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Overview on leafy (Pak Choy) vegetable industry and vertical soilless culture application for Pak Choy production in Malaysia

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ABSTRACT The agriculture industry plays a significant role in the well-being of Malaysia's economy. It provides jobs for more than 1.56 million people and contributes 7.1% to the gross domestic product (GDP). The vegetable industry, however, is lagging behind other agricultural industries, such as oil palm, rubber, and tea. The demand for vegetables in Malaysia increased from 1.58 million metric tonnes (MT) in 2010 to 2.4 million MT in 2020, but the production was only 0.1 million MT in 2010, 1.01 million MT in 2015, and 1.7 million MT in 2020. The trade balance deficit in 2021 stood at Ringgit Malaysia (RM) 3.37 billion. The vegetable industry is under pressure from rising population, shortage of resources, and post-COVID-19 pandemic impacts. Vertical farming (VF) of vegetables is widely promoted worldwide, including Malaysia, to increase production. In VF, the vegetables are produced in environmentally controlled multistorey buildings with different vegetables at different levels, and at any level, the vegetables are cultivated using vertical farming systems (VFSs). In that way, the production per unit area is said to be maximal. However, is Malaysia's leafy (Pak Choy) vegetable industry agronomically ready to embark on VF and VFS? There is a concern about business failure associated with promoting VF and VFS without sufficient knowledge and skills in agronomy about VF and VFS based on the local scenarios. Hence, the present paper aims to review the leafy vegetable industry, specifically Pak Choy production in Malaysia, to assess its readiness to apply VF and VFS to better the direction of future research projects. Keywords used for the search of relevant information in Science Direct, World Wide Science, Google Scholar, Google, and online newspapers were Malaysia plus vertical farming, hydroponic systems, column hydroponic system, agriculture sector, agriculture 4.0, precision agriculture, soilless culture, leafy vegetable industry, and Pak Choy production. The articles and reports obtained were reviewed. Based on the review, the leafy industry in Malaysia, specifically the Pak Choy production, is not yet agronomically ready to venture into VF and VFS, although VF and VFS have gained attention. The agronomic information about VF and VFS based on the local scenarios is still lacking. Local farmers have little guidance for operating VF and VFS. It is understood that VF is an expensive venture and will be relatively unknown to many farmers, but even the agronomic information related to VFS, which is just about the system used in VF, is seldom published. Of the many designs of VFSs in Malaysia, the Column Hydroponic System (CHS) has a markedly higher vegetable yield per unit area. Thus, more research on CHS is needed, and its agronomic and technical information should be published for the local vegetable farmers to use to mitigate the supply shortage and the high foreign exchange of leafy vegetables in Malaysia.

KEYWORDS: *Brassica* vegetable industry; vertical farming; vertical soilless culture system; hydroponic systems; column hydroponic system.
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Review Article

INTRODUCTION

Pak Choy (Pakchoi) or Bok-choy is one of the leafy vegetable groups belonging to the plant family Brassicaceae. *Brassica* species are important as vegetable crops, forage, ornamental plants, or oilseed. Almost all parts of *Brassica* species, such as the roots, stems, buds, leaves, flowers, and seeds, can be processed to be edible (Rakow, 2004). A few members of Brassicaceae are reported to contain anti-cancer properties that could inhibit malignant transformation or regulate the growth of cancer cells, thus, reducing the risk of cancers (Herr *et al.*, 2010). Some *Brassica* species also produce phytochemical properties that could induce detoxification enzymes, scavenge free radicals, alleviate inflammation, and stimulate immune functions (Herr *et al.*, 2010). Nutritionally, Pak Choy contains 1.7 g of protein, 0.2 g of fat, 3.1 g of carbohydrates, vitamins, and minerals such as β-carotene (2.3

mg), vitamin C (53 mg), and calcium (102 mg) in 100 g of its edible portion, respectively (Priadi & Nuro, 2017).

Malaysia is said to be secure in food supply by international standards. However, its dependency on food imports remains high. Thus, more effort is required to ensure the stable availability of healthy and nutritious foods (Chin, 2020). The vulnerability of the situation is significant, as was found during the COVID-19 pandemic. During that period, the Malaysian government imposed a movement control order (MCO) across the country to break the spread of the disease (WHO, 2021). This MCO had affected various sectors, including the agriculture industry, although agricultural activities were allowed to operate. Agricultural inputs and outputs were limited due to the MCO, disrupting food production and distribution (Shaharudin, 2020). The disturbance also happened in overseas food transportation and importation, which increased the prices and limited the availability and affordability of imported foods (Chin, 2020). The prices of imported leafy vegetables are still high even after COVID-19 has slowed down. The prices have soared between 30% and 40% (Tan, 2021) or tripled from RM3.00 to RM9.00 due to the rising costs of agricultural inputs, labour shortage, and unpredictable weather. This price increment also happened for Pak Choy, where production in Malaysia is lower than consumption (FAMA, 2021) and has to be imported to meet the demand. A high dependency on imported Pak Choy is surprising since these vegetables can be grown in this country throughout the year. Reducing the import of Pak Choy while increasing its local production is therefore seen as a way to mitigate the shortage of Pak Choy and other leafy vegetable supplies.

The main challenge in agriculture sectors, either during a pandemic or a regular period, is population and food demand increment. In Malaysia, the population has increased from 29.4 million in 2019 to 29.7 million people in 2020, an increment of 1.1% (DOSM, 2020a). Ten years ago, the world population was increasing by 1.24% per year, and although it has grown a little slower recently at 1.10% (United Nations, 2019), that growth is still an addition of 83 million people annually. By 2050, the world population is expected to reach 9.7 billion, i.e., there will be 2 billion more people to sustain. Kozai (2018) predicted that the expansion of the world's population would lead to three huge impacts, i.e., shortage or unstable supply of food, shortage of resources, increment of the urban population, and reduction of the agricultural population. The shortage of resources includes arable land area, water for irrigation, fertilizer, fossil fuel, and farmers. Environmental degradation, such as pollution of soil, water, and atmosphere, salt accumulation on the soil surfaces, desertification and climate change, and spreading of pest insects, will cause unstable market prices for vegetables. Hence, adaptive management in agricultural practices is necessary so that the nation will be resilient against issues and unpredictable matters now and in the future.

In Malaysia, the leafy vegetable and agriculture industry will remain important over the following decades, especially after realising uncertainty in food security during and after the COVID-19 pandemic. Agricultural sectors have provided food and earnings and served as the economy's backbone. It has contributed markedly to the national GDP and employment (Dardak, 2015). In 2019, the agricultural sector contributed about 7.1%, or RM101.5 million, of GDP (DOSM, 2020b). In 2020, around 1566 thousand people were employed in the agricultural industry (DOSM, 2021). For the leafy vegetable industry, the import has to be reduced, and local production needs to be improved to increase the GDP contribution of the agricultural industry. One of the approaches to increasing food and vegetable production is the application of vertical farming (VF) and vertical farming system (VFS) (Eigenbrod & Gruda, 2015. VF is a crop production technique in vertical levels, such as a repurposed warehouse, a skyscraper, or a shipping container. VFS refers to a growth system approach in VF. VFS can be broadly categorised into two groups: those that comprise multiple levels of traditional horizontal growing platforms and those that the crops are grown on a vertical surface (Beacham *et al*., 2019). The modern VF concepts use indoor farming techniques and controlled-environment agriculture (CEA) technology, which allows all environmental variables to be controlled (Takeshima & Joshi, 2019). VF has been proposed as a solution to increase productivity per area by extending the planting density, thus enhancing land use efficiency for crop production (Eigenbrod & Gruda, 2015. Also, the application of VF can provide more crop rotations per year compared to conventional farming practices and a reliable harvest because the indoor controlled environment can maximise crop yield irrespective of external conditions. One of the often-perceived benefits is the potential reduction of water used for production (FAO, 2013). However, for the leafy vegetable industry in Malaysia, especially Pak Choy production, is it agronomically ready to embark on VF and VFS? The present paper aims to review the leafy vegetable industry, specifically Pak Choy production, in Malaysia to assess its readiness for applying VF and VFS to enhance our understanding of this matter for bettering the direction of future research projects. Keywords used to find the relevant information were Malaysia plus vertical farming, hydroponic systems, column hydroponic system, agriculture sector, agriculture 4.0, precision agriculture, soilless culture, leafy vegetable industry, and Pak Choy production; these keywords were searched in Science Direct, World Wide Science, Google Scholar and Google, and online newspapers. The articles and reports were reviewed, compared, and contrasted to assess the situation of the leafy vegetable industry and vertical soilless culture application, especially for Pak Choy production in this country.

Brassica VEGETABLE INDUSTRY IN MALAYSIA

Food crops and industrial crops are the two general agricultural sectors in Malaysia. Food crops are vegetables, fruits, tubers, and grain crops, usually cultivated by smallholder farmers. Industrial crops are commodity crops, such as oil palm, rubber, and tea, typically planted by large estates and companies (Ng, 2016). Roughly 10% of Malaysians are involved in agricultural activities (Anonymous, 2020). The agricultural sector contributed about 7.1%, or RM101.5 million, of the country's Gross Domestic Product (GDP) in 2019 (DOSM, 2020b). However, the main contributors of agriculture exports are oil palm at 37.7%, followed by livestock (15.3%), fishing (12.0%), forestry and logging (6.3%), rubber (3.0%), and other primary agricultural products (25.9%) (DOSM, 2020b). The vegetable industry in Malaysia lags behind the industrial crop in terms of growth and is often viewed as an uncertain, unprofitable, and socially unattractive industry (Ng, 2016). Vegetable production is characterised by a high degree of volatility. Some of the constraints are that producers have little control over most agricultural commodities since most of them are produced in an open environment, making them more sensitive to extreme weather, such as changes in rainfall patterns and temperature, as well as in pests and disease (Penang Institute, 2020).

Brassica Vegetables Farmed

There are six interrelated *Brassica* species with global economic significance, which are *Brassica nigra* L., *Brassica oleracea* L., *Brassica rapa* L., *Brassica carinata* A.Braun, *Brassica juncea* L. and *Brassica napus* L. The species is classified into oilseed, forage, condiment, and vegetable crops. The *Brassica* vegetables include *B. oleracea* (kale, cabbage, broccoli, Brussels sprouts, cauliflower), *B. rapa* (turnip, Chinese cabbage, Pak Choy, pai-tsai, Chinese mustard, and broccoli raab), *B. napus* (rutabaga, Siberian kale) (Cartea *et al*., 2011). *Brassica oleracea* and *B. rapa* are the main species that dominate the vegetable market (Cartea *et al*., 2011). There is a wide range of varieties belonging to *B. rapa* species planted in Malaysia, such as Dwarf Type Pak Choy, Hybrid Shanghai Dwarf Pak Choy, Ma Yee Pak Choy, Curly Dwarf Pak Choy, Curly Wrap Wong King Pak Choy, Fan Pak Choy, and Pak Choy Purple Red Dwarf (CityFarm, 2022a). Generally, these cultivars can be grown in Malaysia, indicating a wide choice for production using VF and VFS. The only issue is that most of the seeds are imported, which means the leafy vegetable industry in Malaysia is prone to seed shortage when foreign suppliers stop supplying the seeds or when the logistics are complicated. Also, since there are many varieties of *Brassica*, it is difficult to identify them based on their morphological characteristics. OECD (2016) reported that similar plant forms and morphological characters occur in more than one genus or species among *Brassica*. For marketing purposes, that problem also causes difficulties where consumers cannot rely on specific morphological traits to associate a *Brassica* with particular importance, for example, which is better in terms of flavour.

National Production and Trade

The demand for vegetables in Malaysia increased from 1.58 million MT in 2010 to 2.4 million MT in 2020. However, the local production of vegetables was only 0.1 million MT in 2010, 1.01 million MT in 2015, and 1.7 million MT in 2020 (FAMA, 2021). Malaysia's vegetable trade balance deficit stood at RM3.37 billion in 2021 (DOA, 2021). The productive area and the production of *Brassica* in Malaysia are shown in Table 1 (DOA, 2021). The production contributes to around 20% of the total leafy vegetable production, indicating the high demand for *Brassica* in Malaysia. Overall, Malaysia experiences vegetable supply-shortage issues.

Table 1. Hectarages, productions and values of *Brassica* in Malaysia in 2021.

States	*Brassica* productions and values			
	Planted areas (Ha)	Harvested areas (Ha)	Productions (Metric tonnes)	Production values (RM '000)
Johor	4,097.93	4,041.38	64,096.86	168,574.75
Kedah	66.72	65.65	421.88	1,109.53
Kelantan	233.64	232.02	3,535.64	9,298.73
Melaka	99.20	96.40	1,049.30	2,759.66
Negeri Sembilan	394.03	388.54	5,312.37	13,971.52
Pahang	2,176.02	2,035.74	23,456.31	61,690.10
Perak	1,154.25	1,152.42	17,935.68	47,170.84
Perlis	16.08	16.08	65.84	173.16
Pulau Pinang	120.35	120.02	1,707.92	4,491.84
Selangor	784.31	775.17	11,733.44	30,858.96
Terengganu	116.98	115.48	1,283.32	3,375.13
Peninsular Malaysia	**9,259.51**	**9,038.90**	**130,598.57**	**343,474.23**
Sabah	779.20	776.40	7,702.10	20,256.52
Sarawak	1,365.15	1,189.41	14,755.90	38,808.02
W. P. Labuan	20.17	19.23	214.25	563.48
Malaysia	11,424.03	11,023.94	153,270.82	403,102.25

Source: DOA (2021).

In 2020, Malaysia was in sixth place globally with USD146 million worth of vegetable imports, including Pak Choy; this was 18.8% higher than the import value in 2019 (USD123 million) (Anonymous, 2021). Most vegetables imported to Malaysia come from China (USD137 million), Indonesia (USD3.08 million), Australia (USD2.42 million), Thailand (USD2.2 million), Vietnam (USD393 thousand), United Kingdom (USD340 thousand), Netherlands (USD162 thousand), Spain (USD114 thousand), and Bangladesh (USD96 thousand). The import value was more than 16-fold the value of exported *Brassica* in 2020, which was USD9.12 million (Anonymous, 2021). *Brassica* vegetables are not only imported to Malaysia but also to other countries. United States was the largest importer (USD421.99 million) of cabbages and other brassicas, followed by Canada (USD304.69 million), Hong Kong (USD297.77 million), Germany (USD216.25 million, and

Netherlands (USD61.19 million) (Anonymous, 2022a). In other words, if Malaysian farmers can produce more than the local demand, they can also export *Brassica* vegetables to other countries since Malaysia's climate permits an all-year-round production of leafy vegetables.

Production per Farm and per Unit Area

Pak Choy is one of the locally popular leafy vegetables with excellent market potential. The production significantly increased from 128,742 MT in 2018 to 145,427 MT in 2019, 146,894 MT in 2020, and 153,270 MT in 2021 (FAMA, 2021; DOA, 2020; DOA, 2021). The main Pak Choy-growing areas are Tangkak, Johor (17,312 MT), Cameron Highlands, Pahang (11,764 MT), and Kinta, Perak (15,545 MT) (DOA, 2021). There was an increase in the production of Pak Choy over the years, but it was small to match the local demand.

IMPROVING Brassica VEGETABLE PRODUCTION PER UNIT AREA

Application of Modern Agricultural Practice

One of the significant interests of vegetable farmers is the ways of improving the yield. What are the most effective approaches to increase production per unit area? Soilless culture is one of the modern practices to overcome the problem of the low productivity of horticultural plants per unit area faced by farmers practising soil-based farming methods. Soilless culture is frequently used as a synonym for soilless farming. Soilless cultures are basically classified according to the type of plant nutrient supply (whether the roots are partially or entirely dipped in the nutrient solution: *i.e.*, deep-water culture, float hydroponics, nutrient film technique, deep-flow technique, and aeroponics) and substrate (*i.e.*, gravel culture, sand culture, bag culture, and container culture) (Savvas *et al*., 2013). By definition, hydroponics is a soilless culture system with an inert substrate or without any aggregates. This technique is about producing food plants in artificially constructed growing conditions where soils are not used as a rooting medium, and inorganic nutrients for the plants are supplied via a systematic irrigation system. Hydroponic has been derived from the Greek word *hydro*, meaning water, and *ponos*, meaning work. Applying this technique would result in the effective and efficient use of water and fertilizers. This technique would also minimize or eliminate the use of chemicals for pest and disease control (Hussain *et al*., 2014). Over the years, hydroponic system use has become increasingly widespread in Malaysia. These techniques are preferred because they are convincing and efficient (Rabu *et al*., 2015).

Vertical Farming (VF) and Vertical Farming System (VFS)

VF is not a new concept. VF has been known for a long time, but it is increasingly popular only over recent years as an alternative food production technique due to the rapid advancement in technology and increment in land issues (Shamshiri *et al*., 2018). VF involves large-scale production in high-rise structures allowing for quick expansion and planned production by applying cutting-edge greenhouse and technology methods to regulate ambient conditions and nutritional solutions of the crops (Despommier, 2019). A few low-rise VF projects have been developed, while high-rise initiatives are being considered (Al-Kodmany, 2018). Different technologies are involved in the VF technique, from the general structure of VF, lighting system, water supply, renewable energy, and farming system to controlled environment system (Kalantari *et al*., 2017). However, VF is implemented only in a few places worldwide. Table 2 shows several cities that have embarked on VF projects. Based on Table 2, the adoption of technologies used in VF is different between companies and mostly limited to developed countries, such as Korea, Japan, China, Singapore, USA, and Netherlands.

Table 2. Several cities that have embarked on vertical farming projects.

Vertical Farms	Structure s	Growing systems	Growing areas (m^2)	Technology involved
Aerofarm in New Jersey, USA (Birkby, 2016; Kalantari *et al*., 2018)	Warehouse	Aeroponic	650	Without any soil, pesticide or sunlight; LED lights; Track the growing process using sensors; Recycle water technique.
Skygreen in Singapore (Al-Kodmany, 2018)	Greenhouse	Hydroponic	3650	Low carbon hydraulic water-driven; Natural sunlight.
Green spirit Farms in New Buffalo, Michigan, USA (Al-Kodmany, 2018)	Building	Hydroponic	3716	Used commercialized rotary and vertical farming system; Carbon neutral energy to grow pesticide-free plants; LED lights.
Nuvege in Japan (Al-Kodmany, 2018)	Building	Hydroponic	5295	Automated rack system; LED lights.
The Plant Vertical Farm in Chicago, USA (Kalantari *et al*., 2018)	Building	Aquaponic	9290	Recycling waste to energy; Using biogas from an anaerobic digester; Natural sun energy
Republic of South Korea Vertical Farming (Despommier, 2010)	Building	hydroponic	450	Using renewable resources such as geothermal and solar; Automated rack system; LED lights.
Green Sense Farms in Portage Indiana, US in 2014 and Shenzhen, China in 2016 (Kalantari *et al*., 2018).	Greenhouse	hydroponic	1858	Stacking vertical towers concept; Adopting automated computer controls that provide the precise amount of light, nutrients, water, temperature and humidity; Recycle water technique.
PlantLab in Den Bosch, Holland (Al-Kodmany, 2018),	Three-story underground vertical farm	Aeroponic and hydroponic		Advanced LED technology that calibrates light composition and intensity to optimum needs; Automated system to monitor and control humidity, carbon dioxide, light intensity, light colour, air velocity, irrigation, nutritional value and air temperature.

Rahman (2012) commented that if Malaysia were to follow in the footsteps of other countries, which of the current prototypes of VF could serve as a benchmark? The setup in Singapore may be the closest conceivable example due to the similarities in climatic conditions and technology availability. In Singapore, Sky Green is the first commercial tropical vegetable urban farm that utilises A-Go-Gro technology consisting of 38 tiers of growing levels. The company uses natural sunlight by rotating the ties at one millimetre per second to provide uniform solar radiation (Al-Kodmany, 2018).

VFS are classified based on the designs of the structural systems used in vegetable production, such as stacked horizontal systems, multi-floor systems, and green walls to cylindrical growth units (Beacham *et al.*, 2019) (Table 3). As for cylindrical growth units, there are various designs of that system available around the world, from vertical hydroponic towers, Zip-grow towers, Veg towers, and vertical column hydroponic systems (CHS), to the zig-zag vertical hydroponic systems (Singh & Dunn, 2021; Refarmers, 2016; Touliatos *et al.*, 2016; Gobilik *et al.*, 2021; Anonymous, 2022b). The application of each design is mostly determined by the demands of the company or farmer, location, capital, specialised market, and overall vision (Adam, 2021). However, in Malaysia, the adoption of VF and VFS, especially by SME farmers, is still lagging behind the global average.

Table 3. Types of vertical farming systems.

Type of vertical farming systems	Descriptions
Stacked Horizontal Systems	-A system comprise multiple levels of traditional horizontal growing platforms. -The plants can be grown in deep water culture (DWC) or nutrient film technique (NFT)
Multi-Floor Towers	-Each level is isolated from the surrounding levels.
Green Walls	-The system can be positioned on the sides of the building or other vertical surface.
Cylindrical Growth Units	-A system with vertical arrangement of plants, where plants are grown one above another around the surface of upright cylindrical units.

Source: Beacham *et al*. (2019).

VF AND VFS APPLICATIONS FOR PAK CHOY PRODUCTION IN MALAYSIA

VF and VFS have gained an interest in Malaysia. Boomgrow Production Sdn. Bhd. is a Malaysia start-up VF company specialising in precision farming founded in 2013 (Boomgrow, 2022). The company operates 13.3 m^2 repurposed shipping containers equipped with technology and artificial intelligence (Al) capabilities that could provide an optimal environment to produce more than 50,000 kg of vegetables a year. The containers are stacked in five layers to become a VFS on 33.5 m^2 of land, and the system's production is equivalent to the production of one acre of a traditional outdoor farm (Dayangku, 2021). The total capital raised by the company is over RM300,000.00 of investment, including technology and innovation grants from SME Corporation Malaysia, PlaTCOM Ventures, and Malaysia Digital Economy Corporation (MDEC) (Digital News Asia, 2020).

CityFarm, located in Seri Kembangan, Selangor is an organization whose objective is "*to inspire more city farmers with the ability to grow locally from anywhere for a more sustainable future of food production*". The company, founded in 2016, develops indoor controlled-environment vertical show farms (41.8 m^2) capable of producing 2000 heads of lettuce every month (CityFarm Malaysia, 2021). The company exhibits a diverse set of applications, both in terms of business and production models. CityFarm offers a wide range of vegetables, urban farming start-up kits, fertilizer, grow lights, and other agricultural products (Looi, 2018). One of the projects they invented is the four-level plant factory with artificial light (PFAL) for indoor installation; it can produce 648 plants per system, and the indicative price for installation is estimated to be about RM42,000.00.

Fajar Saintifik Sdn. Bhd. is another company that also builds indoor VFS for interested farmers in Malaysia. For example, they build a racking system, which uses polystyrene planting trays and light-emitting diodes (LEDs) as the light source. The environmental condition and resources in the system are controlled and managed via IOT monitoring system. The system can produce 40 kg of plant per day and the monthly income is around RM12,780.00 (Fajar Saintifik, 2022). The company can construct indoor farms for any size and for selected popular vegetables.

In Cameron Highlands, MARDI (2014) has introduced VF to prevent soil erosion due to hill diversion for agricultural and development purposes. Structurally, the Column Multi-tiered System consists of five tiers with four plants for each tier. The system is suitable for cultivating leafy vegetables, such as lettuce, kalian, mustard, and Pak Choy. E-farm is another company founded in 2020 that established an aquaponic prototype. In E-farm, the greenhouse is about 92.9 m^2, has multiple vertical towers, and the pond is as big as the greenhouse that holds 1,000 red tilapia fish (Ahmad, 2021). Kundasang Aquafarm is another company located in Mesilou, Kundasang, Sabah, founded in 2016 that operates an aquaponic business. It uses single-layer and multilayer aquaponic and hydroponic systems that can produce about 30 tonnes of red coral lettuce, green coral lettuce, and butterhead lettuce worth about RM300,000.00; these vegetables are sold to the hypermarkets and hotels in Sabah as well as exported to Sarawak and Brunei (Miwil, 2022). Another company in Papar Sabah, the Sabah Green Sanctuary, was founded in 2019. It designs and builds hydroponic VFS for mini farms. The invention consists of a LED-powered vertical hydroponic system in a ventilated greenhouse, which costs about RM15,000.00 (Anonymous, 2019).

A few industrial players of VF are missing from this review because they have not openly publicised their ventures. Notwithstanding, it can be said that generally, little is reported about a successful VF project in Malaysia where a multilayer building is built and used to produce various crops. As stated above, there are only a few examples of buildings containing a multilayer production platform (i.e., VFS) of leafy vegetables.

CHARACTERISTICS OF VFS IN MALAYSIA'S PAK CHOY INDUSTRY

Since there is little information about VF in Malaysia, it is always of interest to understand deeper the traits of VFS, which is much more common in this country, so that many more farmers and researchers could figure out a better way of setting up their VFS. Hence, the present review will indicate whether knowledge and skills are readily available locally for farmers to use as a guide to construct and operate their VFS for Pak Choy production. The review includes the physical (structural design), biological (plants and microbes), chemical (nutrient solution), and ecological (surrounding environment) traits of VFS.

Structural design

The design, layout, and setup of VFS need to be studied more in-depth and in collaboration between many disciplines, such as hydrobiology, material science, structural and mechanical engineering, industrial microbial, plant and animal genetics, public health, waste management, physics, urban planning, and architectural design in order to ensure that each plant in the VFS receives the optimal ranges of environmental conditions (Heath *et al*., 2012). In general, the structural design of VFS determines the density and the total weight of leafy vegetables produced. Various structural designs are used in Malaysia, from Column Multi-tiered Systems (CMS), Layered Vertical Hydroponics, Vertical Towers, and A-Frame Hydroponic Systems to CHS (MARDI, 2014; Zainudin, 2019; Goh, 2019; Ahmad, 2021; Gobilik *et al*., 2021). While the nutrient solution is supplied in various methods, such as nutrient film (NFT), raft or deep-water culture, drip, and aeroponic techniques, VFS can also be integrated with fish farming, a practice known as aquaponic (e.g., Kundasang Aquafarm: https://www.facebook.com/kundasangaquafarm/). Gobilik *et al*. (2021) reported a mini design of CHS for VFS; structurally, it consists of tall rectangular polyvinyl chloride (PVC) tubes that are 1.5 m tall or more with nine levels (four cups per level) or more. For CHS, 400 leafy vegetables/m² can be planted with a total yield of 18.3 kg (Gobilik *et al*., 2021). Meanwhile, for a four-layer vertical hydroponic system occupying 6.89 m² (5.3 m long x 1.3 m width x 2.7 m tall), the vegetable density will be 130 plants/m² (CityFarm, 2022b). For A-frame Hydroponic System occupying 4.95 m² (3 m long x 1.65 m width x 2 m tall), the density will be 29 plants/m² (Khedr *et al*., 2022). In a CMS of five tiers, the density will be 20 plants/m² (MARDI, 2014). It appears that of the different designs available, CHS has the highest plant/area, but to date, there is still little information available in the literature about the optimal design of CHS.

Media

In soilless culture, non-soil materials are used as the growth media. Takeshima and Joshi (2019) reported that growing media are essential for soilless culture and controlled environment agriculture. The best medium or substrate should provide the basic fundamental needs for plants, such as anchoring, adequate drainage, aeration, biological and chemical stability, and water-holding capacity (Wiggins *et al*., 2020). Various media types are used, from perlite, LECA clay pebbles, jiffy peat pellet, coco mix, peat moss, cocopeat block, and Rockwool to cotton mop yarns (CityFarm, 2022c; Gobilik *et al*., 2021). The suppliers and prices of some popular soilless culture media are shown in Table 4. Most modern farmers in Malaysia use hydroponic systems with clay pebbles and Rockwool as the media. Although having unique properties, clay pebbles are expensive and can cause blockages as the pebbles can easily be sucked into the drain line and filters (Storey, 2016). Rockwool is costly and not ecologically friendly due to the manufacturing process and disposal issues (Drakes *et al*., 2001). In one study operating CHS (Gobilik *et al*., 2021), Pak Choy was successfully produced using cotton mop yarns as the medium, indicating the importance of cotton yarns as an alternative for clay pebbles or Rockwool. So far, for VFS, little information is reported or commented on about the media used in the system, either in Malaysia or other countries where hydroponic technology is much more advanced such as in developed countries. In other words, vegetable farmers have no specific guidance on this matter but to choose based on their experience, based on reports by others, or trial and error. The choice can also depend on the material prices and farmers' budgets rather than scientific factors.

Table 4. Prices and suppliers of several popular soilless culture media.

Media	Prices	Suppliers
LECA clay pebbles Hydrokorrels (40L, approximately 17 kg)	RM82.50	Netherlands
Peat moss (5L, approximately 1.6 kg)	RM7.00	Finland
Perlite 3-6 mm (50L, approximately 4kg)	RM56.00	Malaysia
Cocopeat block (5 kg)	RM17.90	Malaysia
Jiffy peat pellet (100pcs)	RM70.00	Norway
Rockwool (50 plugs)	RM23.90	Netherlands

Source: CityFarm (2022c).

Nutrient solution

In soilless culture, the nutrient solution determines the crop yield and quality. The nutrient solution is an aqueous solution containing mainly the inorganics ion from soluble salts of essential elements for higher yield of crops (Velazquez-Gonzalez *et al*., 2022). There are 17 elements considered essential for most plants: carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, manganese, molybdenum, boron, chlorine, and nickel (Resh, 2013; Benton, 2014). The carbon (C) and oxygen (O) come from the atmosphere. Farmers need to consider factors such as crop type, nutrient composition, electrical conductivity (EC), pH, and temperature when preparing a nutrient solution. So far, for VFS, there is no specific type of NS requirement reported by other authors, meaning the choice of NS still depends on the farmers' judgment. In other words, the commonly known Stock A and Stock B fertilisers used for most hydroponic systems will be applicable for VFS.

Nutrient composition and Nutrient Stock A: Stock B: Water ratio

Five crucial considerations in formulating a nutrient solution are plant variety, growth stage and marketable yield, climate, and weather (Resh, 2013). Generally, leafy vegetables can tolerate higher nitrogen levels since it promotes vegetative growth. Several empirically based nutrient solution formulations, published 38–56 years ago, are still used today (e.g., Table 5), meaning the formulation of the hydroponic nutrient solution has not changed much over the years. Stock solutions A and B are usually 100 times more concentrated than the solution given to plants. Hence, the nutrient solution should be diluted at 1: 100 with clean water (*i.e.*, dilute 10 ml of solution A and 10 ml of solution B to 1 L of water) before being used for growing the plants. Usually, equal volumes of A and B stock solutions are mixed to obtain a balanced nutrient solution (Parks *et al*., 2011). For VFS, the report on nutrient composition and A: B: water ratio is limited. It remains a question whether a vegetable grown in a conventional hydroponic system will require a different nutrient composition and concentration when planted in a VFS.

Table 5. Several well-known nutrient solution formulas for leafy vegetable production.

Nutrient (mg/L)	Hewitt (1966)		Cooper (1979)		Steiner (1984)	
		% per N		% per N		% per N
N	168	100.00	200–236	100.00	168	100.00
P	41	24.40	60	27.52	31	18.45
K	156	92.86	300	137.61	273	162.50
Ca	160	95.24	170–185	81.42	180	107.14
Mg	36	21.43	50	22.94	48	28.57
S	48	28.57	68	31.19	336	200.00
Fe	2.8	1.67	12	5.51	2–4	1.79
Cu	0.064	0.038	0.1	0.046	0.02	0.012
Zn	0.065	0.039	0.1	0.046	0.11	0.065
Mn	0.54	0.321	2.0	0.917	0.62	0.369
B	0.54	0.321	0.3	0.138	0.44	0.262
M	0.04	0.024	0.2	0.092	–	–

pH

pH is a measure of the concentration of hydrogen in a solution. It affects nutrient availability for plant uptake, and due to the lower buffering capacity of soilless systems, it must be adjusted daily (Gomez-Merino *et al*., 2014). Phosphoric acid or nitric acid is used to lower pH, whereas potassium bicarbonate or potassium hydroxide is used to increase pH (Parks *et al*., 2011). The proper pH values of nutrient solution for the optimal development of crops, especially leafy vegetables, range from 5.5–6.5 (Parks, 2011; Gomez-Merino *et al*., 2014; Maludin *et al*., 2020). Priadi *et al*. (2019) found that in a Vertical Aquaponic System of pH 7.2–7.4, the weight/plant of Pak Choy was 25.1–31.5 g. In RHS of pH 5.5–6.5, the weight/plant of Curly Dwarf Pak Choy was 73.16–87.44 g (Maludin *et al*., 2020). For CHS of pH 5.9, the weight/plant of Curly Dwarf Pak Choy was 7.2–80.4 g; the lower weight/plant was due to insufficient sunlight at the middle and bottom parts of the CHS (Gobilik *et al*., 2021). The latter two studies indicate that the pH for optimal development of the same leafy vegetable will be similar. So far, the pH for optimal Pak Choy production in VFS is little known. Hence, for the time being, the typical pH used for non-VFS is also used for VFS, such as in CHS (e.g., Gobilik *et al*., 2021).

Electrical conductivity (EC)

Electrical conductivity (EC) is an index of salt concentration and an indicator of electrolyte concentration of a nutrient solution (Nemali, 2004). It is related to the concentrations of chemical elements available in the solution (Ding *et al*., 2018). Parks *et al*. (2011) reported that leafy Asian vegetables grown in a nutrient film technique grew best in the EC range of 1.5 to 2.5 dS m^{-1}. For Pak Choy, the best EC of the nutrient solution is in the range of 1.8 to 2.4 dS m^{-1} (Ding *et al*., 2018). Maludin *et al*. (2020) reported that for Pak Choy production in tropical areas using RHS, the total yield per area increased markedly from 4.21 kg/m^2 at EC 2.2 dS m^{-1} to 5.33 kg/m^2 at EC 2.8 dS m^{-1}. However, due to the concern about the limit of nitrogen in vegetables for safer consumption, EC 2.2 dS m^{-1} is the appropriate threshold (Maludin *et al*., 2020). The trend from the study by Maludin *et al*. (2020) indicates that higher EC is required for Pak Choy production in warmer conditions. Generally, depending on plant species, low and high EC will not support optimal plant development or will be toxic to plants (Oztekin *et al*., 2018). So far, the optimal EC for Pak Choy production in VFS is little known.

Rootzone temperature

Root zone temperature is one of the crucial factors in hydroponics because it regulates the synthesis of plant metabolites, affects the amount of oxygen used by plants, and balances between the fertilisers' availability and nutrient uptake capacity of roots in various plants (Sakamoto *et al*., 2015). Generally, growth is inefficient with root temperatures below 20°C and above 30°C for many plant species (Benton, 2014). In the tropical area, raft-hydroponic Pak Choy at 25°C rootzone temperature grew to 160.08 g/plant compared to only 85.28 g/plant in uncontrolled (ambient) temperature of 25°C–38°C (Maludin *et al*., 2020). For VFS, little is known about rootzone temperature. It is commented that the top side of the CHS will be warmer than the bottom side (Gobilik *et al*., 2021). However, it is not known whether controlling the rootzone temperature is beneficial for VFS, specifically CHS, as there is already a marked shade effect in the middle of the system, or in other words, a lower ambient temperature condition associated with the shade effect.

Plant nutrient uptake: Effectiveness and Efficiency

A proper nutrient management plan is essential to ensure that plant nutrient uptake is effective and efficient. The nutrient use efficiency of plants is determined by the ability of the plants to absorb nutrients efficiently, which depends on the growth and architecture of the roots (Prieto *et al*., 2017). Thus, for optimal vegetable production in hydroponics, the medium and nutrient solution must be excellent for root establishment. Baiyin *et al*. (2021) stated that the flow rate of nutrient solution also affects nutrient use efficiency. Thus, in a hydroponic system, regulating the nutrient flow rate at a reasonable volume is recommended to enhance the effectiveness and efficiency of nutrient uptake to increase yield. Applying the correct water and nutrient supply in a hydroponic system is essential to reduce plant nutrient-uptake stress (Gohler *et al*., 1989). Plants retain 70%–95% water in their roots, stems, and leaves. If the water content decreases by 20%–30% of the optimum amount, plants will likely wither quickly. Plants are stressed when the water loss by transpiration is higher than the water uptake by roots, resulting in lower photosynthetic activities and poor growth and development (Lawlor, 2002). For hydroponic vegetables, water and nutrients must be sufficient at all times. However, one of the challenges in VFS is ensuring sufficient water and nutrient supply to every plant at different levels in the system. There is a tendency that plants in the upper section have received a much higher amount of nutrients compared to those in the lower section of the system (Touliatos *et al*., 2016; Gobilik *et al*., 2021). This trend influences the uniformity of plant growth and yield in the system. Hence, in VFS, it is not easy to ensure that plant nutrient uptake is effective and efficient unless each level has its water and nutrient supply nozzle.

Ambient temperature

Ambient temperature is one of the factors affecting the rates of development and growth of plants in hydroponics. Ambient temperature affects plant photosynthetic activities where plant species have the minimum, optimum, and maximum ambient temperatures for growth and development (Zhou *et al*., 2022). In four seasons or arid countries, heating or cooling devices are required to balance the temperature in the greenhouses. Generally, lowland temperate vegetables require an ambient temperature of 25°C–30°C (Baudoin *et al*., 2002). Pak Choy in the tropical area was reported to have achieved the highest growth and yield at 25°C–27°C ambient temperature (Maludin *et al*., 2020). The effects of ambient temperature on plant growth and photosynthetic characteristics have been discussed widely, but the specific knowledge on the effects of ambient temperature on Pak Choy in VFS is still limited. The effects are assumed to be similar to the general trends known for non-VFS.

Light Condition

Lighting is one of the key issues in VF. Plants use light energy for photosynthesis and adjust their development, growth rate, and yield based on the quantity and quality of light (Wang & Folta, 2013). Plants in soilless culture systems rely on natural light (sunlight), artificial light, or both. Systems that use sunlight primarily require creative architectural solutions and a thorough understanding of building technological performances (Heath *et al*., 2012). For example, to optimise solar radiation on the plants, it is necessary to optimise the building shape and light reflection and the structures or equipment, such as light reflectors or light tubes. In addition, rotating technology would also be required to increase the light supply to the plants. Sky Green in Singapore, which utilizes sunlight, rotates the ties at one millimetre per second to provide uniform solar radiation to the plants (Al-Kodmany, 2018). When light is inadequate, plants' development and growth will be slow (Benton, 2014). For VFS, there is a shade effect issue, i.e., plants on the top shade those on the bottom. Plants at the bottom are thus growing slowly and failing to achieve the marketable size at harvesting. Although CHS has a better yield performance than other hydroponic system designs, light intensity in CHS is not optimum and is suspected to be decreasing from top to base and from out to inner sides (Touliatos *et al*., 2016; Gobilik *et al*., 2021). Pak Choy on the outer columns of CHS, which were facing the morning and afternoon sunlight, and on the top of the system were heavier (39.2–71.7 g/plant) compared to those on inner columns and at the bottom of the system (8.8–20.3 g/plant) (Gobilik *et al*., 2021). For CHS, column spacing determines plant spacing and light intensity between columns, where 40.0 cm instead of 30.0 cm column spacing is proposed to be suitable (Gobilik *et al*., 2021).

To increase the light supply to the vegetables, top VF and VFS companies use artificial light (Tao, 2019). It is now a common practice in VF and VFS applications. In Malaysia, indoor vegetable producers (e.g., CityFarm) have already used artificial light to grow vegetables. However, the profitability of this approach, especially for small companies, is still debated (Shao *et al*., 2016). Over-reliance on artificial light increases the initial cost of VF or VFS, reaching over USD100 million for 60 hectares of VFS (Heath *et al*., 2012). Converting a building into high technology VF might still be expensive, as can be said about the high land costs in major cities (Birkby, 2016). This cost issue will be a problem for most vegetable farmers in Malaysia because many of them are smallholder farmers. To date, the use of the sunlight is still an affordable source of light. However, the amount of sunlight required by plants in outdoor and indoor hydroponic systems, especially in VFS, is still not well reported.

Quality

Light quality is essential for plants' photosynthetic activities, organ development, growth, and other physiological responses (Nguyen *et al*., 2019). In commercial VF and VFS practices, the light quality is manipulated to improve crop plants' growth, yield, and quality. Light-emitting diodes (LEDs) have been widely used as an alternative to natural sunlight. Generally, a combination of red and blue LED is more effective in enhancing the photosynthesis and productivity of vegetables (He *et al*., 2019a; He *et al*., 2019b). For example, red and blue LEDs of R660/B450 (=4/1) at 190 µmol $m^{-2} s^{-1}$ photosynthetic photon flux density (PPFD) in Stacked Horizontal Hydroponic System of spinach produced the highest shoot fresh weight with 43.74 g/plant (Nguyen *et al*., 2022). However, the profitability of this technology is still debated even though recent findings validate that it is affordable.

Photoperiod

Photoperiod affects the productivity and quality of hydroponic vegetables (Thomas & Awadh, 2020). In VF and VFS with artificial lighting, the intensity and composition of light are essential to be optimized for the economic and environmental sustainability of the farms. The best growth for most indoor leafy vegetables occurs at 100–300 µmol $m^{-2} s^{-1}$ PPFD and 10–18 hours of photoperiod (Kozai, 2018). At 290 µmol $m^{-2} s^{-1}$ PPFD and 6/2 (light/dark) photoperiod, the development and growth of lettuce are reported to be optimum, with a yield of 77.63 g/plant (Kang *et al*., 2013). That means, at a higher PPFD, leafy vegetables require a shorter photoperiod to grow well. Generally, leafy vegetables or herbs growing under natural sunlight (6–8 hours of photoperiod) require daily light integral intensity around 16–19 mol $m^{-2} d^{-1}$, i.e., equivalent to 185–219 µmol $m^{-2} s^{-1}$ (Nate, 2021). As light intensity increases, more photons will strike the chlorophyll pigments, increasing plants' photosynthetic rate and growth (Halliday *et al*., 2007). However, for sunlight-dependent VFS, data are still lacking on the methods to ensure the plants will receive uniform solar radiation.

SUMMARY

Based on the above review, it can be summarised for the leafy (*Brassica*) vegetable industry in Malaysia that:

(1) The local leafy vegetable production is markedly lower than the demand. Leafy vegetables have to be imported to meet the consumption.
(2) Leafy vegetable production per unit area can be increased by applying technology, such as the use of soilless farming technology, particularly the VF and VFS.
(3) Around the world, the attempt to encourage farmers to be interested in VF and VFS, as well as the process to get these matters into practice, is progressing, but the achievement rate is slow, although there is an increase in scientific papers published about VF and VFS. Some of the papers, however, cover only conceptual ideas based on the general public's opinion and old studies or case studies with little data. Some of the ideas are also not tested or researched enough. Even if there is information, probably, the information is confidential and not published. Generally, information on commercial VFs and VFSs is rarely published. Hence, no specific technical information can be modified for use in Malaysia.
(4) In Malaysia, VF and VFS are also gaining attention, but there is only a little progress in the applications. A lot of agronomic and technical information about VF and VFS is not yet available, or even if available, the information has not been shared with most of the local vegetable farmers. There is also a lack of publications or reports on VFs and VFSs from government or private agencies.
(5) Of the many designs of VFSs, the CHS is the most effective in increasing leafy vegetable yield per unit area. However, some CHS-features limit Pak Choy's production in the system,

especially factors associated with plant spacing (i.e., related to column spacing) and light intensity.

The above review indicated that Malaysia's leafy (*Brassica*) vegetable industry is not yet agronomically ready to embark on VF and VFS. There is still much agronomic and technical information about VF and VFS unavailable to vegetable farmers. Even the information on effective VFS, such as the CHS, is little known and seldom reported. Generally, there is a need to generate more agronomic and technical information about the CHS so that the application of this VFS by many more local farmers will come to a realisation to mitigate the supply shortage and the high foreign exchange of leafy (Pak Choy) vegetables in Malaysia.

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REFERENCES

[1] Adam, M. 2021. *Top 3 Best Types of Vertical Farming System* (https://mygreenvalue.com/top-3-best-types-of-vertical-farming-systems/). Last accessed on 12 September 2021.

[2] Ahmad, A. 2021. *Interactive: Young Entrepreneurs Thriving on Aquaponic Farming* (https://www.thestar.com.my/news/nation/2021/04/03/interactiveyoungentrepreneurs-thriving-on-aquaponic-farming). Last accessed on 02 November 2021.

[3] Al-Kodmany, K. 2018. The vertical farm: A review of developments and implications for the vertical city. *Buildings*, 8(2), 24.

[4] Anonymous. 2019. *Sabah Green Sanctuary* (https://www.sabahgreensanctuary.com/). Last accessed on 07 November 2021.

[5] Anonymous. 2020. *Agriculture Sector* (https://www.trade.gov/knowledgeproduct/malaysia-agricultural-sector). Last accessed on 07 June 2021.

[6] Anonymous. 2021. *Malaysia/ Imports and Exports/ World/ Cabbages, Cauliflowers, Kohlrabi, Kale/ Value (US$) and Value Growth, YoY (%)/ 2009–2020* (https://trendeconomy.com/data/h2/Malaysia/0704). Last accessed on 22 July 2021.

[7] Anonymous. 2022a. *Overview of Global Bok Choy Market* (https://www.tridge.com/intelligences/bok-choy/import). Last accessed on 26 April 2022.

[8] Anonymous. 2022b. *Vertical Hydroponic – A Basic Introduction* (https://www.trees.com/gardening-and-landscaping/vertical-hydroponics). Last accessed on 29 December 2022.

[9] Baiyin, B., Tagawa, K., Yamada, M., Wang, X., Yamada, S., Yamamoto, S. & Ibaraki, Y. 2021. Effective of substrate flow rate on nutrient uptake and use efficiency in hydroponically grown swiss chard (*Beta vulgaris* L. ssp. *cicla* 'Seiyou Shirokuki'). *Agronomy*, 11, 2050.

[10] Baudoin, W. O. & Zabeltiz, C. H. R. 2002. Greenhouse construction for scale farmer in tropical regions. *Acta Horticulturae*, 578, 171-179.

[11] Beacham, A. M., Vickers, L. H. & Monaghan, J. M. 2019. Vertical farming: a summary of approaches to growing skywards. *Journal of Horticultural Science and Biotechnology*, 94(3), 277-283.

[12] Benton, J. Jr. 2014. *Complete Guide for Growing Plants Hydroponically*. Boca Raton: CRC Press.

[13] Birkby, J. 2016 Vertical farming. *ATTRA Sustainable Agriculture*, IP516, 1-12.

[14] Boomgrow. 2022. *Boomgrow* (https://www.linkedin.com/company/boomgrow). Last Accessed on 29 December 2022.

[15] Cartea, M. E., Lema, M., Francisco, M. & Velasco, P. 2011. Basic Information on Vegetable Brassica Crops. *In*: Sadowsky, J. & Kole, C. (Eds.). *Genetics, Genomics and Breeding of Vegetable Brassicas* (1st edition). Boca Raton: CRC Press.

[16] Chin, C. F. 2020. The impact of food supply chain disruptions amidst covid-19 in Malaysia. *Journal of Agriculture, Food System, and Community Development*, 9(4), 161-163.

[17] CityFarm Malaysia. 2021. *Hydroponic A and B Liquid Fertilizer for Leafy Greens* (https://cityfarm.my/products/hydroponics-fertilizer). Last accessed on 09 October 2021.

[18] CityFarm Malaysia. 2022a. *Pak Choy* (https://cityfarm.my/collections/pak-choy). Last accessed on 25 April 2022.

[19] CityFarm Malaysia. 2022b. *4 Level Plant Factory with Artificial Light (PFAL) Module* (https://cityfarm.my/collections/all-hydroponic-setup/products/custom-setup). Last accessed on 12 October 2022.

[20] CityFarm Malaysia. 2022c. *Germination and Growing Media* (https://cityfarm.my/collections/growing-media-1). Last accessed on 29 December 2022.

[21] Ding, X., Jiang, Y., Zhao, H., Guo, D., He, L., Liu, F., Zhou, Q., Nandawi, D., Hui, D. & Yu, J. 2018. Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of Pakchoi (*Brassica campestris* L. ssp. *chinensis*) in a Hydroponic System. *PLoS ONE*, 13(8), e0202090.

[22] Dardak, R. A. 2015. *Transformation of Agricultural Sector in Malaysia through Agricultural Policy* (https://ap.fftc.org.tw/article/818). Last accessed on 26 May 2021.

[23] Dayangku, S. 2021. *It Took this Malaysian Smart Farm 5 Years to Find an Ideal Method to Grow Pesticide-Free Vegetable* (https://vulcanpost.com/753391/boomgrow-malaysia-smart-farm-organic-vegetable-delivery/). Last accessed on 29 December 2022.

[24] Department of Agriculture (DOA). 2020. *Vegetables and Cash Crop Statistics Malaysia 2020* (https://fliphtml5.com/flqg/suyx/basic). Last accessed on 11 July 2022.

[25] Department of Agriculture (DOA). 2021. *Vegetables and Cash Crop Statistic Malaysia 2021* (http://www.doa.gov.my/index/resources/aktiviti_sumber/sumber_awam/maklumat_pertanian/perangkaan_tanaman/statistik_tanaman_sayur_tanaman_kontan_2021.pdf). Last accessed on 06 January 2023.

[26] Department of Statistic Malaysia (DOSM). 2020a. *Current Population Estimates, Malaysia, 2020* (https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=155&bul_id=OVByWjg5YkQ3MWFZRTN5bDJiaEVhZz09&menu_id=L0pheU43NWJwRWVSZklWdzQ4TlhUUT09#:~:text=The%20growth%20rate%20of%20Citizens,to%2029.7%20million%20in%202020). Last accessed on 30 December 2022.

[27] Department of Statistic Malaysia (DOSM). 2020b. *Selected Agricultural Indicator, Malaysia, 2020* (https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=RXVKUVJ5TitHM0cwYWxlOHcxU3dKdz09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09). Last accessed on 13 April 2022.

[28] Department of Statistic Malaysia (DOSM). 2021. *Selected Agricultural Indicator, Malaysia, 2021* (https://www.dosm.gov.my/v1/index.php?r=column/cthemeByCat&cat=72&bul_id=TDV1YU4yc1Z0dUVyZ0xPV0ptRlhWQT09&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09). Last accessed on 06 January 2023.

[29] Despommier, D. 2010. *The Vertical Farm: Feeding the World in the 21st Century*. New York: Picador.

[30] Despommier, D. 2019. Vertical farms, building a viable indoor farming model for cities. *In*: Martin-Moreau, M. & Ménascé, D. (Eds.). *Urban Agriculture: Another Way to Feed Cities.* Aubervilliers: Institut Veolia.

[31] Digital News Asia. 2020. *MaGIC's GAP Cohort 4 Startups Post Revenue Growth of 53%* (https://www.digitalnewsasia.com/entrepreneurial-nation/magics-gap-cohort-4-startups-post-revenue-growth-53). Last accessed on 23 May 2021.

[32] Drakes, D., Briercliffe, T., Lightfoot-Brown, S., Arnold, D. & Mackay, N. 2001. *The Use and Disposal of Growing Media – Summary of Current Practice* (https://www.hse.gov.uk/pesticides/pesticides-registration/data-requirements-handbook/fate/resources/use-disposal-growing-media-adas.pdf). Last accessed on 29 December 2022.

[33] Eigenbrod, C. & Gruda, N. 2015. Urban vegetable for food security in cities: A review. *Agronomy for Sustainable Development*, 35, 483-498.

[34] Fajar Saintifik. 2022. *Indoor Farming-Plant Factory* (https://fajar.com.my/indoor-farming/plant-factory/). Last accessed on 06 May 2022.

[35] Federal Agricultural Marketing Authority (FAMA). 2021. *Memperkukuhkan Industri Sayur-Sayuran dan Buah-Buahan serta Memulihkan Industri Kelapa* (https://www.fama.gov.my/documents/20143/64638/Bab+6+-+Memperkukuhkan+Industri+Sayur-sayuran+dan+Buah-buahan+serta+Memulihkan+Industri+Kelapa.pdf/bad0fcab-44f5-397a-781c-4098a9c6b590). Last accessed on 29 December 2022.

[36] Food and Agriculture Organization (FAO). 2013. *Good Agricultural Practices for Greenhouse Vegetable Crops: Principles for Mediterranean Climate Areas*. Rome: Food and Agriculture Organization (FAO) of The United Nations.

[37] Gobilik, J., Rechard, C. T., Maludin, A. J., Alam, M. A. & Benedick, S. 2021. Efficacy of column hydroponic system for increasing growth and yield of Pak Choy (*Brassica rapa* L.) per unit area. *Transactions on Science and Technology*, 8(1), 7-24.

[38] Goh, D. 2019. *John-Hans Oei on How Cultiveat is Revolutionising Agriculture in Malaysia* (https://www.augustman.com/my/amselect/john-hans-oei-on-how-cultiveat-is-revolutionising-agriculture-in-malaysia/). Last accessed on 02 November 2021.

[39] Gohler, F., HeiBner, A. & Schmeil, H. 1989. Control of Water and Nutrient Supply in Greenhouse Vegetable Production by Means of Hydroponic Systems. *Acta Horticulturae*, 260, 237-246.

[40] Gomez-Merino, F. C. & Trejo-Tellez, L. I. 2012. *Nutrient Solution for Hydroponic Systems. In Hydroponics: A Standard Methodology for Plant Biological Researches.* Rijeka: InTech.

[41] He, J., Qin, L. & Chow, W. S. 2019b. Impacts of LED spectral quality on leafy vegetables: productivity closely linked to photosynthetic performance or associated with leaf traits. *International Journal Agricultural and Biological Engineering*, 12(6), 16-25.

[42] He, J., Qin, L., Teo, L. J. L. & Choon, T. W. 2019a. Nitrate accumulation, productivity and photosynthesis of *Brassica alboglabra* grown under low light with supplemental LED lighting in the tropical greenhouse. *Journal of Plant Nutrition*, 42(15), 1740-1749.

[43] Heath, T., Zhu, Y. & Shao, Z. 2012. *Vertical Farm: A High-Rise Solution to Feeding the City?* Shanghai: Council on Tall Buildings and Urban Habitat (CTBUH) 2012 9th World Congress.

[44] Herr, I., & Buchler, M. W. 2010. Dietary constituents of broccoli and other cruciferous vegetables: implication for prevention and therapy of cancer. *Cancer Treatment Reviews*, 36(5), 377-383.

[45] Hussain, A., Iqbal, K., Aziem, S., Mahato, P. & Negi, A. K. 2014. A review on the science of growing crops without soil (soilless culture) – A novel alternative for growing crops. *International Journal of Agriculture and Crop Sciences*, 7(11), 833-842.

[46] Kalantari, F., Tahir, O. M., Lahijani, A. M. & Kalantari, S. 2017. A review of vertical farming technology: a guide for implementation of building integrated agriculture in cities. *Advanced Engineering Forum*, 24, 76-91.

[47] Kalantari, F., Tahir, O. M., Joni, R. A. & Fatemi, E. 2018. Opportunities and challenges in sustainability of vertical farming: a review. *Journal of Landscape Ecology*, 11(1), 35-60.

[48] Kang, J. H., Kumar, S. K., Atulba, S. L. S., Jeong, B. R. & Hwang, S. J. 2013. Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. *Horticulture, Environment, and Biotechnology*, 54(6), 501-509.

[49] Khedr, A. F., Kishk, S. S. & Zedan, M. I. 2022. Impact of "A" frame angle design on hydroponic system production. *Misr Journal of Agricultural Engineering*, 39(3), 391-408.

[50] Kozai, T. 2018. The Next Generation Indoor Vertical Farms. *In*: Kozai, T. (Ed.). *Smart Plant Factory*. Singapore: Springer.

[51] Lawlor D.W. 2002. Limitation to Photosynthesis in Water-stressed Leaves: Stomata vs. Metabolism and the Role of ATP. *Oxford Journals, Annals of Botany*, 89, 871-885.

[52] Looi, C. B. 2018. *CityFarm's Jayden Koay: Let the Lettuce Bloom, Even When There's Little Room* (https://cityfarm.my/blogs/cityfarm-press-release/astro-awani-cityfarms-jayden-koay-let-the-lettuce-bloom-even-when-theres-little-room). Last accessed on 29 December 2022.

[53] Maludin, A. J., Lum, M. S., Lassim, M.M. & Gobilik, J. 2020. Optimal plant density, nutrient concentration and rootzone temperature for higher growth and yield of *Brassica rapa* L. 'Curly Dwarf Pak Choy' in raft hydroponic system under tropical climate. *Transactions on Science and Technology*, 7(4), 78-188.

[54] MARDI. 2014. *MARDI Perkenal Teknologi Pertanian Menegak* (https://blogmardi.wordpress.com/2014/03/03/mardi-perkenal-teknologi-pertanian-menegak/). Last accessed on 06 January 2023.

[55] Miwil, O. 2022. *Ranau Quake Victim Helping Community Trough Hydroponic Farming* (https://www.nst.com.my/news/nation/2022/06/809196/ranau-quake-victim-helping community-through-hydroponic-farming). Last accessed on 16 August 2022.

[56] Nate, L. 2021. *Do You Have Enough Natural Light for Plants* (https://www.geturbanleaf.com/blogs/lighting/enough-lighting-for-plants). Last accessed on 09 July 2022.

[57] Nemali, K. S. & Van Iersel, M. W. 2004. Light intensity and fertilizer concentration in estimating optimal fertilizer concentration from water-use efficiency of wax begonia. *HortScience*, 39, 1287-1292.

[58] Ng, C. 2016. What it Means to be a farming smallholder in Malaysia. *UTAR Agriculture Science Journal*, 2(1), 40-48.

[59] Nguyen, T. P. D., Tran, T. T. H. & Nguyen, Q. T. 2019. Effect of light intensity on the growth, photosynthesis and leaf microstructure of hydroponic cultivated spinach (*Spinacia oleracea* L.) under a combination of red and blue LEDs in house. *International Journal of Agricultural Technology*, 15(1), 75-90.

[60] Nguyen, T. P. D., Vu, N. T., Nguyen, Q. T., Tran, T. T. H., Cao, P. B., Kim, I. S. & Jang, D. C. 2022. Quality of hydroponic cultivated spinach (*Spinacia oleracea* L.) affected by the light intensity of red and blue LEDs. *Sains Malaysiana*, 51(2), 473-483.

[61] OECD. 2016. *Safety Assessment of Transgenic Organism in the Environment*. Paris: OECD Publishing.

[62] Oztekin, G. B., Uludag, T. & Tuzel, Y. 2018. Growing spinach (*Spinacia oleracea* L.) in a floating system with different concentrations of nutrient solution. *Applied Ecology and Environmental Research*, 16(3), 3333-3350.

[63] Parks, S. & Murray, C. 2011. *Leafy Asian Vegetables and Their Nutrition in Hydroponics* (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/385576/Leafy-Asian-veg-final-Low-Res.pdf). Last accessed on 08 May 2021.

[64] Penang Institute. 2020. *Penang Agricultural Policy Report* (https://penanginstitute.org/wp-content/uploads/2020/10/Penang-Agricultural-Policy-report-final.pdf). Last accessed on 08 June 2021.

[65] Priadi, D. & Nuro, F. 2017. Seedling production of Pak Choy (*Brassica rapa* L.) using organic and inorganic nutrients. *Biosaintifika*, 9(2), 217-224.

[66] Priadi, D., Wibowo, H. & Mulyaningsih, E. S. 2019. The growth optimization of Pak Choy (*Brassica rapa* L. var. *chinensis*) in household-scale aquaponic system. *Jurnal Biodjati*, 4(2), 175-183.

[67] Prieto, K. R., Echaide-Aquino, F., Huerta-Robles, A., Valerio, H. P., Macedo-Raygoza, G., Prado, F. M., Medeiros, M. H. G., Brito, H. F., da Silva, I. G. N., Cunha Felinto, M. C. F., White Jr., J. F., Di Mascio, P. & Beltran-Garcia, M. J. 2017. Endophytic bacteria and rare earth elements; promising candidates for nutrient use efficiency in plants. *In*: Hossain, M.A., Kamiya, T., Burritt, D.J., Phan Tran, L.S., Fujiwara, T. (Eds.). *Plant macronutrient use efficiency: Molecular and Genomic Perspectives in Crop Plants*. London: Academic Press.

[68] Rabu, M. R. & Muhammad, R. M. 2015. *The Potential of Urban Farming Technology in Malaysia: Policy Intervention* (https://ap.fftc.org.tw/article/965). Last accessed on 06 March 2021.

[69] Rahman, Y. 2012. *MARDI Vertical Farming Research Institute* (https://mdrxa.wordpress.com/architecture/mardi-vertical-farming/). Last accessed on 28 May 2021.

[70] Rakow, G. (2004). Species origin and economic importance of Brassica. *In*: Pua, E. C., Douglas, C. J. (Eds.) *Brassica: Biotechnology in agriculture and forestry* (Vol. 54) (https://doi.org/10.1007/978-3-662-06164-0_1). Berlin: Springer.

[71] Refarmers. 2016. *ZipGrow Vertical, Easy, Efficient* (https://wfghub.blob.core.windows.net/b4fdb68b97a83cff3fbe67337909f932/ZipGrow-Vertical-Easy-Efficient2016_65rjn.pdf). Last accessed on 06 January 2023.

[72] Resh, H. M. 2013. *Hydroponic Food production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower* (7th edition). Florida: CRC Press.

[73] Sakamoto, M. & Suzuki, T. 2015. Effect of root-zone temperature on growth and quality of hydroponically grown red leaf lettuce (*Lactuca sativa* L. cv. Red Wave). *American Journal of Plant Science*, 6, 2350-2360.

[74] Savvas, D., Gianquinto, G., Tuzel, Y. & Gruda, N. 2013. Soilless culture. *In*: Baudoin, W., Nono-Womdim, R., Lutaladio, N., Hodder, A., Castilla, N., Leonardi, C., de Pascale, S., Qaryouti, M. and Duffy, R. (FAO Plant Production and Protection Paper 217). *Good agricultural practices for greenhouse vegetable crops: Principles for Mediterranean climate areas*. Rome: Food and Agriculture Organization (FAO) of The United Nations.

[75] Shaharudin, A. A. 2020. *Protecting the Agriculture Sector During the COVID-19 Crisis* (https://www.krinstitute.org/assets/contentMS/img/template/editor/200330%20Views_Agri%20COVID-19_EN.pdf). Last accessed on 29 December 2022.

[76] Shamshiri, R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., Ahmad, D. & Shad, Z. M. 2018. Advances in greenhouse automation and controlled environment agriculture: a transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering*, 11(1), 1-22.

[77] Shao, Y., Heath, T. & Zhu, Y. 2016. Developing an economic estimation system for vertical farms. *The International Journal of Agricultural and Environmental Information Systems*, 7(2), 26-52.

[78] Singh, H. & Dunn, B. 2021. *Building a Vertical Hydroponic Tower* (https://extension.okstate.edu/fact-sheets/building-a-vertical-hydroponic-tower.html). Last accessed on 09 March 2021.

[79] Storey, A. 2016. *Pros and Cons of Hydroton (Clay Pebbles) in Hydroponic* (https://university.upstartfarmers.com/blog/pros-cons-hydroton-hydroponics). Last accessed on 07 October 2021.

[80] Takeshima, H. & Joshi, P. K. 2019. *Protected Agriculture, Precision Agriculture and Vertical Farming: Brief Reviews of Issues in the Literature Focusing on the Developing Region in Asia*. Washington: International Food Policy Research Institute.

[81] Tan, V. 2021. *Price Hike of Vegetables in Malaysia Due to Weather, Labour Shortage and Production Costs, Say Farmers* (https://www.channelnewsasia.com/asia/malaysia-vegetable-price-hikes-2345001). Last accessed on 19 April 2022.

[82] Tao, M. 2019. *Top 25 Vertical Farming Companies* (https://roboticsandautomationnews.com/2019/05/03/top-25-vertical-farming-companies/22181/). Last accessed on 06 January 2023.

[83] Thomas, B. M. & Awadh, D. G. 2020. Light quality and photoperiod influence crop growth, productivity and produce quality in hydroponic vegetables production. *Acta Horticulture*, 1273, 271-280.

[84] Touliatos, D., Ian, C. D. & Martin, M. 2016. Vertical Farming Increases Lettuce Yield Per Unit Area Compared to Conventional Horizontal Hydroponics. *Food and Energy Security*, 5(3), 184-191.

[85] United Nations (UN). 2019. *How Certain Are the United Nations Global Population Projections* (https://www.un.org/en/development/desa/population/publications/pdf/popfacts/PopFacts_2019-6.pdf). Last accessed on 29 December 2022.

[86] Velazquez-Gonzalez, R. S., Garcia-Garcia, A. L., Ventura-Zapata, E., Barceinas-Sanchez, J. D. O. & Sosa-Savedra, J. C. 2022. A review on hydroponics and the technologies associated for medium and small-scale operation. *Agriculture*, 12, 646.

[87] Wang, Y. & Folta, K. M. 2013. Contributions of green light to plant growth and development. *American Journal of Botany*, 100(1), 70-78.

[88] Wiggins, Z. D., Akaeze, O., Nandwani, D. & Witcher, A. 2020. Substrate Properties and Fertilizer Rates on Yield Responses of Lettuce in a Vertical Growth System. *Sustainability*, 12, 6465.

[89] World Health Organization (WHO). 2021. *COVID-19 Situation Reports for Malaysia* (https://www.who.int/malaysia/emergencies/covid-19-in-malaysia/situation-reports). Last accessed on 30 April 2021.

[90] Zainudin, A. 2019. *Percepat Tempoh Tuaian* (https://www.hmetro.com.my/xpresi/2019/09/499150/percepat-tempoh-tuaian). Last accessed on 02 November 2021.

[91] Zhou, J., Li, P. & Wang, J. 2022. Effect of light intensity and temperature on the photosynthesis characteristics and yield of lettuce. *Horticulturae*, 8, 178.