

MECHANIZATION IN MALAYSIAN AGRICULTURE: A SYSTEMATIC REVIEW OF PRODUCTIVITY, SUSTAINABILITY, AND SOCIO-ECONOMIC PERSPECTIVES

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ABSTRACT

Mechanisation is in fact much needed by Malaysia's agricultural sector that has been dealing with the issues of food security, labour shortage and environmental sustainability. Recent technologies advanced, especially in IoT (Internet of Things), AI (Artificial Intelligence) and Automation provide new revolution to improve productivity and operational efficiency. Nonetheless, the contribution of these technologies to sustainable agricultural development in Malaysia needs to be thoroughly assessed. This review followed a PRISMA based systematic literature review. Literature search was performed in Scopus and Web of Science for articles between 2022 and 2024 with defined search string and inclusion criteria. After screening, 27 articles published in peer-review journals were identified for further screening. This review was synthesized in the following three themes: (i) Smart Farming and IoT Applications, (ii) Artificial Intelligence and Computer Vision, (iii) Sustainable Agriculture and Related Technologies. The review concludes that IoT-based smart farming enhances irrigation management, live monitoring, and resource utilization. Crop and weed detection are enabled by AI, computer vision technology to support early disease diagnosis and yield estimation using next generation of imaging and machine learning. Energy use and environmental pollution can be reduced by sustainable mechanization technologies. Despite these advantages, the barriers of high implementation cost, low digital literacy, and inconsistent policy enforcement hinder the widespread adoption of Malaysian smallholders. Adoption of IoT and AI technology with sustainable mechanization as the solution can serve as a promising approach in modernizing Malaysian agriculture. Advance mechanisms, cost-effective innovations and focused training programmes are necessary to enhanced productivity, resilience and environmental sustainability of the farming system

Keywords: agriculture, automation, mechanization, smart farming, systematic literature review.

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1.0 INTRODUCTION

In recent years, there have been significant changes in the Malaysian agriculture sector, with heavy emphasis on productivity and efficiency through mechanization. As a key to

the national economic base, agriculture not only ensures food security, but is also an important source of income and livelihoods for a significant proportion of people [1]. The continuing shift from traditional to commercial cropping emphasises the need for agricultural mechanisation as the country progresses from an agriculturally based economy to industrialisation. The high demand for agricultural production, shortages of labour and the decision to save costs have forced them to implement new technologies in order to continue growth.

Various technologies, including traditional mechanical systems and the use of artificial intelligence (AI) and drone applications have been at the centre stage of automated practices in modernise Malaysian agriculture. These new tools and methods have repeatedly shown a potential to improve productivity, cut down intensity of labours, as well as the sustainability of farming [3]. For example, the utilization of unmanned aerial vehicles (UAVs) to monitor crops and manage weeds have enabled farmers to reduce operational costs and increase output efficiency [4]. In view of the significance of technological development, Malaysia Agricultural Research and Development Institute (MARDI) has been taking an initiative to further enhance mechanization and automation toward modernized agro-food sector [5].

However, the mechanization campaign is not free from problems, despite of its advantages [6]. Environmental concerns coupled with deficiencies in supportive government regulations continue to pose significant barriers to large scale use. The mechanisation-environmental sustainability link is inherently complex, if not well managed, traction machinery may bring about soil degradation and a loss of biodiversity despite improving on farm efficiency [7]. Thus, an appropriate balance between technological development and preservation of environment is inevitable [7].

Mechanization has been viewed as a solution to both productivity and labour problems in the Malaysian agriculture sector. Its application is intended to enhance work efficiency and reduce physical burden on farmers, particularly in rice cultivation which covers about 600,000 ha across the country [8]. There is significant improvement in the productivity per worker following mechanization of the agricultural operation at countries that have successfully applied it, a benchmark for Malaysia to follow [8]. Nevertheless, the move to mechanized farming has been difficult, particularly for small-scale farmers who cannot afford new machinery [9], [10]. Most rural farmers are financially unable to mechanize. In Sarawak, the exorbitant price of farm machineries has retarded the income earning potentials of farmers, may have accentuated rural poverty and stimulated urbanization [9].

This discrepancy illustrates the ongoing disconnect between theoretical benefits in mechanisation and actual smallholder realities despite them being almost 90% of Malaysia's farming workforce [10], [11]. The high cost of mechanization also discourages investment in superior technologies with the result being low productivity and economic insecurity [11]. In addition, mechanization brings environmental and agronomic problems, such as soil degradation and overextension of agricultural land due to bulky machines [12], [13]. In response to these challenges, the National Agrofood Policy 2021–2030 (NAP 2.0) advocates for modernization of the agro-food sector that is focused on integrating technologically and ecology progress to ensure that productivity gains are in line with sustainability objectives [12].

Proper and efficient agricultural extension services are also fundamental for the successful adoption of mechanization. Extension officers are vital in guiding farmers on sustainable methods and showing them the benefits of mechanization [14]. However, the lack of access to recent information on new agricultural technologies still prevents extension workers from being able to transfer knowledge effectively [14]. The competence of these services could be significantly improved by focussing training and support.

And then there's the issue of climate change as well. The predictability of weather patterns are important in many farming practices that depend on mechanical operations,

and disturbances related to changes in climate can have significant impacts on productivity as well as economic considerations [15], [16]. Adaptation to these changes will necessitate new investment in technology and training, so that the machines can be put to best use under different climate conditions [15]. Combining mechanization with adaptive measures that improve both productivity and environmental sustainability will play a crucial role for Malaysia in ensuring the robustness of its' agricultural sector against the challenges posed by climate change [17], [18].

Even though Malaysia's agricultural industry has enjoyed incremental improvements through mechanization and government-mandated modernization efforts, the digital revolution has evolved unevenly, especially among smallholder farmers responsible for the bulk of food production in general. Continuing roadblocks, including lack of affordable technology access, poor digital infrastructure and lack of technical literacy continue to inhibit the effective adoption of Internet of Things (IoT), artificial intelligence (AI) and automation solutions. In view of these gaps, this paper seeks to review the existing state of IoT, AI and automation tools in Malaysia's agriculture sector. It aims to highlight potential opportunities, challenges and policy implications that will help steer the dynamic integration of these technologies in improving productivity and environmental sustainability and contributing to the long-term resilience of Malaysia's agro-food system.

2.0 METHODOLOGY

A systematic literature review is based on methodology, which is necessary to conduct a thorough and transparent overview of current research. This process is typically structured into five essential steps: identification, screening, eligibility, data extraction and analysis. In the search for identification phase, A comprehensive search has been conducted across multiple databases and relevant literature, utilizing keywords and predetermined inclusion criteria to achieve a comprehensive but specific range of studies. After being retrieved, a screening phase is conducted to eliminate studies from the titles and abstracts retrieved from the search which do not meet the initial criteria, so as refine the pool of possible articles. The selection from the large number of eligible articles is further refined in the eligibility phase through the application of additional stringent criteria, including quality assessments, to include only high quality and relevant studies. Finally, data extraction and analysis, which entails data extraction from considered studies and synthesizing the result, for meaningful conclusions regarding the study.

2.1 Identification

To gather a substantial amount of relevant literature, keywords were selected to search for related terms from dictionaries, thesauri, encyclopaedias, and prior research. Search strings were created with Web of Science and Scopus databases (see Table 1) for all relevant terms identified. From the two databases, the systematic review produced 9927 publications suitable to the study topic during this first phase.

Table 1: The search string

Data base	The search string
Scopus	TITLE-ABS-KEY ((mechanization OR automation) AND agriculture) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024)) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (AFFILCOUNTRY , "Malaysia"))
Date of Access: Oct 2024	

WoS	(mechanization OR automation) AND agriculture (Topic) and 2022 or 2023 or 2024 (Publication Years) and Article (Document Types) and Article (Document Types) and English (Languages) and English (Languages) and MALAYSIA (Countries/Regions)
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Date of Access: Oct 2024

2.2 Screening

Next, during the screening phase, all potentially relevant studies were carefully examined to ensure alignment with the predefined research questions and the overarching focus on mechanisation in Malaysian agriculture. At this stage, duplicate records were removed to avoid redundancy. From the initial pool of 9,889 publications, only 38 papers remained after applying the inclusion and exclusion criteria outlined in Table 2. The subsequent screening process involved a closer review of the literature to filter out studies and recommendations—such as conference papers, books, and reviews—that did not directly contribute to the aims of this study. Consistent with the established criteria, only peer-reviewed journal articles published in English between 2022 and 2024, and specifically related to Malaysia, were retained. In total, eight publications were excluded due to duplication, ensuring that the final dataset represented a focused and reliable body of evidence for analysis.

Table 2: The selection criterion in searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2022 – 2024	< 2022
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Country	Malaysia	Besides Malaysia

2.3 Eligibility

In step three, the eligibility phase, 30 articles were prepared for review. For this stage, the titles and key content specifics for all articles was thoroughly investigated to ensure that they met the inclusion criteria and dealt with the subject matter currently being explored. Due to being out of the field, title not significant or abstract not related to the objective of the study, three articles have been excluded due to the lack of full text access founded on empirical evidence. This leaves a total of 27 articles, which are displayed in Table 3.

Table 3: Primary data

No	Authors	Title	Year	Journal	Database
1	Al Mashhadany Y.; et al. [19]	Irrigation intelligence—enabling a cloud-based Internet of Things approach for enhanced water management in agriculture	2024	Environmental Monitoring and Assessment	Scopus & WoS

No	Authors	Title	Year	Journal	Database
2	Wan Nurazwin Syazwani R.; et al. [20]	Automated image identification, detection and fruit counting of top-view pineapple crown using machine learning	2022	Alexandria Engineering Journal	Scopus
3	Jayanthiladevi A.; et al. [21]	Radio frequency-based periodic cloud data analysis for smart farming	2022	International Journal of Cloud Computing	Scopus
4	Abdullah M.S.T.; Mazalan L. [22]	Smart Automation Aquaponics Monitoring System	2022	International Journal on Informatics Visualization	Scopus
5	Tey Y.S.; et al. [23]	Evolution of precision agricultural technologies: a patent network analysis	2024	Precision Agriculture	Scopus & WoS
6	Alsayaydeh J.A.J.; et al. [24]	Empowering crop cultivation: harnessing internet of things for smart agriculture monitoring	2024	International Journal of Electrical and Computer Engineering	Scopus
7	Shafie S.M.; Hami N.; et al. [25]	Energy Consumption on Farm Automation: Case of Paddy Plantation	2023	Journal of Advanced Research in Fluid Mechanics and Thermal Sciences	Scopus
8	Wang G.; Li J.; Xue N.; et al. [26]	Risk assessment of organophosphorus pesticide residues in drinking water resources: Statistical and Monte-Carlo approach	2022	Chemosphere	Scopus
9	Ani A.I.C.; et al. [27]	A dataset for computer-vision-based fig fruit detection in the wild with benchmarking you only look once model detector	2024	Bulletin of Electrical Engineering and Informatics	Scopus
10	Mohd Azmi K.H.; et al. [28]	The Future Of Sustainable Agriculture: A Review Of Iot And Autonomous Control In Vertical Hydroponic Farming	2024	Advances in Electrical and Electronic Engineering	Scopus
11	Woo Y.S.; et al. [29]	3D grape bunch model reconstruction from 2D images	2023	Computers and Electronics in Agriculture	Scopus & WoS
12	Che Aziz D.H.; et al. [30]	Systematic framework to select the sustainable best design for an automated fertiliser blending system	2023	Journal of Cleaner Production	Scopus
13	Mustaza S.M.; et al. [31]	Directional Shape Feature Extraction Using Modified Line Filter Technique for Weed Classification	2022	International Journal of Electrical and Electronics Research	Scopus
14	Azman N.; et al. [32]	Smart Agricultural Monitoring System using IoT Application for Chili Plants	2023	Journal of Advanced Research in Applied Sciences and	Scopus

No	Authors	Title	Year	Journal	Database
				Engineering Technology	
15	Obaideen K.; et al. [33]	An overview of smart irrigation systems using IoT	2022	Energy Nexus	Scopus
16	Alsayaydeh J.A.J.; et al. [34]	Greenhouse Horticulture Automation with Crops Protection by using Arduino	2023	International Journal of Advanced Computer Science and Applications	Scopus
17	Ismail B.I.; et al. [35]	Robotic Research Platform for Agricultural Environment: Unmanned Ground Vehicle for Oil Palm Plantation	2023	Journal of Cases on Information Technology	Scopus
18	Sun B.; et al. [36]	Analyzing the mechanism among rural financing constraint mitigation, agricultural development, and carbon emissions in China: A sustainable development paradigm	2024	Energy and Environment	Scopus
19	Abiri R.; et al. [37]	Application of digital technologies for ensuring agricultural productivity	2023	Heliyon	Scopus & WoS
21	Abdikadir N.M.; et al. [38]	Smart Irrigation System	2023	SSRG International Journal of Electrical and Electronics Engineering	Scopus
22	Sultan U.; et al. [39]	Multi crop high efficiency seed drill with solar hybrid seed metering: A step toward precision and sustainability	2023	Frontiers in Sustainable Food Systems	Scopus & WoS
23	Ee K.Y.; et al. [40]	Black soldier fly (<i>Hermetia illucens</i> L.) larvae in degrading agricultural waste as a sustainable protein production: feedstock modification and challenges	2022	International Journal of Tropical Insect Science	Scopus & WoS
24	Anser M.K.; et al. [41]	Beyond climate change: Examining the role of environmental justice, agricultural mechanization, and social expenditures in alleviating rural poverty	2023	Sustainable Futures	Scopus
25	Ramadan S.T.Y.; et al. [42]	Improving Wheat Leaf Disease Classification: Evaluating Augmentation Strategies and CNN-Based Models with Limited Dataset	2024	IEEE Access	Scopus & WoS
26	Huo, DY; et al. [43]	Mapping smart farming: Addressing agricultural challenges in data-driven era	2024	RENEWABLE & SUSTAINABLE ENERGY REVIEWS	WoS

No	Authors	Title	Year	Journal	Database
27	Singh Thakur et al. [44]	Deep transfer learning based photonics sensor for assessment of seed-quality	2022	Computers and Electronics in Agriculture	Scopus

2.4 Data extraction and analysis

This review brings together findings from different research studies. The aim was to identify the main topics and subtopics that have been discussed in existing literature. The process began with collecting and reviewing the selected articles. A total of 27 studies, shown in Figure 1, were examined to locate statements, insights, or gaps related to the focus of this review. After the initial reading, the key studies on mechanisation in Malaysian agriculture were analysed in more detail. This included looking closely at the methods used and comparing the findings reported across the studies. From there, recurring patterns started to emerge, which helped shape the themes used in this review.

Throughout the analysis, a simple log was kept to note important observations, questions, or issues that needed a second look. This also made it easier to check for any inconsistencies when the themes were compared later on. If any concepts did not fit well or appeared contradictory, they were discussed and refined to ensure the final themes were clear and coherent.

The analysis was guided by two research questions:

1. How has the adoption of IoT-based smart farming technologies influenced the productivity and operational efficiency of Malaysian farmers?
2. How do AI and computer-vision applications in crop and weed management contribute to productivity improvements and more efficient resource use in Malaysian agriculture?

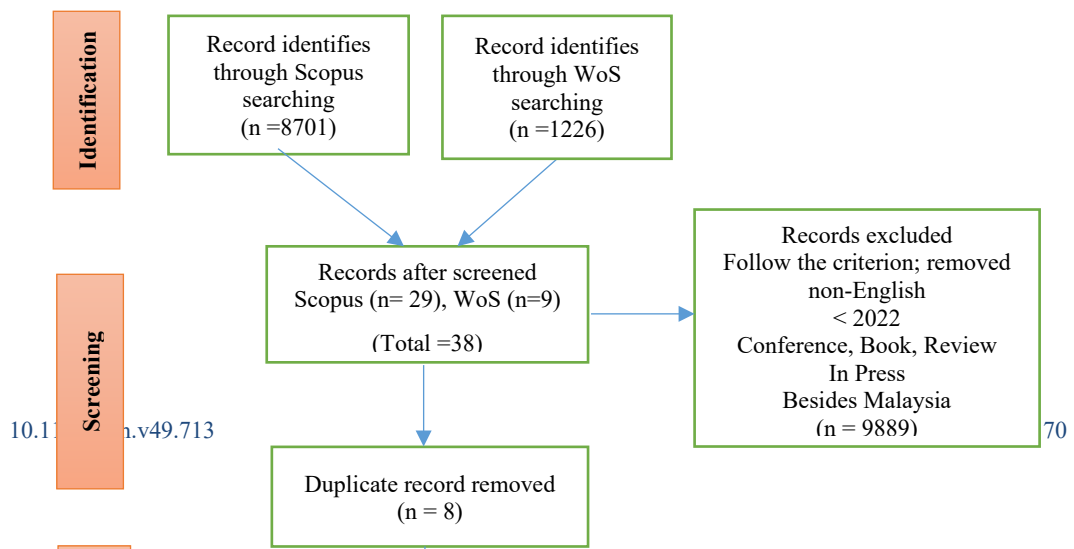


Figure 1. Flow diagram of the proposed searching study [45]

3.0 RESULTS AND DISCUSSION

Technology is transforming the nature of agriculture, providing essential solutions to address the issue of food security worldwide and sustainable resource management. This systematic literature review focuses on three key themes: Smart Farming and IoT Applications in Agriculture, Artificial Intelligence and Computer Vision in Agriculture, and Sustainable Agriculture and Agricultural Technologies. IoT turns smart farming into a means of optimizing operational efficiency, time monitoring and data-driven decision making in agriculture. At the same time, AI and computer vision technologies are enabling precision agriculture capabilities, like early disease detection and optimized planting strategies, that change old fashioned farming to a nearly perfect precision and almost zero human involvement. Modern technologies, as well as sustainable agriculture, support the implementation of resource efficient practices and lower the environmental impact, while still meeting growing needs on a global scale. These themes, when paired together, provide a comprehensive picture of how digital innovations are integrated throughout agriculture, what is happening currently and what the future could look like for a resilient, efficient and environmentally sustainable agricultural sector.

3.1 Theme 1: Smart Farming and IoT Applications in Agriculture.

With the emerging role of Smart Farming and IoT application in resource management and efficient agriculture, there has been an increase in demand for these technologies. Digital agriculture (DA) technologies like AI, automation, and robotics, as emphasized by Abiri et. al [37], as shown in Figure 2, are clear that they help increase the production of crops and provide real time information about crops and the environment, like soil quality and health of plants. In like manner, Jayanthiladevi et al. [21] assess the potential of radio frequency (RF) technology in smart farming, to acquire, analyze, and use the data on crop

performance and climate conditions to enhance productivity and reduce ecological impacts. At the same time, Alsayaydeh et al. [34] introduces an IoT based environmental parameter monitoring system to show how temperature, soil moisture, and light intensity control can help increase crop yields. By themselves, these studies collectively spotlight IoT based solutions as key enablers for adopting sustainable agricultural practices via efficient monitoring and management. Water management is another critical area, where IoT applications are emphasized by Mohd Azmi et al. [28] and Obaideen et al. [33]. They also point out that it works towards the automation of irrigation systems, guiding water usage to a precise level with a view to preserving such resources, a practice that is aligned to sustainable development objectives (SDGs) for conservation of resources. In their work, Al Mashhadany et al. [19] demonstrate the utilization of integrating AI and IoT to monitor plant growth stages and intelligently control remote irrigation, pest management, and disease detection, while optimizing water usage. It is significantly lead to water use efficiency in drought-prone regions with benefits of intelligence introduced in the control systems.

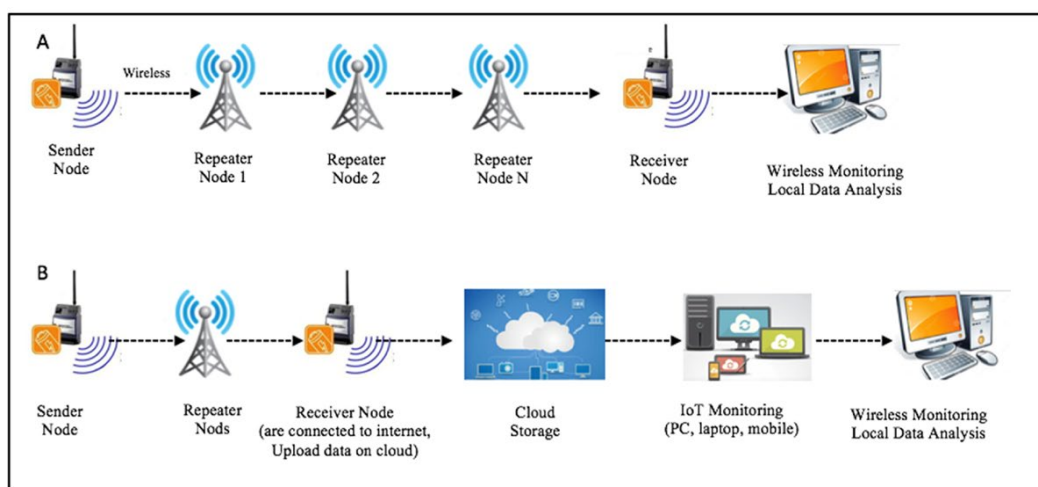


Figure 2. A) Schematic demonstration of field measurement and data collection using a wireless sensor network and B) IoT monitoring and cloud-based data analysis. [37]

The aquaponic and hydroponic food production represents an alternative way of satisfying food security and addressing sustainability challenges out of those currently used. A focus for Abdullah and Mazalan [22] is on aquaponic monitoring systems based on IoT and sensor technology that control water quality, temperature and nutrient levels for fish and plants to reduce labour requirements and to increase food production. Further work on this includes vertical hydroponic farming discussed Mohd Azmi et al. [28], to name a few who discussed how the integration of IoT and autonomous control systems (ACS) is the key aspect to counterproductive interruption in confined cropping facilities. Together, these studies highlight how integration of IoT-ACS in these systems aids in maximizing resource use that saves on productivity and reduces environmental loop-footprints, particularly in urban areas. Agriculture productivity and sustainability advancement relies on the convergence of AI, IoT and automation. Combining these technologies, researchers in all of the studies point out that the labour being substituted by technology in practice allows for a better output while also ensuring resource conservation. For example, such innovations depicted by Azman et al. [32] enable farmers to monitor and automate the monitored processes in real time so they can take action before challenges like pest infestation and nutrient deficiency arise. The path toward sustainability for this rising global demand in food production cannot be approached without collaboration across technologies.

3.2 Theme 2: AI and Computer Vision in Agriculture.

An integration of artificial intelligence (AI) and computer vision capable of improving agricultural practices was shown to possess great potential in the areas of precision crop management, fruit detection, and disease identification. As one example, Wan Nurazwani Syazwani et al. [20] studied the identification and counting of pineapple crowns using machine learning techniques, such as Artificial Neural Networks (ANN) and Support Vector Machines (SVM). The challenges encountered in processing images under natural lighting and complex shapes were this study's highlights, yet fruit counting was performed with 94.4% accuracy. This indicates the great potential of high-resolution aerial image analysis in the pineapple industry. Ani et al. [27] also created a fruit detection dataset using You Only Look Once (YOLO) models to help fill a gap in specialized figure data. Real-time monitoring of figure maturity can support farmers' decision-making process by showing the impact on crop yield management through object detection of the figure. Noteworthy also are efforts to improve 3D modeling techniques in agriculture. The 3D models of grape bunches that Woo et al. [29] developed from 2D images allow accurate berry counting and aid in the thinning process, a primary practice for maximizing grape quality. This work demonstrated the advantages for robotics to automate berry selection in the future, further underscoring the limitations of 2D images for tasks that require spatial awareness and the promise of 3D modeling. Figure 3 depicts the process for refining the 3D semantic bunch model. Furthermore, Mustaza et al. [31] tried weed classification using a modified line filter technique which separates broadleaf and narrow leaf weeds. This approach promises an accuracy rate of approximately 97% on automated identification of weed types and subsequent selective herbicide application, which would reduce environmental and cost impact.

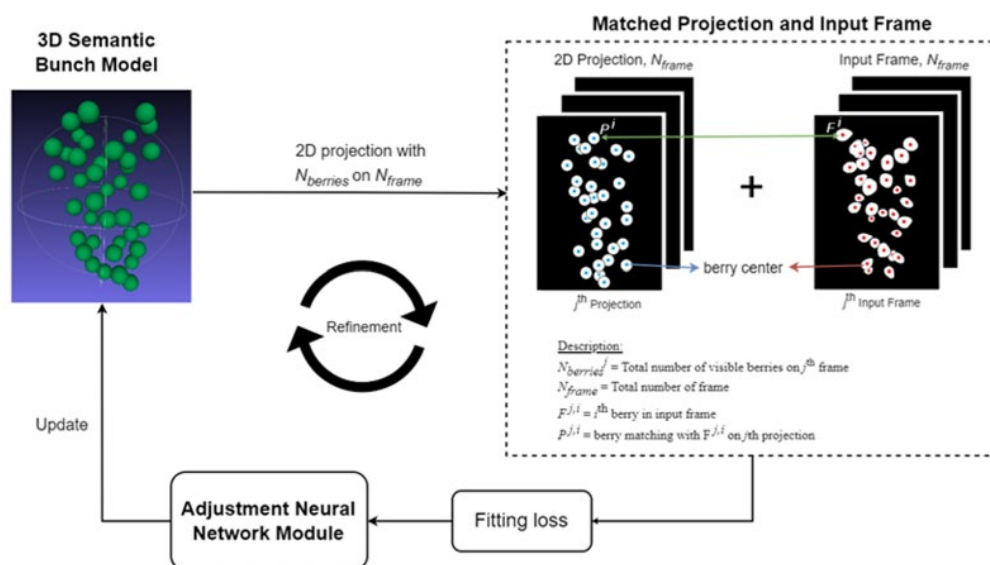


Figure 3. 3D semantic bunch model refinement, guided by the captured 2D video frames. [29]

This is also beneficial for seed quality assessment by AI. Most recently, Singh Thakur et al. [44] engineered a deep transfer learning-based photonics sensor to determine seed quality through the analysis of backscattered laser images using convolutional neural networks (CNNs). A variety of models were considered, and InceptionV3 demonstrated the highest classification accuracy [98.31%] demonstrating the power of transfer learning to identify morphological and biological features characteristic of seed health. This approach improves the reliability of quality assessment and at the same time reduces memory requirements while simplifying experimental procedures, which makes it very applicable

for real-time agricultural settings. Stable disease detection and management is necessary for sustainable agriculture, especially to counter challenges with few datasets. Wheat leaf disease classification accuracy is evaluated using data augmentation techniques by Ramadan et al. [42]. Augmentation of continuous datasets using CycleGAN led to significantly improved model performance, where MobileNetV2 achieves 100% accuracy on augmented datasets and addresses dataset scarcity and class imbalances. Outlining further the importance of data augmentation in improving model robustness for plant disease detection, this study is the first to point out how such data augmentation may be essential to the global food security of timely and accurate disease detection.

These studies provide an emphasis on the progress made in the application of AI and computer vision for agriculture. These technologies have great potential to transform crop yield estimation and weed management, seed quality assessment, and disease detection, among others, in the movement of improving agricultural productivity and sustainability. Today, AI-driven solutions are pushing the future of agriculture using high precision image processing, deep learning, and powerful creative data augmentation to help farmers make better decisions and become more efficient in their day-to-day operations.

3.3 Theme 3: Sustainable Agriculture and Agricultural Technologies

Notable technologies have been focused on precision agriculture, automated fertilization systems as well as energy efficient farm automation. In his study of precision agriculture, Tey et al. [23] investigated the evolution of precision agriculture through patent trend analysis, which shows that precision agriculture has progressed from motorized to digital mechanization phases over decades. This matches the evolution described by Shafie et al. [25] who investigated energy use in paddy plantations. The findings also demonstrate that while they have been used in Malaysia's MADA region, there is a greater need for the implementation of more advanced systems to mitigate dependency on energy. At the same time, Sultan et al. [39] indicate the precision of seed sowing with solar hybrid drills helps to increase efficiency by regulating seed and fertilizer distribution, indicating the role of mechanization in sustainability [24],[25],[39]. Automating is highlighted as crucial in further studies to encourage sustainable agricultural practices. Che Aziz et al. [30] describes an automated fertilizer blending system for precision nutrient application to reduce fertilizer wastage. This idea correlates with the work of Alsayaydeh et al. [34] about crop protection using an IoT-integrated greenhouse system. Similarly, Ee et al. [40] observe that sensor-based automation in greenhouse settings would be more productive and resource-efficient and we also echo this work. These technologies not only enhance the resilience of the crop, but also meet Malaysia's sustainability goals, signaling a major change in agricultural practice [30]; [34].

Mechanizing complex agricultural tasks is also important in Malaysia's oil palm sector, for which robotics also plays a critical role. Ismail et al. [35] discuss integrating robotic systems into palm oil plantations, which are completely unstructured environments. Figure 4 demonstrates the transformation of an ATV into platform robot. With substantial technological advances, their study shows that realizing these systems is a struggle because they must overcome environmental barriers, and long-distance communication is needed for optimal control of these systems. Wang et al [26] also consider risks of pesticide residues in water and proposed a mechanized pest control in sustainable agriculture. These findings are in line with the study by Sun et al. [36] on the synergies and antagonism between carbon emissions and agricultural financing to suggest that Malaysia's approach to sustainable agriculture must consider the conflicts between mechanization and environmental impact [35], [26], [36].



Figure 4. From ATV to robot. [35]

3.4 Discussion

Currently Malaysia's agriculture industry is progressively transitioning from traditional to digital. In the field of smart farming and IoT applications, ambient-based technologies such as automatic watering, real-time environment sensing, and sensor-controlled hydroponic or aquaponic systems has demonstrated considerable benefits in water management optimization crop consistency and reducing labour costs. These efforts show how digital systems can help smallholders make better decisions and stay ahead of growing labour gaps. However, adoption remains uneven. For many farmers, the barriers are still cost, a lack of community understanding and an inability to access consistent connectivity. Such challenges indicate that greater policy support such as targeted financial incentives, farmer-centric digital training, more active extension service would be needed to expand the application of IoT in the Malaysian agricultural sector.

Subsequently, there exists the technological advancement facilitated by artificial intelligence and computer vision. Investigations into fruit identification, weed categorization, plant disease diagnosis, and seed quality assessment have shown that AI can provide precise and prompt information that is often difficult to obtain manually. Such tools could also aide in better predicting yield, preventing waste, and making more informed in-field decisions. But in practice, their use is still rare. Local crop specific datasets are lacking, and many smallholder farmers have low technical confidence to run such system effectively. There is much more to do, and we will need continuous investment in food data infrastructure, better coordination between academia and industry, as well as AI tools tailored for the variety of crops and climate conditions in Malaysia.

Then, Malaysia has begun incorporating environmental concerns into its mechanized processes, as seen by agricultural mechanization and sustainable agriculture innovation technologies. Advances such as solar-assisted seed drills, automatic fertiliser blending systems and renewable-energy-driven greenhouse technologies demonstrate mechanisation does not have to cut into the environment if it is supporting environmental objectives without reducing productivity. 'These tools also have the potential to cut down on input waste, minimise dependence on energy and promote more rationalized, more ecologically considerate agricultural activities. The adoption of environmentally friendly mechanization, however, has been limited primarily by its high costs and farmers' concerns regarding long run operational requirements. A national policy framework that fosters the uptake of renewable energy in agriculture, encourages the availability of precision equipment and mainstreams sustainability considerations into mechanization programmes will be important to ensure the sustained impact of such programme.

Collectively, these three themes characterize a sector that has high potential but continues to face structural and socio-economic challenges. The success of Malaysia's agriculture transformation will rely not just on technological innovations, but also whether farmers, especially smallholders, are prepared and supported to use these tools. The crucial role of financial support, long-term training strategies and coherent policy frameworks in translating technological possibilities into changes on the ground will be decisive. With concerted backing, mechanization, including IoT, AI, and sustainable technologies, can

enable the country to develop a more resilient, efficient and ecologically balanced agro-food system.

4.0 CONCLUSION

This paper demonstrates that agricultural mechanization in Malaysia is steadily evolving towards a more advanced, engineering-oriented framework through the adoption of digital technologies, automation, and data-driven systems. Technologies such as IoT-based smart farming platforms, artificial intelligence, and computer-vision applications have shown clear potential to improve operational efficiency, enhance precision in crop monitoring, and reduce dependence on manual labour while supporting sustainable agricultural practices. Despite these advances, the review identifies several enduring challenges, including high implementation costs, limited technical readiness among farmers, uneven infrastructure development, and gaps in policy execution, which collectively restrict broader adoption, particularly among smallholder operators. These findings indicate that technological progress alone is insufficient and must be complemented by coordinated engineering solutions, targeted capacity building, and effective mechanisms for technology transfer. Overall, mechanization remains a critical pathway for improving productivity and sustainability in Malaysia's agricultural sector; however, its long-term effectiveness will depend on the successful development and integration of cost-effective, locally adaptable technologies within existing farming systems.

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