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A REVIEW ON MECHANIZATION AND DIGITALIZATION IN UPSTREAM ACTIVITIES FOR THE COCOA INDUSTRY – CHALLENGES AND VIEW FROM ERGONOMICS PERSPECTIVES

Farah Ayuni Fauzi*
Malaysian Cocoa Board,
Peti Surat 30, Jalan Sg Dulang,
36307 Sungai Sumun, Perak, Malaysia
**Corresponding author: ayuni@koko.gov.my*

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ABSTRACT – *Upstream activities in the cocoa industry play an important role in ensuring the optimum productivity of cocoa production. It starts from land preparation until harvesting and has always been associated with the use of technology. Nevertheless, technology utilization either mechanization or digitalization, has known as the most efficient way to maximize cocoa farming management and ensure the continuity of the cocoa supply chain. Thus, this paper aims to review the technology development, i.e., mechanization and digitalization in upstream activities of the cocoa industry, in view of the ergonomics perspective in the agricultural industry. This paper also highlights some common injuries in the agricultural industries that might hinder the productivity of the farmers. Finally, this review points out several challenges in adopting technological development in the cocoa industry in terms of environmental, economic and technical issues. This review provides references for researchers, and more technology should be applied in the upstream activities of the cocoa industry as one of the solutions to enhance cocoa farming management and increase production.*

Key words: Upstream activities, mechanization, digitalization, challenges, ergonomics

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a vital economic for millions of people worldwide (Wickramasuriya and Dunwell, 2018). It has a lot of health benefits that have been linked to a variety of biological properties such as antioxidant, antiproliferative, antiapoptotic, anti-inflammatory and anti-cancer (Aranaz *et al.,* 2019; Barrera-Reyes *et al.,* 2019; Martín *et al.,* 2016; Martins *et al.,* 2020; Pinto *et al.,* 2021). Moreover, cocoa has been investigated in different health conditions and positively responds to vascular function and intestinal function and improves immune response against influenza virus infection (Álvarez-Cilleros *et al.,* 2020; Heiss *et al.,* 2015; Sansone *et al.,* 2017). Despite the health benefits and high economic value of this industry, the volume of cocoa produced in Malaysia is still low and needs to be increased. It has become a challenge for all the cocoa industry players as the upstream sector experienced a declining trend in the 2000s; meanwhile, the downstream sector showed an increasing trend. The productivity, quality and sustainability of cocoa might be improved with the reduction of the upstream and downstream gaps in this industry (Mulyono, 2017).

Upstream activities for the cocoa industry in Malaysia are shown in Figure 1. Activity in the upstream division starts from land preparation until harvesting. It is important to address that proper management of upstream cocoa activities is a crucial element for better yields, as supported by Aboah *et al.* (2019), who emphasized that upstream disruptions will strongly impact the availability of raw materials, which leads to the cocoa supply chain problems. Moreover, to sustain cocoa production, the adoption of advanced growing practices must be maximized and not be hindered by insufficient technology transfer (Ahmad Kamil *et al.,* 2013). Several studies in conjunction with agricultural mechanization have been done on various crops such as paddy, wheat, apple, corn, onion and oil palm to provide a solution to minimize the problems faced in upstream activities (Amoozad-Khalili *et al.,* 2020; Isaak *et al.,* 2020; Kumawat & Raheman, 2022; Mokhtor *et al.,* 2020; Shi *et al.,* 2021; Shuib *et al.,* 2020; Zhang *et al.,* 2020).

While the objective of the technology implementation in agriculture is to reduce heavy work, labour and enhance productivity, the ergonomic perspective when proposing a novel technology must not be neglected. Bey-Temsamani *et al.* (2022), Salwei *et al.* (2022), and Taifa (2022) have agreed that ergonomics must be considered to increase the usability of the technology. In Malaysia, the research on ergonomics in other commodities such as oil palm, paddy and rubber is accessible (Md Tamrin, 2014; Myzabella *et al.,* 2019). The results of their works have benefited agricultural practitioners in improving the working condition of the industry. However, no prior studies were found to examine the ergonomics perspective in the cocoa industry.

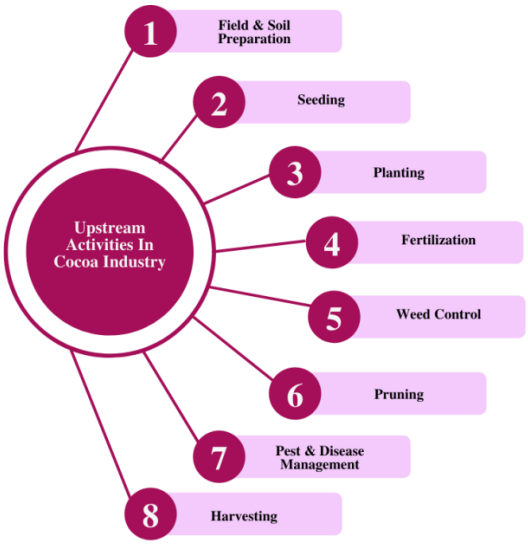

Figure 1: Upstream activities for cocoa industry

In the past few decades, many cocoa research activities have focused on downstream activities such as cocoa beans' pre-fermentation and fermentation treatments in order to solve certain quality or flavour problems. Thus, this paper explores the technology development in upstream activities for the cocoa industry. The author reviews the mechanization and digital agricultural development in upstream activities for the cocoa industry, ergonomics in agricultural activity and the challenges of technology implementation in the cocoa industry.

MECHANIZATION AND DIGITALIZATION IN COCOA INDUSTRY

Mechanization is defined as the use of technologies to replace human labour with animal and mechanical power (Daum *et al.*, 2022). It has the potential to drive future growth by ensuring the timeliness of operations and minimizing associated costs (Rahman *et al.*, 2021). Additionally, the use of mechanization is important when applying the inputs such as fertilizer and pesticides to a cocoa tree. On the contrary, some operations such as weeding, harvesting, sorting and cleaning are still manually operated (Rehman & Khan, 2019). Meless Siméon *et al.* (2019) suggested that the use of mechanization can make cocoa cultivation more attractive and profitable. Since the appearance of the agricultural tractor at the end of the 19th, the use of tractors in agriculture has increased tremendously (Melo *et al.*, 2019; Renius, 2020; Vogt *et al.*, 2018, Vogt *et al.*, 2021). However, there is a consensus that the power growth curve of these machines is hitting the asymptotic limit (Albiero *et al.*, 2022).

Digital farming can be described as the utilization of digital technology such as sensors, robotics and data analysis for the automation process in an agricultural chain (Ramin Shamshiri *et al.*, 2018). Due to the emergence of technologies such as the Internet of Things (IoT), smart farming is becoming a major interest for many researchers (Bökle *et al.*, 2022; Gharakhani *et al.*, 2022; Jerhamre *et al.*, 2022; Raj *et al.*, 2021; Tao *et al.*, 2021). Optimists believe that digital tools will empower farmers with knowledge, maximize agricultural productivity, and improve their access to upstream and downstream markets (Daum *et al.*, 2021; Fabregas *et al.*, 2019; Reardon *et al.*, 2019). However, some researchers have claimed that there is a need to study their economic implications, operationalization of the technologies in the field and environmental implications (Clapp & Ruder, 2020; Lowenberg-DeBoer *et al.*, 2020; Mao *et al.*, 2021).

In Malaysia, the technology used in the cocoa industry for upstream activities needs some improvement to be in parallel with the current trend of agriculture. Since cocoa commercial planting was introduced in the 1950s in Malaysia, various researches related to upstream activities such as improvement of fertilizer, soil and pest and disease management have been conducted by Malaysian researchers to improve the yields and quality of Malaysian cocoa beans (Adnan *et al.*, 2021; Tee *et al.*, 2019; Tee *et al.*, 2022). However, the mechanization and digitalization in upstream activities for the cocoa industry have rarely been studied. In the Cocoa Planting Manual provided by the Malaysian Cocoa Board, Lee *et al.* (2013) listed the recommended tools and lists of machinery used for cocoa tree planting, and it is presented in Table 1. It can be seen that conventional tools and machinery are favourably used throughout the cocoa planting cycle. Therefore, it is of interest to innovate, invent or develop the current tools used by the farmers to an advanced stage.

Smart farming is not new in agriculture, and much research have been introduced and evolved, with some of them were already applied on the field in different crops (Fernandes *et al.*, 2020; Gonzalez-De-Santos *et al.*, 2020; Martinez *et al.*, 2020; X. Zhang *et al.*, 2020). For cocoa, Adhitya *et al.* (2020) investigated a systematic approach to detect the classification of cocoa beans based on industry standards for processing cocoa beans. The author designed a smart farming framework concept scheme to explain their requirements and contributed to more reliable results. Additionally, they claimed that the study has enabled the use of IoT technologies and increased the security of the food supply chain.

Martinez *et al.* (2020) concluded in an analysis of information by using the exploration and deductive method that the proposal based on IoT is an efficient option for collecting, transporting, processing, and delivering information in the process of sowing and harvesting cocoa. On the other hand, Albiero *et al*. (2022) suggested that automated technologies help maximize agricultural operations by reducing the man-hour spent on dangerous and repetitive processes.

Lomotey *et al.* (2018) developed a mobile-based application called *CocoaGuard* to help the cocoa industry by assisting the farmers to easily access agronomic information, perform self-assessment of cocoa pod infestation, perform stock analysis of their production, and provide a forum space for the farmers to discuss cocoa-related issues. The results showed a hugely positive response, with more than 85% satisfied and finding the apps helpful; meanwhile, 100% expressed their interest in using the application.

Another technology development that is interesting to review and could be adopted in the cocoa industry is the detection of pests and diseases among crops. In fact, a 100% loss of cocoa yield might occur if the pest was left untreated (Adnan *et al.*, 2018). *Torai et al.* (2020) designed an early detection system for a plant by classifying the results as "healthy," "infected," "diseased," or "aged." The author concludes that hyperspectral imaging, probabilistic latent semantic analysis (pLSA), Bayesian network, and Artificial Intelligence (AI) technology enable the detection of the pests and diseases of their subject. This research is a good example of a remote sensing technology applied to agriculture that requires an extremely high data resolution.

Table 1: Summary of the activities, tools and machineries recommended to be used in cocoa planting (Ahmad Kamil *et al.*, 2013).

Activity	**Tools / Machineries**
Field preparation	Chain saw Machete Brush cutter Bulldozers Excavators
Seeding	Manual labour
Planting	Manual labour
Watering	Sprinkler Drip irrigation system
Fertilization	Fertilizer Spreader (Rozita *et al.*, 2017)
Weed Control	Lawn mower Machete Brush cutter Manual labour
Pruning	Secateurs Pruning saw Long knife Pole with modified scissor
Pest and Disease Management	Manual labour Knapsack sprayer Mist blower Tractor mounted with insecticide sprayer (Rozita *et al.*, 2018)
Harvesting	Secateurs Sharp curved knife Scissor-like tools attached to long pole Mini tractor (for collection)

ERGONOMICS IN AGRICULTURAL INDUSTRY

Ergonomics is the discipline concerned with the design of tools, machines and systems that consider human capabilities, limitations and characteristics. It is needed in engineering design, including agriculture, to reduce the risk of injuries, avoid errors and enhance productivity (Harari *et al.*, 2019; Sun *et al.*, 2019). Generally, ergonomics can be categorized as physical, cognitive and organizational, which are particularly effective in optimizing the engineering design. Physical ergonomics focuses on human physiology, anthropometry and biomechanics. Cognitive ergonomics deals with mental interaction, and organizational ergonomics is used to optimize policies, processes and risk management (Benos *et al.*, 2020). In agriculture, work-related musculoskeletal disorders (WMSDs), which are related to physical ergonomics, are common among all non-fatal injuries (Fathallah, 2010). Additionally, manual operations such as pruning, weeding and harvesting includes several risk factors such as awkward postures, repetitive motions, vibrations and lifting heavy loads (Benos *et al.*, 2020). These factors caused the WMSDs in the region of the low back and upper limbs as well as knee injuries (Çakmak & Ergül, 2018; Fathallah *et al.*, 2008).

Mechanization has helped to ameliorate the aforementioned injuries to a great extent. In addition, it

has been discovered that even a slight modification in ergonomic efforts resulted in a significant change in reported discomfort (Fathallah & Duraj, 2017). It can be seen when Ramahi & Fathallah (2006) introduced a long-handled hoe for manual weeding, and it aggressively reduced the flexion of the trunk. In view of more complex mechanization, a tractor was created to solve a variety of arduous tasks. Few components in tractors, such as operating button levers, steering wheels, and clutching and braking pedals, have solved some ergonomics issues in conventional agriculture (Benos *et al.,* 2020). On the other hand, most of the time, pruning is carried out in an awkward posture, which contributes to WMSDs. The common pruners may not fit with the anthropometry of farmers due to different heights of the tree or incorrect size of the tools. *Nurfadzilah et al.* (2019) have designed a pioneer tool in the cocoa industry called the *Multipurpose Agricultural Tool* that helps workers in pruning and harvesting in an efficient way that subsequently increases the production of cocoa. The introduction of this three-in-one tool might solve a few ergonomics problems in the cocoa industry, such as WMSDs, blisters, cut injuries and injuries while bringing the tools to the farm.

Despite the relative progress of agricultural machinery in minimizing production costs, enhancing the overall production cycle, and reducing the environmental impact, there are still several issues to be addressed (Lampridi *et al.,* 2019). Benos *et al.* (2020) found that high vibration due to the ground or engine operation in a tractor inevitably will cause discomfort to the driver and pain in the regions of the spine, low back, shoulders, hip, knees and neck. Thus, a few researchers suggested that human-robot collaboration by applying cognitive ergonomics such as perception, memory and decision making might solve the problems (Albiero *et al.,* 2022; Gualtieri *et al.,* 2022; Gualtieri *et al.,* 2021; Matt & Rauch, 2020). Apart from that, many researchers have developed a variety of apple harvesting robot prototypes that adopt cognitive ergonomics (Tian *et al.,* 2019; Zhang *et al.,* 2020; Zhang *et al.,* 2020). It is a systematic design that involves sensing, automation, mechanical design and machine vision that fulfill four basic procedures, which are data acquisition, image segmentation, feature extraction and object detection (Tian *et al.,* 2019).

The discipline of ergonomics is commonly overlooked. Moreover, the adoption of this discipline in agriculture is versatile and has a multidisciplinary topic that involves the identification of the risk factors for WMSDs, determination of root causes, assessment of ergonomics intervention, as well as development and implementation. Nonetheless, it contributes to the accomplishment of an optimal harmonized system, capable of minimizing costs, improving cooperation, productivity and product quality, as well as increasing worker commitment and job satisfaction (Christy & Duraisamy, 2020; Matt & Rauch, 2020).

CHALLENGES OF TECHNOLOGY IMPLEMENTATION IN THE COCOA INDUSTRY

The agricultural industry is currently experiencing a revolution named Agriculture 4.0 (Lezoche *et al.,* 2020; Wolfert *et al.,* 2017). This revolution has spurred a new direction of research in agriculture, and some potential challenges are significant for a review. This situation could provide some references for other researchers and can be used as consideration for further studies to improve the current practice on cocoa farms. This paper will focus on discussing on few major challenges, which are environmental, economic and technical challenges. They were identified during literature studies and believed might hinder the technological development of the cocoa industry.

The cocoa tree is a complex plant that needs a specific requirement to survive. It is prone to natural variability, unpredictability, and unanticipated circumstances (Bechar & Vigneault, 2017). In addition, any technology invented with the goal of sustaining cocoa production needs to optimize agricultural operations such as logistics, operations, geometry, efficiency, and safety. It seems to be a challenge to find the suitability of certain applications because different technologies have different characteristics and are only suitable for specific conditions (Tao *et al.,* 2021). However, this can be overcome by combining more than one technology in the developed system, and it is customizable to predict circumstances in order to fit the needs of the cocoa farmers (Jerhamre *et al.,* 2022; Kamienski *et al.,* 2019; Nam *et al.,* 2017). As an example, in the development of swarm robots that can be applied to many agricultural crops, Osaba *et al.* (2020) affirmed that combining a few technologies guaranteed the success of swarm robots in the field. The author listed intelligent sensing, combined with communication and organization features that are linked with the operationalization of the environment, as the key to having a successful swarm robot.

The implementation of any new technologies will need some investment. The high initial cost of the investment might cause a slow rate of innovation adoption since the profit margin in agriculture is already small (Elijah *et al.,* 2018). It is supported by

Bosompem *et al.* (2011), that highlighted the uncertainty in return of investment for technology innovation become one of the challenges that need to be considered. The uncertainty and fluctuating of world cocoa bean prices further worsen the scenario. The technology adoption in agriculture will succeed if the farmers believe that the technology provides a value that exceeds their physical and privacy costs, as well as their investment is worth of money they spend (Turgut & Boloni, 2017).

There are several technologies that have been developed recently in agricultural industries which can be adopted in the cocoa industry. However, the implementation of IoT will be more challenging in terms of technical issues whereby the data security, data reliability and customizability need to be addressed (Jerhamre *et al.*, 2022; Tao *et al.*, 2021). Although studies have been conducted by many authors, there is no clear solution on how the data should be managed, either technically or legally. However, to make the cocoa industry more data-driven and digital, Jerhamre *et al.* (2022) suggested securing the technical infrastructure and, at the same time, promising that sensitive data is not available to hackers. Besides that, the suitability of technology that is subjected to different geographical locations, soil types and climatic conditions also becomes the interest in terms of their technical solutions (Elijah *et al.*, 2018).

CONCLUSIONS

In conclusion, technology development in upstream activities, either in mechanization or digitalization for the cocoa industry, provides a huge potential for further enhancement. The increasing trend of adopting current technologies forces researchers to study the possible aspects. Additionally, the technology development of the cocoa industry in upstream activities should incorporate robust human motion, gestures, activities and cognitive to build sustainable and safe cocoa production. Finally, ergonomics risk assessment is vital for preventing work-related injuries and increasing the productivity of the cocoa industry. Primary data on ergonomics must be available to support future engineering design in order to provide a viable application for upstream activities in the cocoa industry. The environmental challenges, economic challenges and technical challenges that have been addressed in this paper should provide a general idea of how to adopt any existing technology to a dynamic and unstructured condition in the cocoa industry. Certainly, there is still a long way to go to establish safe and productive cocoa farming management. As a consequence, ergonomists, agriculturists, physicians, engineers and manufacturers need to intensively and systematically collaborate to improve and ensure sustainable productivity in this demanding and promising field.

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