The FFTC Journal of Agricultural Policy
http:/ap.fftc.org.tw/e-journal

Current Situation, Direction, Policy Support, and Challenges of Plant Factories with Artificial lighting (PFAL) in Thailand

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Received March 31, 2022; Accepted July 22, 2022

ABSTRACT

One of the greatest challenges in the 21st century is how to sufficiently and sustainably feed the world population with nutritional and safe food. Plant factory with artificial lighting (PFAL) is a closed plant production system. Regardless of environments outside, PFAL is considered as an alternative technology for food and feed production with high efficiency, high quality and low risk to health of customers. Therefore, the aim of this review is to provide the basic information on the current situation, direction, government policy and support and challenges of PFAL technology in Thailand. PFAL was introduced to Thailand in the early 2000s for academic purposes. Several universities and research institutes have paid more attention to research and development on plant production in PFAL as well as developing new PFAL systems. Moreover, PFAL is now attracting great attention among plant producers because it creates new markets and business opportunities. The government has launched a policy of using advanced technology for strengthening the agriculture sector, and PFAL technology is considered as a frontier technology in the agricultural sector to be an engine driving BCG (bio-economy, circular economy and green economy) model including the establishment of large-scale plant factories as for The Eastern Economic Corridor of Innovation of Thailand or EECi which have planned to establish large-scale plant factories for demonstration and training sites that is a part of technology implementation. The Board of Investment of Thailand or BOI has added the PFAL as a new activity eligible for BOI incentives to promote this technology. However, the challenges of this technology are high initial construction and production costs. Moreover, shortage of knowledge, know-how and best practices in plant production under controlled environments and lack of skilled operators may be the problems encountered on how to adopt this technology for plant production on an industrial scale. To ensure the sustainable growth of the PFAL industry, the government should support the business through research investment and subsidy for PFAL construction, PFAL and PFAL-related technology development as well as promoting the technology for commercial scale plant production.

Keywords: bio-economy, closed plant production system, environmental control, medicinal plant, plant factory

INTRODUCTION

One of the greatest challenges in the 21st century is how to sufficiently and sustainably feed the world population with nutritional and safe food. According to the world population prospect of 2019 which was reported by the United Nations (UN, 2019), the world population is estimated to be 7.7 billion in 2015, and projected to grow to more than 9.1 and 11.2 billion by 2050 and 2100, respectively (FAO, 2017). The rapid

growth in population, urbanization and ageing of people have shaped socio-economy and agricultural production. A huge demand for food production is rapidly increasing, but food supply especially from agricultural production is slowly increasing; the increasing supply seems not able to meet the increasing demand. Shortage and competition of natural resources such as agricultural land and water from agriculture, industry and cities are important limiting factors for agricultural production. Since the green revolution in 1950 until now, the expansion of agricultural lands is still a major driving force for deforestation, which clearly reveals that an increase in agricultural lands by deforestation is not a choice for increasing productivity. Moreover, climate change and variable environments that are not favorable for plant growth and productivity, significantly reduce yields of field crops and horticultures, and these make the situation of food shortages even worse. Today, not only food security is very important, but also nutrition security. Malnutrition, i.e. undernutrition, micronutrient deficiencies and overweight and obesity are still the major causes of various diseases and deaths especially in young children around the world (UNICEF, WHO & World Bank, 2016). In addition, unsafe foods including contaminated foods with heavy metals, microbials and pesticides have become serious problems to public health. Therefore, how to feed the world population is a challenge in the invention of a new agricultural cultivation system that sustainably improves agricultural productivity, nutrition and/or functions of foods, and resource use efficiency, and at the same time protect health as well as the natural environment.

Plant factories as closed plant production systems or indoor vertical farms, are built of warehouse like structures equipped with thermally insulated walls, cultivation systems having multiple shelves, artificial lighting, and other necessary devices such as air conditioners, air ventilation, CO_2 and nutrient supply and control units (Kozai *et al*., 2020). This plant production system could be used to continuously produce plants under controlled environments, regardless of outside environments, allowing anywhere and anytime production. The major environments being controlled to promote plant growth and development are light (intensity, spectrum and period), CO_2 concentration, nutrients, temperature, humidity and wind speed. In open field and greenhouses, the previously mentioned environments are not controllable. Hence, optimally controlled environments in plant factories could promote growth and development of plants, resulting in higher yield than those grown in open field or in greenhouses. Being able to manipulate environments stably and precisely, the plant factories allow producing high quality products of medicinal plants and functional vegetables either enriched with desired phytochemicals for pharmaceutical and cosmetic industries or lowered undesired substances such as low-potassium vegetables for kidney disease patients (Kameoka and Hashimoto, 2019; Nakamura and Shimizu, 2019; Zobayed, 2020). With multiple shelves stacked vertically inside the plant factory, the cultivation system increases high land use efficiency. The plant factories with proper design and management can provide high resource use efficiency (CO_2, water, fertilizers, etc.) due to recycling system of the resources, and can be achieved with minimum of pollutant emissions and wastes. Moreover, produced in almost nearly airtight warehouses with intensively controlled hygiene environments, the plant products are free from pesticides and less contaminated with microbes, generally 10^2 - 10^6 colony conforming unit per gram (CFU g^{-1}) resulting in longer shelf life (Kubota, 2020). Being built anywhere regardless of solar light and soil, plant factories can reduce energy for transportation when built near urban areas. However, there are many disadvantages of plant factories, and the disadvantages are the high initial and production cost. The high initial cost is for the construction of building, materials and equipment. The high production costs are mainly for electricity and labor (Kozai and Nui, 2020). The better design, skill of labor force and management could help in reducing initial and production costs. For example, a better design of the lighting system (placement of light bulbs or tubes) can increase light intensity and improve light distribution on cultivation panels. On the other hand, the better design can reduce the number of bulbs or tubes in cultivated shelves. The reduced number of bulbs or tubes could reduce not only the initial cost for lighting system in the PFAL construction, but also the production cost since electricity charge for lighting is one of the major production costs (Kozai *et al*., 2020). Other challenges of having plant factories are breeding new crops suited for plant factories, optimally controlling environment to meet the best produce (or meeting crop requirement), culture information, and marketing of produce.

Thailand is a resource rich country with high potential to be a “kitchen of the world,” even though the agricultural sector of Thailand is contributing to only about 8% to the national GDP. The Thai government has addressed a policy on food security, quality and safety that Thai citizens have the right to receive enough quality and safe food. However, the Thai National Food Committee (TNFC) revealed that the threatening factors to food security, quality and safety of Thailand are shortages of resources for

agricultural production, i.e. land use, water and labor. In addition, climate change also threatens food situation by lowering agricultural productivity. There is immense increase in demand of high quality medicinal plants or herbs as supply for industries of pharmaceutical and cosmetics especially in the crisis situation of expansion of plagues. The major encountering problem for high quality herb production is instability of production among seasons and instability of quality (concentration of bioactive compounds). In Thailand, share of urban population to total population has increased from 42% in 2009 to 50% in 2019 (https://www.statista.com/statistics/455942/urbanization-in-thailand/). This urbanization causes big problems of not only labor shortage in agricultural production, but also relocation of agricultural markets resulting in higher cost of logistics, subsequently, the total cost of products. In order to solve the previously mentioned problems and to achieve the mission of addressed policy of the government, plant factories may be the alternative technology. Moreover, plant factories are now attracting great attention among plant producers because they create new markets and business opportunities. For example, fresh vegetables with less bitter taste can be produced under controlled environment in plant factories; this product is good for children and can be sold at a higher price. One big problem of exporting fresh vegetables and herbs is being rejected due to contamination with heavy metals and pesticides (Commission Regulation (EC) No. 669/2009 edited by Commission Regulation (EU) 212/2010). Production of fresh vegetables and herbs in plant factories can control and reduce the contaminants efficiently, and could be an alternative for solving export problems.

Therefore, this article briefly describes the current situation, direction, policy support and challenges of plant factories (mainly, plant factory with artificial lighting: PFAL) in Thailand.

CURRENT SITUATION OF PFALS IN THAILAND

The plants produced in closed or semi-closed production systems started at the late 1980s. Greenhouses and glass houses have been used for plant production in closed or semi-closed environment. In the early 2000s, PFAL has been introduced to Thailand, mainly for research and development (R&D) in universities and research institutes. A few researches on PFAL were conducted by companies. During the last few years, there has been immense interest in PFALs not only for R&D but also for plant production in commercial scale. Therefore, in this section, the current situation of PFAL in Thailand including the R&D of the government and private sectors are described. Furthermore, commercialization and related business on PFAL are discussed.

Research and Development

The PFAL R&D in Thailand started in the early 2000s. Since then, the conduct of R&D continued during the last two decades (Table 1). At Mahidol University, the mini PFAL called 'Plantopia was established in 2002 and used for researches focusing on investigating the environmental effects on growth and phytochemical substances of medicinal plants. In 2005, the container-type PFAL was constructed at Kanchanaburi Campus of Mahidol University, and applied to study of high-value leafy vegetables, as well as to develop environment control systems including some environment control devices, e.g., sensors and controllers. Recently, Mahidol University collaborated with Chiba University, Japan which established MU-CU PFAL research and training center for developing a pilot model of mobile PFAL for industrial scale production of leafy vegetables and medicinal plants (Chintakovid and Supaibulwatana, 2020). In 2008, the National Center for Genetic and Biotechnology (BIOTEC) started a contracted research with a private company to grow leafy vegetables (leaf lettuces) in a 2×3 m^3 PFAL equipped with fluorescent lighting in order to study cost/benefit analysis. In 2018, the BIOTEC received a BigRock project funding from Thai Government to establish a PFAL with production area of 915 m^2 and a model-type community scale PFAL to develop the advance technology for production of high quality herb and functional vegetables (Figure 1) (Chintakovid and Supaibulwatana, 2020). At present, researches are focused on the Thai traditional herbs, i.e. Asiatic pennywort (*Centella asiatica*), king of bitter (*Andrographis paniculata*), Holy basil (*Ocimum tenuiflorum*), and leafy vegetables. Maejo University, one of the leaders in agricultural research, started the research on petunia seed production in 2012, then PFAL system was applied to produce high quality seed of petunia and other flower crops (Sakonwaee *et al*., 2017). The King Monkut' University of Technology North Bangkok (KMUTNB) has conducted the production of organic vegetables using PFAL system since 2015. Kasetsart University, an agricultural academy, established a container-type PFAL facilitating research on phenotyping and plant production of orchids and herbs in 2018. Furthermore, they constructed two

PFALs with more than 128 m^2 planting area for high-quality plant production serving cosmetic industry. Civic media Co., Ltd., one of the leading companies in LED business, has been interested in developing suitable LED for plant production. The company started researches on effects of light spectrum on growth and development of leafy vegetables and strawberries. In 2019, King Monkut's University of Thonburi applied PFAL to produce high quality young sprouts of vegetables and herbs, and Government Pharmaceutical Organization (GPO) has studied the production of Marihuana (*Cannabis sativa*) in a PFAL (Table 1). Recently, the King Monkut's Institute of Technology Ladkrabang has constructed container type PFALs for researches on plant production under controlled environments.

Table 1. Plant Factories R&D on plant production in Thailand

	University, Research institute and business sector	Year of beginning R&D	R&D	References
1	Mahidol University	2002	Herbs & leafy vegetables	Chintakovid and Supaibulwatana, 2020
2	BIOTEC[c]	2008	Thai herbs & leafy vegetables	Chintakovid and Supaibulwatana, 2020
3	Maejo University	2012	Petunia & strawberry	Chintakovid and Supaibulwatana, 2020
4	KMUTNB[b]	2015	Organic vegetables	https://www.kmutnb.ac.th/news/university-news (accessed April, 2021 – in Thai)
5	Kasetsart University	2018	Herbs & leafy vegetables	Chintakovid and Supaibulwatana, 2020
6	Civic media Co., Ltd.	2018	Leafy vegetables	https://ledfarm.co.th/ (accessed April, 2021 – in Thai)
7	KMUTT[c]	2019	Vegetable sprout (microgreen)	https://pr.kmutt.ac.th/pr2/research-innovation-news (accessed April, 2021 – in Thai)
8	GPO[d]	2019	Cannabis	https://www.gpo.or.th/view/51?lang=en (accessed April, 2021 – in Thai)
9	KMITL[e]	2020	Leafy vegetable	https://www.agrowlab.com/portfolio

[a]National Center for Genetic Engineering and Biotechnology, Thailand
[b]King Monkut's University of Technology North Bangkok, Thailand
[c]King Monkut's University of Technology Thonburi, Thailand
[d]The Government Pharmaceutical Organization, Thailand

Plant factory R&D in PFAL system, devices, machines and artificial intelligent systems have been started since 2010. Growlab Agritech (Thailand) Co., Ltd. was funded by National Innovation Agency (NIA) for development of PFAL system, advised by Mahidol University. They also formed a start-up business of indoor hubs with specially designed LED lighting system (Chintakovid and Supaibulwatana, 2000). Agro Intelligent Co., Ltd. started their business of construction and control system in PFALs as well as in smart greenhouse. Collaborated with Hanmo Co., Ltd., Japan and Mahidol University, Agro Intelligent Co., Ltd. developed household type plant factories. The GROBOT model, a household PFAL with smart device and automated system, has been introduced to customers who are interested in high quality vegetables in their houses or condominiums. The King Monkut' University of Technology North Bangkok developed an innovative PFAL system for production of organic vegetables and herbs. In 2016 Mahidol University paid high attention to researches on cultivation system, lighting systems, control systems and data storage and analysis system as well as established a joint collaboration with Chiba University, Japan in PFAL Research and Training Center, located at the Faculty of Science. Civic media Co., Ltd. and AgroLab Co., Ltd. are the two PFAL manufacturer companies leading in the innovation and design of PFAL construction, lighting system, cultivation system, as well as control device and automation systems in PFALs. They provide many customers on-demand PFAL systems, not only with closed plant production systems but also semi-closed and open plant production systems such as smart greenhouses and microcontroller devices.

In conclusion, R&D on PFALs in Thailand during the last two decades can be divided into 3 main topics: 1. Effects of controlled environments on growth; development and phytochemicals of vegetables and herbs; 2. PFAL system including constructs, cultivation system, lighting systems, control system; and 3. PFALs management for applying PFALs technology and internet of things (IoT) to produce plants industrially with lower production costs.

Figure 1. PFAL for R&D in pilot scale production of functional vegetables and herbs at National Center for Genetic Engineering and Biotechnology (BIOTEC), Thailand
Source: author.

Table 2. Plant Factory R&D on PFAL system, related devices and artificial intelligence systems in Thailand

	University, Research institute and business sector	Year of beginning R&D	R&D	References
1	Growlab Agritech (Thailand) Co., Ltd.	2010	PFAL system	Chintakovid and Supaibulwatana, 2020
2	Agro Intelligent Co., Ltd.	2015	Construction and control system	Chintakovid and Supaibulwatana, 2020
3	KMUTNB[b]	2015	PFAL system	https://www.kmutnb.ac.th/news/university-news (accessed April, 2021 – in Thai)
4	Mahidol University	2016	Micro controller, Robot & sensors	Chintakovid and Supaibulwatana, 2020
5	Civic media Co., Ltd.	2019	PFAL system	https://ledfarm.co.th/ (accessed April, 2021 – in Thai)
6	Agrowlab	2020	PFAL system	https://www.agrowlab.com/

[b]King Monkut's University of Technology North Bangkok, Thailand

PFAL business in Thailand

Since PFAL technology was introduced to Thailand in the early 2000s, it is attracting attention especially in

agricultural business. This may be because it creates a new market for agricultural products, e.g. clean and safe products (without toxic contaminants), and high quality raw materials for medicinal and cosmetic industries. To date, there have been more than 7 companies employing PFALs for high-quality and safe plant production (Table 3). The noBitter Co., Ltd. was founded in 2018 as a start-up company, constructing small commercial plant factories located in urban areas around Bangkok, Thailand. They have been producing high-quality and hygienic vegetables, e.g. kales (*Brassica oleracea* var. sabellica) for city people. The trademark 'noBitter' represents the quality and taste of vegetables they produced. WangreeFresh® is a trademark of a startup company funded by NIA to develop a prototype of PFAL. In 2018, a successfully designed PFAL was built at Wanree Resort, Nakoh Nauok, Thailand. With planting area of 100 m^2, the PFAL of WangreeFresh has produced many leafy vegetables such as kale, greenoak, etc. Moreover, they have started the Siam Pun Suk plant factory project at Prabath Nampu Temple, Saraburee province. In this project, a large scale PFAL with 1,800 m^2 planting area is under construction. Civic media Co., Ltd., a company leading in LED products, has created a new line of their business; PFAL system and products. They mainly produce fresh leafy vegetables with a trademark of 'LEDFARM'. They have invested money not only for plant production from PFALs but also for research and development on PFAL to find the best solution for their customers. VT Namnueng is a Vietnamese restaurant company producing Vietnamese style foods (www.vtnamnueng.net), which require large quantities and high quality of various vegetables. In 2020, they invested more than 100 million Baht (US$3.2 million) to build a large scale PFAL with production capacity of 1,000 kg fresh veggie/day to produce in demand vegetables such as lettuce (*Lactuca sativa*), kitchen mint (Mentha × villosa Huds), and culanttro (*Eryngium foetidum*). The technology for building VTnamnueng PFAL is from a Japanese company, Hanmo Co., Ltd. After construction, this PFAL will be the biggest PFAL in Thailand. Recently, medium-scale plant factories (production capacity of 200-500 kg/day) have been established by Barramepirum Co. Ltd. and Plant A Co., Ltd. (farm on the moon) for high quality vegetables and edible flowers. Recently, Thailand has pushed to scrub cannabis from the country's narcotics list. This helps in promoting the plant factory technology for cannabis production under controlled environment for medical grade of cannabis extract. For example, the golden triangle group of companies has constructed a giant plant factory for hemp production.

The four companies including Agrolab Co., Ltd., Growlab Agritech Co., Ltd., Agro Intelligent CO., Ltd. and Taiki-sha (Thailand) Co., Ltd. run their business of PFAL design and construct on customer demands. The design and construct include warehouse-like structure with insulated wall, lighting system, environment controlled systems (air temperature, relative humidity, CO_2 concentration, wind speed and nutrient solution), cultivation system (hydroponics and aeroponics), and IoT based device for controlling and data storage as well as robot and artificial intelligence (A.I.) in plant production. The new start-up companies for providing PFAL system are FlexiFarm Co., Ltd. and Thiva Innovate Co., Ltd., offering small-to- medium scale PFALs (container size) for vegetable production in the urban area.

Table 3. Plant Factory businesses in Thailand

	Business company	Business	References
1	noBitter	Fresh vegetables (e.g. kale)	https://nobitter.life/
2	Wangree Fresh	Fresh vegetables	https:// wangreefresh.com
3	VT Namnueng	Fresh vegetables	https://www.prachachat.net/local-economy/news-468476
4	Barramepirun	Fresh vegetables & Edible flowers	https://www.barramepirun.com/
5	Plant A (Farm on the moon)	Fresh vegetables	https://www.farmonthemoon.com/
6	LED farm	Fresh vegetables & PFAL system	https://ledfarm.co.th/
7	Agrowlab	PFAL system	https://www.agrowlab.com/
8	Growlab Agritech	PFAL system	http://www.growlaboratory.com/

9	Agro Intelligent	PFAL system	http://agrointelligent.net/
10	Taiki-Sha (Thailand)	PFAL system	https://www.taikisha.co.jp/vegefactory/en/
11	FlexiFarm	PFAL system	https://flexifarmtech.com/
12	Thiva Innovate	PFAL system	https://www.thivainnovate.com/
13	Golden Triangle Group	Hemp	https://www.gtg.co.th/

Related business to PFAL

The related business to PFAL can be divided into two types: 1) businesses related to PFAL system, and 2) businesses related to products from PFAL. The PFAL system consists of "building and infrastructure", "facilities and equipment" and "measurement and control" (Kozai *et al*., 2020). Therefore, there are several related businesses according to the components of PFAL; - hardware - thermally insulated wall, lighting system including LED with control system, the cultivation system, air temperature and humidity control systems, CO_2 supply system and control, nutrient control system, as well as – software- automatic control and interface, data storage and data analysis, and artificial intelligence, etc.

DIRECTIONS

It has been almost two decades that PFALs have been introduced to Thailand, but not many PFALs are constructed for R&D. Moreover, there have been very few PFALs constructed for plant production in commercial, and all of them are small to medium type PFALs, except for Vt Namnueng company. In the recent years, supported by both government agencies and private companies, there have been immense increase in research projects, carrying out for improving PFAL productivity and quality. Those knowledge and know-how from those research projects, e.g. lighting recipe for growing plants, are being patented. Moreover, some PFAL companies have established their own research section for carrying the research both for inventing new plant growing recipes and develop new PFAL system. To date, the PFAL research and commercialization have been directed for improving the quality of life in urban areas and for producing raw plant materials for pharmaceuticals and cosmetics industries.

PFALs for improving the quality of life in urban areas

The urban population in Thailand has reached 35 million people or 51% of Thailand population in 2019 (statista.com, 2021). The traditional systems of producing fresh food in agricultural areas and transporting to urban areas have changed to a new system of production in urban areas. The trend of healthy and safe foods has risen rapidly. Functional foods as medicine concept have been accepted widely. To these requirements of urban residents, PFAL can serve by producing fresh vegetables for local consumption (less logistics cost). Due to precisely controlled environments and being pesticide free, the plant products of safe and high quality can be guaranteed. Inducing and controlling nutrients and phytochemicals of plants produced in PFAL could allow functional food production such as low potassium vegetable for patients with kidney diseases (Kameoka and Hashimoto, 2019). Furthermore, PFALs can produce more with less resource consumption including land use, water, fertilizers, and labor, and with less wastes released to nature. Therefore, PFALs can allow us to improve the quality of life in urban areas. For example, the noBitter Co., Ltd., one of the leading companies of PFAL business has started producing high-quality vegetables for local consumption. They built 4 small-to-medium PFALs around Bangkok. They provide fresh and safe vegetables to local customers by a model of online marketing (https://nobitter.life/where-we-are/). The customers order and choose how to receive the products (picking up themselves or delivery) at the nearest PFALs. Another model of online marketing of vegetables from PFALs products is pre-order and networking customers. Wangree Fresh Co., Ltd. offers its customers with pre-ordered vegetables from PFALs. If the customers can form up their network containing more than 10 customers living in the same area (e.g. living in the same village), the price of the product would have 60% discount for all customers. With these marketing models, the logistic costs can be minimized. This business of producing vegetables using PFAL in urban areas is attracting many companies both in start- up and big companies.

PFALs for production of raw plant materials for pharmaceutical and cosmetic industries

Thailand is a resource-rich country, especially for medicinal plants as phytochemical resource for pharmaceutical and cosmetic industries. The Thai government has policies to make Thailand a hub of wellness and medicinal services, called "Thailand medical hub of Asia." However, medicinal plant production under variation of environment in field conditions has been accompanied by issues of quality and consistency of the phytochemical substances. Recent research indicates that cultivating medicinal plants under controlled environments such as temperature, relative humidity, light intensity, light quality etc. can ensure the efficacy and safety of the medicinal plant products (Zobayed, 2020). At present, funding sources from government and private sectors are provided more for research and development of medicinal plant production under controlled environment in PFAL. For example, production of *Andrographis paniculata* is under investigation at PFAL of BIOTEC, Thailand. Moreover, the research on the production of some medicinal plants such as Asiatic pennywort (*Centella asiatica*), and holy basil (*Ocimum tenuiflorum*) has been conducted for phytochemical substances serving the cosmetic industries. The Cannabis (*Cannabis sativa*) (may be prohibited to be grown in other countries) has been raised as an important medicinal plant in Thailand due to its properties of containing medicinal substances. There has been high interest in applying PFAL technology for cannabis production. The National Science and Development Agency (NSTDA) and the Government Pharmaceutical Organization (GPO) have launched research projects on cannabis production under controlled environment in Plant Factories with an aim to establish a standard protocol for high-quality cannabis plants. Under the national strategic plan of BCG (bioeconomy, circular economy and green economy) model addressed by the government, the major R&D organization and funding agencies e.g. National Innovation Agency (NIA) have provided research funds to universities and private companies to conduct research on PFAL.

POLICY AND SUPPORT

The Ministry of Higher Education, Science, Research and Innovation officially launched a policy of using advanced technology driving a new s-curve economy of Thailand. PFAL technology is considered as a frontier technology in agricultural sector to be an engine driving BCG (bioeconomy, circular economy and green economy) model via BigRock Project and EECi. Moreover, the Thailand Board of Investment (BOI) approved the PFAL as one of the five large scale projects to strengthen the country's agriculture sector.

Table 4. Policy and support from Thai government

Year	Policy and support
2018	In the BigRock Project, US$5.4 million funded BIOTEC to establish pilot scale PFALs at Thailand Science Park, Pathum Thani, Thailand, for basic and applied researches for plant production in PFAL.
2019	Eastern Economic Corridor of Innovation or EECi started constructing large-scale PFAL for demonstration and training site for entrepreneurs.
2020	The BOI added the PFAL as a new activity to the list of activities eligible for BOI incentives through corporate income tax exemption for 5 to 8 years.

BigRock project

In 2018, the Ministry of Higher Education, Science, Research and Innovation officially launched a policy of using advanced technology driving a new s-curve economy of Thailand. They funded US$105.04 million for 14 BigRock projects. PFAL was one of those chosen as part of the advance technology for production of High Quality Herb Project with the aim of improving standard production of Thai medicinal herbs. PFAL and other related facilities were constructed and equipped at National Center for Genetic Engineering and Biotechnology in 2019. This PFAL consists of a pilot scale production unit with a production area of 690 m^2 and three research units with a production area of 225 m^2. Other related facilities and equipment are a biochemical extraction and analysis room with analytical equipment (e.g. LCMS,

HPLC and UV-spectrophotometer) and a plant tissue culture room. The main goal of this project is to establish basic research and development of PFAL for vegetable and medicinal plant production.

Plant Factory at EECi

The Eastern Economic Corridor of Innovation or EECi is an innovation hub located in Wangchan District, Rayong Province. In EECi BIOPOLIS, a plant factory with fully controlled environment will be established and provide support to research of large-scale production of high-value crops. This facility can also serve as a demonstration site for trials in large-scale production and training site for technology transfer to plant growers and entrepreneurs (https://www.eeci.or.th/en/rental-space/greenhouse-plant-factory). The floor area of 2 modules of plant factory will be 425 m^2 with 9.55 m ceiling height and 1,000 kg/m^2 floor load (https://www.eeci.or.th/storage/photos/1/pdfs/EECi_GreenhouseandPlantFactory.pdf).

Board of Investment (BOI)

Recently, the BOI has announced the adjustment of the investment promotion terms and benefits for the agricultural industry based on the BCG model to encourage the development and adoption of technology to add value to the sector's output and help improve its productivity. The BOI added the PFAL as a new activity to the list of activities eligible for BOI incentives. They considered that PFAL technology can enable Thailand to improve quantity and quality of agricultural products. Such business will be eligible for corporate income tax exemption for a period of 5 to 8 years (https://www.boi.go.th/). The Vt Namnueng Co., Ltd. was the first business to take advantage of this from the BOI.

CHALLENGES

The major challenges for sustainable PFAL commercialization in Thailand are reducing the initial and production costs, increasing profit by growing high-value plants, and increasing number of skilled labor and expert managers for efficient production.

The initial cost of PFAL building with all necessary facilities is estimated to be US$957.7 – 3,830.9 per m^2 of planting area. This PFAL cost is 7 – 10 times more expensive when compared to that of a simple greenhouse with ventilators. The improved design, good management of construction and lowering land price may reduce the initial cost of PFAL. Electricity, labor and depreciation are three major components of the production cost. The major electricity cost is for lighting. The electricity consumption can be reduced by improving optimal light quality, light cycle and light schedule. Using a well-designed light system with reflectors to maximize the ratio of light received by plant canopy would reduce the electricity cost. Labor cost can be reduced by improving the skill of labor force or using advanced robotic technologies including remote sensing, image processing, intelligent robot hands, cloud computing, big data analysis and 3-D modeling (Kozai and Niu, 2020). Moreover, good management of production can reduce production cost by increased resource use efficiency.

Increasing profits by growing high-value plants can be considered as alternative for sustainable PFALs. Recently, there has been increasing interest in the production of medicinal plants, herbs and functional vegetables in PFALs, because PFALs can create new unique products different from those produced in greenhouses or fields. The stability of the medicinal components and consistency of production in PFALs can help in increasing the price of those plant materials for pharmaceutical and cosmetic industry. PFAL is ideal for the production of medicinal substances from genetic modified plants with advantages over fields including stable plant production, efficient use of resource, fulfillment of good manufacturing practice (GMP) and low risk of gene diffusion (Goto, 2020). Plants with higher price such as cannabis and others could be considered as good candidates for production in PFAL, guaranteeing high income and benefit to cost ratio.

Another challenge of PFALs in Thailand is how to increase the number of skilled labor and expert managers. Plant factories with artificial lighting technology are multidisciplinary and much of PFAL technology differs from that used in horticulture. Laborers must join the intensive course on training in plant production in PFAL to improve their skill, and must understand both GAP (good agricultural practice) and GMP (good manufacturing practice). Good managers for plant production in PFAL must know the basic knowledge and know-how of plant production under controlled environments. Moreover, they should understand plant physiology, especially plant responses to environmental factors, factory engineering and management of production in PFAL.

Other interesting challenges include the improvement of resource use efficiency, such as improving lighting system, breeding and seed propagation, development of new cultivation for root mass, data mining using big data obtained from PFAL and development of a phenotyping unit for non-invasive method for monitoring of plant growth and development real-time.

To drive and sustain PFAL commercialization in Thailand, more R&D activities on PFAL engineering and plant cultivation method, which is successfully applied for reducing the initial and production costs, should be conducted, and the research funding on these topics may be prioritized by the government. Moreover, the collaboration between the government, research center, academy, and business sectors should be established, probably in the form of PFAL association or consortium to enhance joint venture investment and training site for skilled operators and managers.

CONCLUSION

Plant Factory with artificial lighting or PFAL is one of the alternative technologies used to sufficiently and sustainably feed the world population with nutritional and safe foods to the world population. PFAL was introduced to Thailand in the early of 2000s. Several universities and research institutes have conducted their R&D focusing on increasing yield and medicinal substances of leafy vegetables and herbs by controlling optimum factors to meet crop requirements. Moreover, R&D on PFAL system including cultivation system, lighting systems, control systems and data storage and analysis system have been conducted. Commercialization of PFAL for plant production is few, but trends of PFAL commercialization are increasing due to improved technology by R&D. To date, the PFAL research and commercialization have been directed to improve the quality of life in urban areas and to produce raw plant materials for pharmaceutical and cosmetic industries. The Thai government by Ministry of Higher Education, Science, Research and Innovation officially launched a policy of using advanced technology to drive a new s-curve economy in Thailand, and PFAL is one of the frontier technologies to be supported in terms of funding and provision of improved technology to the private sector. The major challenges for sustainable PFAL commercialization in Thailand are reducing the initial and production costs, increasing more profit by growing high-value plants, and increasing the number of skilled labors and expert managers for efficient production.

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ACKNOWLEDGEMENTS

The author would like to express gratitude to Dr. Suttirat Rattanapan and Dr. Prapat Punpee (NSTDA, Thailand) for their valuable suggestion and information of PFAL business in Thailand. The author also express special thanks to members of Thailand PFAL consortium for information and knowledge of PFAL situation in Thailand.

AUTHOR'S CONTRIBUTION

Author contribution: K.M. conceived the idea of the study, searched the information, interviewed people from private companies and research institutes and analyzed data and information, wrote and revised the paper.

COMPETING INTEREST

K.M. declares that he has no conflict of interest.