

Review Article

A Review of Mechanization and Automation in Malaysia's Pineapple Production

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Abstract: This work reviews the current state of the art for pineapple production in Malaysia from mechanization and automation. It examines the issues and challenges facing this industry. The review has led us to the conclusion that pineapple production still relies heavily on manual labour. The problems facing this industry are no different from other food crops in that low yield labour and high cost are the primary issues that need to be tackled. Although numerous engineering research work to overcome production issues have been done for rice and maize, engineering research for pineapples has been scarce. The lack of engineering research literature on this crop presents an opportunity for the scientific community to invest effort in this relatively untapped industry. This work further proposes areas where Industry 4.0 technologies can be exploited to increase productivity and reduce input costs. Cyber-physical systems that could address issues in planting, crop maintenance, and harvesting are put forth as a possible solution.

Keywords: Pineapple; Industry 4.0; Cyber-Physical System; Smart Agriculture; Mechanization

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1. Introduction

Pineapples are one of the most consumed fruits globally (De Ramos & Taboada, 2018). Apart from their pleasant fragrance and sweet taste, pineapples are high in nutrition and minerals (Mohd Ali *et al.*, 2020). Pineapples (*Ananas Comosus*) are suitable to be planted in tropical countries. Its biggest producer in Costa Rica, followed by the Philippines and Brazil. Table 1 ranks countries based on their production size.

Pineapples can be consumed fresh, canned, or made into a juice (Adzahan *et al.*, 2011). The variety of downstream products derived from the fruit makes it an attractive commodity (Mohd Ali *et al.*, 2020). The production value of pineapple in Malaysia was USD153 million (RM621 million) in 2019 (MoA, 2020).

Table 1. Top 5 countries producing pineapple (Source: FAO, 2020)

Country	Volume (tonnes)	Rank
Costa Rica	3,328,100	1
Philippines	2,747,860	2
Brazil	2,426,530	3
Indonesia	2,196,460	4
China	1,727,610	5

The Malaysian government listed pineapple as one of ten premium fruits. Realizing the tremendous potential for the export market, the government encourages farmers to venture into this industry, offering various schemes such as farmland ownership and seed grants (MPIB, 2019).

Although the response has been encouraging, there are issues regarding the production value chain that hamper the full potential of this industry. Pineapple production is very labour intensive (PIP, 2011). As agriculture is often perceived as a 3D (dirty, challenging, and demeaning) occupation, attracting young people to the sector is challenging. This is exacerbated by urbanization, causing people to move to the cities, making labour a scarce commodity (FAO, 2020). Malaysia has always relied on cheap foreign labour to make up for the shortage of domestic workforce. However, due to the recent pandemic of COVID-19 and competition from neighbouring countries, foreign workers are becoming less of a reliable source of labour.

The high cost of production is also an issue that needs to be tackled. Profit margins are affected by inefficient management and the crop (Raziah, 2009). Blanket use of agricultural inputs can lead to wastage and loss of income. Overapplication of fertilizer and chemicals is also destructive to the environment (Havlin & Heiniger, 2009). Suitable solutions have to be found in order to overcome these challenges.

This work aims to review the state of the art of pineapple production in terms of mechanization and automation. Section 2 describes the pineapple production value chain, from land preparation to post-harvest handling. It describes the status of mechanization and automation in each production stage. Section 3 reviews some of the automation technologies for different crops. Section 4 discusses the potential areas in the pineapple production value chain that Industry 4.0 technologies can help address the industry's issues. We finish this

review with Section 5, which gives an overall conclusion of the ideas presented in this manuscript.

2. Status of Mechanization and Automation in Pineapple Production

Figure 1 shows the stages of pineapple production. Land preparation is the first step in ensuring proper conditions for crop production. Pineapples can be planted on a variety of land (Hossain, 2016). It relies mainly on rain-fed irrigation. Hence the slope of the land needs to be controlled. Pineapple suckers, slips, or crowns are planted on a bed. The beds need to be prepared such that there is ample space for each planting material to grow.

After the planting material is planted, the next stage of crop production is crop care and maintenance. The crop needs to be taken care of so that it has the best chance of survival. Fertilizer is applied every 14 days (PIP, 2011).

Pesticides and herbicides are also used to control pest and disease attacks. After about 11 months, a specified amount of hormone is sprayed on each plant to stimulate fruit growth. The fruits take about 14–16 months from planting to mature (Bartholomew *et al.*, 2012).

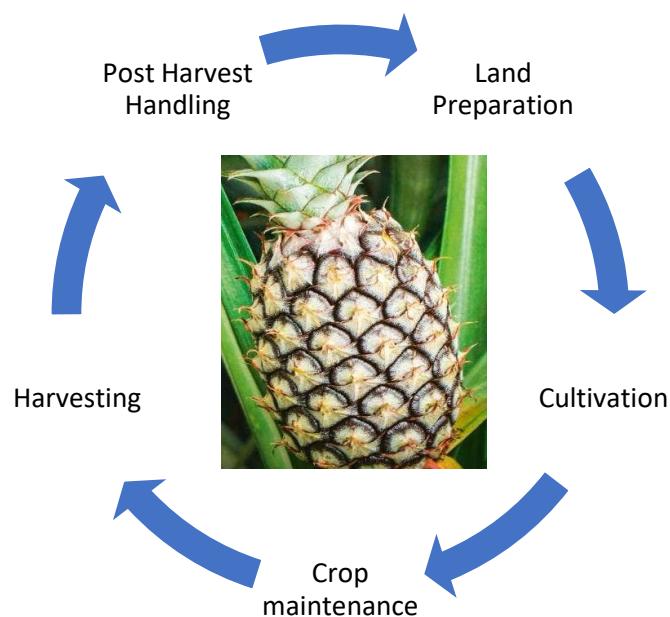


Figure 1. Stages of pineapple production.

The harvesting stage follows crop care and maintenance. At this stage, pineapple fruits are harvested based on their maturity index. This stage continues until all fruits have been harvested.

The last stage of crop production is the post-harvest handling process. For fresh consumption, the fruits are graded and sorted based on their size. For canning, the fruits

undergo further processing before being shipped out to customers all over the world (PIP, 2011).

The status of mechanization in pineapple production varies across the planting stage (Cotabato, 2015). In Costa Rica, the largest pineapple exporting country globally, machines are used for land preparation, crop maintenance, and crop residue removal (Sun , 2011; Nennie & Boer, 2018). In the crop maintenance stage, chemicals are applied using boom sprayers mounted on a tractor (Dorey *et al.*, 2018). The tractor travels across the field and sprays the crop using a blanket rate. This is also true for hormone application. In contrast, planting and harvesting fruits, as well as weeding, are still semi-mechanized.

Compared to Costa Rica, Malaysia's mechanization situation is very similar. In the land preparation stage, tilling of the land and bed preparation is fully mechanized. Malaysian researchers have done work to address the issue of mechanization. In the planting stage, a semi-mechanized planter was developed (Hassan *et al.*, 2009; Ahmad *et al.*, 2013). Pineapple suckers are loaded in a bin mounted on a tractor. Two operators sit at the rear of the bin, take the suckle one by one, and plant them in the ground while being pulled by a tractor. In the harvesting stage, a conveyor is mounted on a tractor and acts as an aid to harvesting. Workers follow the slow-moving tractor across the field and harvest mature fruits manually (Hamid & Kassim, 2013). The harvested fruit is then placed on the harvesting aid, where the conveyer brings it to a collecting bin also mounted on the tractor. The pineapples are dipped in water for cleansing and graded using a grading machine in the post-harvest handling stage. Table 2 shows the level of mechanization and automation at every stage of crop production.

Looking at the crop production stages, it can be seen that the planting and harvesting stages rely heavily on manual labour. In the planting stage, suckers loaded into a bin varies in size.

Table 2. Mechanization and automation level at every crop production stage.

Stage	Mechanization Level
Land Preparation	Fully mechanized
Cultivation	Semi-mechanized
Maintenance	Semi-mechanized
Harvesting	Semi-mechanized
Post-harvest	Fully mechanized

The varying size makes it challenging to automate the process of planting the suckers. In the harvesting stage, workers use a long machete to chop off the bottom of the fruit from the plant. A successful mechanized method has not yet been developed for this task. Research has been done to tackle this issue; however, only computer simulations were done, and a

working prototype has not been tested on the field (Li *et al.*, 2010; Mohammad *et al.*, 2012; Li & Wang, 2013).

Surprisingly, only a handful of research has gone into modernizing pineapple production. Issues faced in this industry are similar to the ones faced in other crops. Inefficient farm management is a prevalent problem among all crops. Labour shortage is also a common problem in all agricultural crop production. Overuse of chemicals is another problem faced by the industry (Savci, 2012; Patra *et al.*, 2016). One reason is that this sector relies heavily on industry players and is not seen as a staple crop by governments. Therefore, governments are reluctant to provide incentives for producers. However, the Malaysian government has realized the export potential for pineapples and has encouraged more farmers to be involved in this crop. The Malaysian government has provided incentives to modernizing this sector through mechanization and automation to cut costs and optimize yield (MPIB, 2019).

3. Automation Technologies for Field Crops

Unlike pineapples, other crops have received a substantial amount of attention from the research communities. Cereal crops such as wheat, maize, and paddy have seen much activity in crop production research (Ikenaga & Inamura, 2008; Schepers & Holland, 2011; Shao *et al.*, 2012). This section reviews some of the work done to solve problems in each production stage for other field crops using automation.

In the land preparation stage, determining soil properties can be useful in making operation decisions on the farm. For example, soil fertility indicates the yield that can be expected and the amount of fertilizer that must be applied. Fertility maps can be generated to determine a yield target for an area. A method to detect soil nutrient content for paddy fields was developed (Aliah Baharom *et al.*, 2015). An optical probe was mounted at the bottom of a soil penetrator. The soil penetrator digs into the soil and moves across the field. The spectral reflectance of the light on the soil was measured, and a correlation study was done to determine the relationship between several nutrients, such as nitrogen and spectral reflectance. The author reported a correlation of determination $R^2 =$ of 0.8 for nitrogen (N), $R^2 = 0.4$ for potassium (P) and $R^2 = 0.4$ for phosphorus (K). Other researchers used alternative methods to detect soil nutrient content (Adamchuk *et al.*, 2004; Gholizadeh *et al.*, 2012; Peets *et al.*, 2012; Serrano *et al.*, 2014).

The topography of the land is essential in deciding whether the farmland needs to be leveled. For example, in paddy production, a flat field is desirable in controlling weedy rice (Agarwal & Goel, 1981; FAO, 2015). An undulating land can cause yield loss due to weedy rice. A method to determine the leveling index of a paddy field was developed (Abu Bakar *et al.*, 2019). A GNSS antenna was mounted on a smoothing flap of a tilling implement pulled by a tractor. At the final stage of land tilling, the GNSS antenna measured the land height in the field. This was done repeatedly as the implement was pulled through the land. The density

of the measurements could be set through an onboard computer. Once the measurements were done, the data was processed to generate a seed application treatment map. This map could then be used by a variable rate applicator when applying seeds.

Much research has been done on wheat, maize, and paddy in crop cultivation and maintenance. The research concentrated primarily on specific nutrient management of a field. MARDI developed a precision farming system for paddy production (Abu Bakar, Abdul Rahman, *et al.*, 2019). An unmanned aerial vehicle was used to acquire below cloud images of paddy fields. The colour of the plant canopy indicated the nitrogen content in the plant. A model was used to correlate the images taken with the status of crop nutrients. A fertilizer application treatment map was generated to allow site-specific nutrient management. Similar work can be seen in (Zhang *et al.*, 2002; Xie *et al.*, 2003; Mahajan *et al.*, 2014).

An optical sensor was used to sense the nitrogen (N) status and develop a variable rate application strategy for rice (Bijay-Singh *et al.*, 2015). An N management strategy based on the GreenSeeker canopy sensor (NTech Industries, Inc., Ukiah, California, USA) was compared to a management strategy based on conventional farmers' practice. It was shown that the sensor-based management strategy obtained similar yields but with a reduced N rate of up to 21.7%. However, the sensor could only be used at the panicle initiation stage, and sufficient N application had to be ensured at earlier stages of growth using a conventional method.

An active canopy reflectance sensor was used to estimate rice plant N status (Cao *et al.*, 2018). This sensor emits light and measures the reflectance of three spectral bands from a plant canopy. In contrast, the GreenSeeker canopy sensor had only two spectral bands. The authors derived several vegetation indices from the sensor measurements. They found that some of the indices had a good correlation with the nutrition index (NNI), which indicates the crop N content. The best vegetation indices had an R^2 of 0.76. The authors found that using multiple linear regression did not outperform the best indices and suggested that more studies were needed to explore other synthesizing data methods. Recent advances in machine learning showed that it was possible to synthesize many inputs to achieve good results (Chlingaryan *et al.*, 2018; Kamilaris & Prenafeta-Boldú, 2018).

Holland and Schepers (2013) used the active canopy reflectance sensor to estimate the N content for corn. They incorporated a simple learning algorithm to develop a variable rate fertilizer application system using a virtual reference concept. This system continuously updated a histogram to calculate the reference vegetation index instead of an N-rich strip in the field. The authors compared two strategies of variable rate fertilizer application using the virtual reference concept. The first strategy was the Drive-First approach, where the vegetation index was determined before N application was initiated by driving around in the field to collect sensor data. The second strategy involved the Drive-and-Apply approach. The fertilizer was applied "on the go" while the tractor moved through the field, collecting sensor data to update the histogram. They found that the Drive-and-Apply approach over-applied N

by 15% compared to the Drive-First approach when starting from the part of the field where the plants were most vigorous. The system underapplied N by about 25% when starting from the least vigorous part of the field.

An early warning system to detect pest attacks for paddy was developed (Masarudin *et al.*, 2019). A light trap containing a roll of sticky tape was placed strategically across an area of interest. The light trap was turned on-off at night in ten-minute intervals. This was done to attract brown planthoppers from nearby fields. The sticky tape samples were collected the next day for analysis. The samples were put in an image recognition device to detect and count the number of brown planthoppers on a particular sample tape. The system would then trigger a warning to participating farmers in the area via phone messaging if a threshold level were passed. The farmers would then be advised to take necessary measures to control the pest attack. Similar work to detect and control pest and disease attacks can be seen in (Kim *et al.*, 2017; Nettleton *et al.*, 2019; Partel *et al.*, 2019)

In the harvesting stage, monitoring the yield of a particular area can help determine farm management decisions for the following planting season (Das *et al.*, 2015; Fulton *et al.*, 2018; Toscano *et al.*, 2019). Many commercial products such as Trimble and Ag Leader offer systems installed on existing combine harvesters and used a yield monitoring system to optimize yield. Data from several seasons were analyzed, and a decision support system was developed to decide on a variety to use for a particular area. This increased the yield of the area.

4. The Potential for Industry 4.0 Technologies in Pineapple Production

Industry 4.0 is a term to describe the fourth industrial revolution concept (Lasi *et al.*, 2014). The first industrial revolution started with the introduction of the steam engine. The second revolution followed when electricity was discovered. The third industrial revolution happened when computers and automation were introduced in the production line. The fourth industrial revolution is powered by three technological pillars; automation, connectivity, and intelligence. These three pillars allow society to be interconnected with businesses and machines. This revolution will allow the personalization and customization of products (EDB Singapore, 2018). Automation allows products to be made by machines without human intervention. Connectivity allows production processes to be connected. The internet powers machine-to-machine and machine-to-human communication. Intelligence allows products and processes to be executed autonomously based on vast amounts of data.

A culmination of technologies makes up Industry 4.0. Artificial intelligence, big data analytics, augmented reality, and the internet of things are among the enabling technologies of Industry 4.0 (Koppen-Seliger *et al.*, 1995). Examples of such technologies can be seen in online food ordering and ride-sharing apps. The overarching advantage of the concept is in its modularity. A production value chain can be scaled based on demand and resource availability.

Pineapple production is no exception. Even though pineapple production-related technologies can be categorized as having second industrial revolution characteristics, there is a huge opportunity to push the whole sector towards Industry 4.0. In the following, we describe the potential of implementing innovative technologies.

In the land preparation stage, the technologies described in the previous section regarding soil nutrient management can be applied to pineapple production. The work done by (Aliah Baharom *et al.*, 2015) has addressed the automation part of Industry 4.0. It can be enhanced to include connectivity to transmit data directly to the cloud. An intelligent decision support system can then be developed to generate a soil fertility map. These maps serve as the input to an augmented reality device worn by a farm manager to diagnose a specific location.

Autonomous machines can prepare the land. Smart tractors carrying implements can communicate and negotiate with other tractors on what tasks need to be done, such as bed preparation and tilling of the land.

In the crop cultivation and maintenance stage, technologies such as (Schepers & Holland, 2011; Abu Bakar *et al.*, 2019; Masarudin *et al.*, 2019) mentioned in the previous section can be implemented to plant and manage the pineapple plants. Again, autonomous tractors may be used to plant pineapple suckers, eliminating the need for human workers. The precise location of each suckle can be specified, making it easier for further maintenance. This gives the ability to phenotype each plant.

It would also be possible to maintain and monitor the crop autonomously (Kamal & Amin, 2010; Yao *et al.*, 2012; Huuskonen & Oksanen, 2018). Since the location of each plant is known precisely, unmanned aerial vehicles (UAV) can autonomously carry out scouting tasks and relay the information back to an intelligent decision support system located in the cloud (Wolfert *et al.*, 2017). The decision support system could then prescribe intervention actions to autonomous field robots (e.g., UAVs and intelligent tractors). This would presumptively be in the form of how much fertilizer and chemicals to spray for a specific pineapple plant. It could also decide when and where to apply hormones to stimulate fruit growth. The autonomous field robots would work in a multi-agent system carrying out these tasks.

In the harvesting stage, collaborative robots or cobots have the potential to be used to aid harvesting. As harvesting pineapples require a sequence of movements, these robots could be taught this sequence (Wang *et al.*, 2012). Mounted on a harvesting conveyor, they can check diligently for mature fruits to harvest.

The potential applications of Industry 4.0 in pineapple production mentioned above are just some of the areas that can be explored. Pineapple production is one of the rare, relatively untouched industries that provides an opportunity for researchers and academicians to explore further.

5. Conclusions

This work reviewed the state of pineapple production in Malaysia. It can be deduced that the level of mechanization through the production value chain varies with each stage. There is a lack of literature regarding engineering research in this area.

Considering engineering research done in other crops, the potential implementation of Industry 4.0 related technologies in pineapple production was discussed for some of the crop production stages. The pineapple industry provides a golden opportunity for research and development to scientists.

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