musculoskeletal Disorder and Association with Productivity Loss: A Preliminary Study among Labour Intensive Manual Harvesting Activities in Oil Palm Plantation," *Ind Health*, vol. 52, no. 1, p. 78, 2014, doi: 10.2486/INDHEALTH.2013-0017.

[9] Y. G. Ng, M. T. S. Bahri, M. Y. I. Irwan Syah, I. Mori, and Z. Hashim, "Ergonomics observation: Harvesting tasks at oil palm plantation," *J Occup Health*, vol. 55, no. 5, pp. 405–414, 2013, doi: 10.1539/joh.13-0017-FS.

[10] "How Manual Labour Affects The Body | CPR First Aid." Accessed: Sep. 27, 2024. [Online]. Available: https://cprfirstaid.com.au/on-manual-labour-and-its-effects-on-the-body/

[11] T. R. Cunningham, R. J. Guerin, J. Ferguson, and J. Cavallari, "Work-related fatigue: A hazard for workers experiencing disproportionate occupational risks," *Am J Ind Med*, vol. 65, no. 11, pp. 913–925, Nov. 2022, doi: 10.1002/ajim.23325.

[12] "Extreme heat's impact on labor | Stanford Report." Accessed: Sep. 30, 2024. [Online]. Available: https://news.stanford.edu/stories/2022/07/extreme-heats-impact-labor

[13] "CCOHS: Work-related Musculoskeletal Disorders (WMSDs)." Accessed: Sep. 30, 2024. [Online]. Available: https://www.ccohs.ca/oshanswers/diseases/rmirsi.html

[14] "5 Emerging Technologies in Ergonomics and Why They Matter." Accessed: Sep. 30, 2024. [Online]. Available: https://www.assp.org/news-and-articles/5-emerging-technologies-in-ergonomics-and-why-they-matter

[15] M. Barneo-Alcántara, M. Díaz-Pérez, M. Gómez-Galán, Á. Carreño-Ortega, and Á. J. Callejón-Ferre, "Musculoskeletal Disorders in Agriculture: A Review from Web of Science Core Collection," *Agronomy 2021, Vol. 11, Page 2017*, vol. 11, no. 10, p. 2017, Oct. 2021, doi: 10.3390/AGRONOMY11102017.

[16] M. K. F. Md Radzi, M. A. Mohd Bakri, M. R. Mohd Khalid, M. I. H. Azaman, and M. R. Ahmad, "Preliminary Assessment of Exoskeleton Suit Assistance for Fresh Fruit Bunch (FFB) Collecting Task in Oil Palm Plantation," *Advances in Agricultural and Food Research Journal*, vol. 3, no. 2, Nov. 2022, doi: 10.36877/AAFRJ.A0000313.

[17] H. Selamat, T. Islam, M. F. Haniff, and A. J. Alimin, "Design and Implementation of Hybrid Exoskeleton for Oil Palm Harvester to Reduce Muscle Strain," *Journal of Advanced Research in Applied Mechanics*, vol. 105, no. 1, pp. 1–11, May 2023, doi: 10.37934/aram.105.1.111.

[18] B. M. Deros, D. Mohamad, and D. D. I. Daruis, "Ergonomic Risk Assessment on Oil Palm Industry Workers," 2016. [Online]. Available: http://ijph.tums.ac.ir

[19] Y. G. Ng, M. T. S. Bahri, M. Y. I. Irwan Syah, I. Mori, and Z. Hashim, "Ergonomics observation: Harvesting tasks at oil palm plantation," *J Occup Health*, vol. 55, no. 5, pp. 405–414, 2013, doi: 10.1539/JOH.13-0017-FS.

[20] "Looking at the impact of automation on health and safety in the workplace - MOHS Workplace Health." Accessed: Sep. 30, 2024. [Online]. Available: https://mohs.co.uk/looking-at-the-impact-of-automation-on-health-and-safety-in-the-workplace/

[21] Z.-M. Muhamad and M. F. A. Aziz, "Mechanization in Oil Palm Harvesting," *International Journal of Academic Research in Business and Social Sciences*, vol. 8, no. 5, May 2018, doi: 10.6007/ijarbss/v8-i5/4098.

[22] A. R. Shuib, M. K. F. M. Radzi, M. A. M. Bakri, and M. R. M. Khalid, "Development of a harvesting and transportation machine for oil palm plantations," *Journal of the Saudi Society of Agricultural Sciences*, vol. 19, no. 5, pp. 365–373, Jul. 2020, doi: 10.1016/j.jssas.2020.05.001.

[23] R. Dhillon and Q. Moncur, "Small-Scale Farming: A Review of Challenges and Potential Opportunities Offered by Technological Advancements," Nov. 01, 2023, *Multidisciplinary Digital Publishing Institute (MDPI)*. doi: 10.3390/su152115478.

[24] D. J. Choruma *et al.*, "Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa," *J Agric Food Res*, vol. 18, p. 101286, Dec. 2024, doi: 10.1016/J.JAFR.2024.101286.

[25] L. Judijanto, "Analysis of the Economic Feasibility of Using Modern Agricultural Machinery in Oil Palm Plantations in South Sumatra," *West Science Agro*, vol. 2, no. 03, pp. 99–108, Aug. 2024, doi: 10.58812/WSA.V2I03.1201.

[26] "Mechanisation and Automation Vital For Smooth Operation of Nation's Oil Palm Plantations." Accessed: Sep. 30, 2024. [Online]. Available: https://www.asia-palmoil.com/post/mechanisation-and-automation-vital-for-smooth-operation-of-nation-s-oil-palm-plantations

[27] D. Michael, "Economies of size in production agriculture," *J Hunger Environ Nutr*, vol. 4, no. 3–4, pp. 375–392, Jul. 2009, doi: 10.1080/19320240903321292.

[28] "Implementing IR 4.0 Technology in Oil Palm Plantation – PALM OIL ENGINEERING BULLETIN." Accessed: Sep. 30, 2024. [Online]. Available: http://poeb.mpob.gov.my/implementing-ir-4-0-technology-in-oil-palm-plantation/

[29] R. P. Siti-Dina, A. C. Er, and W. Y. Cheah, "Social Issues and Challenges among Oil Palm Smallholder Farmers in Malaysia: Systematic Literature Review," *Sustainability 2023, Vol. 15, Page 3123*, vol. 15, no. 4, p. 3123, Feb. 2023, doi: 10.3390/SU15043123.

[30] D. S. N. A. Ahmad *et al.*, "Exploration of the Challenges in Adopting Smart Farming Among Smallholder Farmers: A Qualitative Study," *Journal of Advanced Research in Applied Sciences and Engineering Technology*, vol. 45, no. 1, pp. 17–27, Mar. 2025, doi: 10.37934/araset.45.1.1727.