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The Potential of Vertical Farming in Brunei Darussalam

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Abstract

The issue of food security in Brunei justifies the need to increase the local agricultural production effectively due to the constraint of land scares for farming where the soil acidity in Brunei is high which affect the crop production. Furthermore, climate change has affected the way we do farming. Vertical Farming (VF) plays an important role in modern agricultural practices today. VF has the potential to produce crops all year round and using less land. Therefore, the aim of this paper is to highlight how VF works and determine the economic potential of vegetables vertical farming in Brunei. It is a content analysis of literature review. The findings show the potential of vegetables vertical farming in Brunei although may face some challenges. The findings may benefit the policymakers and farmers moving towards modern application of vertical farming and attract the interest of youth to participate in the agricultural sector.

1.0 Introduction

Agriculture has always been and continues to be extremely important globally and contributes significantly to economic growth and development (Blandford, 2011; Mănescu et al., 2016). According to the World Bank (2021), agriculture accounted for 4% of global gross domestic product (GDP) in 2018, and in some developing countries, it accounted for more than 25% of GDP. With the rapid growth of the global population, it is expected to rise to 10 billion people by the year 2050 and the world's food production needs to increase 70 per cent by the year 2050 (UN,2018; FAO, 2021). Furthermore, around 7 billion people worldwide are expected to live in urban cities (UN, 2018). According to D'Amour et al. (2017), urban expansion is projected in a 1.8-2.4% loss of global farmlands by the year 2030, and the Asia region would be the most likely to experience urban expansion; highest loss in farmlands, whereas Africa with highest percentage loss of farmlands (Ambroise, 2019; D'Amour et al., 2017). Therefore, food security has become a critical issue for countries with different levels of economic development, and the agricultural sector plays a vital role in improving food availability and with the rapid urbanisation, urban agriculture is in high demand (Chatterjee et al., 2020; Pawlak et al., 2020). In the context of Brunei Darussalam, the economy is still heavily relying on its hydrocarbon resources, such as oil and gas upstream and downstream industries and has been known for its exports and revenue for the past 90 years (ITA, 2019; Wawasan Brunei, 2021). While, the low price of oil in 2013 has affected the budget deficit and weakened economic growth (The Commonwealth, 2021). Moreover, according to the Labour Force Survey (2020), the unemployment rate in Brunei has increased from 6.8% in 2019 to 7.4% in 2020. Therefore, Brunei Darussalam would be vulnerable to economic shocks, posing challenges to Bruneian's lives.

According to the Department of Agriculture and Agrifood (DAA) (2021), agriculture is one of Brunei Darussalam's primary and most essential contributor sectors to the country's economic diversification. Therefore, the growth and development of agriculture industries will support the country's vision of 'Wawasan 2035', which is to achieve a dynamic and sustainable economy. The Minister at Prime Minister Office (PMO) delivered his speech at the United Nation Foods Systems Summit (UNFSS) in 2021, ''Brunei Darussalam's commitment to strengthen the food system by accelerating the production growth of the agriculture and fisheries sector; promoting both domestic and foreign direct investment (FDI); and increasing productivity through the use of technology to meet domestic demand and for export" (PMO, 2021). In 2019, Brunei's sources of food were obtained through imports from over ninety countries (MOFE, 2020). Between 2015 and 2020, Brunei's overall trend of importation of food has been increasing while the exportation of food has been stagnant, resulting in the trade balance in the food sector being increasingly deficit (Department of Economic Planning and Statistics, 2021). The overall trend of Brunei's agriculture GDP is increasing. The highest Brunei's agriculture GDP was recorded at B$91.36 million in 2018 and the lowest at B$89.07 million in 2015. However, the contribution of agriculture's GDP towards Brunei's GDP has been very low. The data for the year of 2015-2020, shown the contribution of agriculture sector was averaging 0.53 percent (DoAA, 2021).

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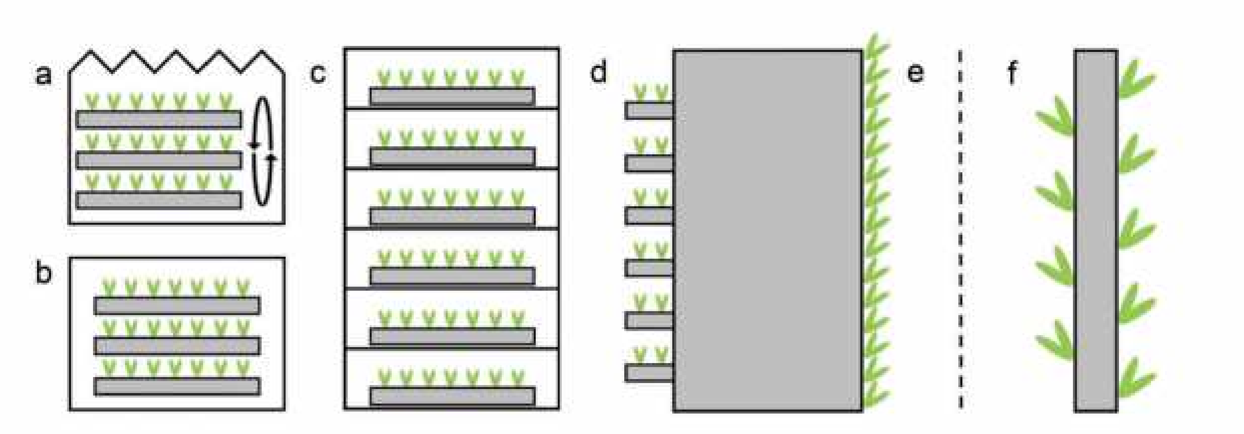
As the concern now is heavily on the food security, therefore, the ministry concerned stressing on the important of local production. However, one of Brunei's constraints is the limited land space for agricultural purposes. This issue was confirmed by the MPRT Dato Seri Setia Awang Haji Apong in 2017 during the signing ceremony for Brunei and Singapore for Vertical-Land-based and Aquaculture Farming projects in Brunei. ''Although Brunei Darussalam is slightly bigger than Singapore, the land limitation is also one of our constraints'' (MPRT, 2017). According to the Ministry of Primary Resources and Tourism (MPRT) (2021a), during Brunei Mid-Year Conference and Exhibition (MYCE) 2021 on the 'Forests and Biodiversity: Unveiling its Economic Potential, 72% of Brunei's total land area is currently forested which in pristine condition and yet to be explored (Department of Forestry, 2021). Moreover, according to the Secretariat of the Convention on Biological Diversity (2022), Brunei's forest reserves account for 41% of the total land area and 15% of the land is purposed for gazettement. Therefore, most of the land in Brunei is reserved for forest conservation, and there is little for agricultural purposes. According to the preliminary research from the Head of the Department of Agriculture and Agrifood's Agricultural Site Unit, Farah Ani Hj Gapor, the current status of the agricultural site as of 2021, the total government land gazetted area under the department is 8,244.69 hectares. Moreover, according to Agriculture and Agrifood Statistics 2020 (2020), total overall Brunei's developed agricultural land for crops and livestock is 10,020.73 hectares. The developed agricultural land for crops accounts for 52.3% (5,242.20 hectares), while the developed agricultural land for livestock accounts for 47.7% (4,778.53 hectares).

According to the Department of Agriculture of Brunei (2008) on the project 'Soil Fertility Evaluation/Advisory Service in Negara Brunei Darussalam'. Under the Soils and Land Suitability of the Agricultural Development of Area concludes that the soil acidity is high in Brunei, with pH values between 4.2 and 4.9. Thus, it affects crop production due to toxic chemicals and deficiencies in micronutrients. Moreover, Brunei's climate, landscape, and soils predisposed much of the country to waterlog due to high rainfall, shallow groundwater (typically less than 0.5m from the surface), perched water table (overlying unsaturated soil), poor surface drainage and convergent runoff. It is evident that Brunei is facing land limitations for agricultural purposes and most of the soil in Brunei is not suitable for farming due to high soil acidity that affects crop production, climate, landscape and soil predisposition. Therefore, the aim of this paper is to highlight how VF works and determine the economic potential of vegetables vertical farming in Brunei. Vertical Farming (VF) is one of the modern agricultural solutions for urban agriculture to tackle these problems. It is a content analysis of literature review. In the context of this paper, VF is a system of commercial urban indoor farming of vegetables which can be done vertically. VF can significantly boost agricultural productivity and enhance overall efficiency, while lowering the agricultural sector's environmental footprint by reducing the usage of land, water, chemicals, and fertilisers.

2. Literature Review

One of the ways to deal with the issues of local vegetables production is to introduce vertical farming (VF). There are several definitions of VF have been defined by scholars. First, Banerjee et al. (2014) described VF as a system of commercial farming whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fibre or other products or services by artificially stacking them vertically above each other. Second, Chalabi (2015) defined VF as 'the urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre'. Third, Lu & Grundy (2017) defined VF as 'an indoor agricultural strategy to growing food in protected environments (e.g., buildings, glasshouses)'. Finally, Oliviera et al. (2020) defined VF as a method of food production that uses vertical dimension to grow crops hydroponically'. The concept of VF was coming into known by Professor Despommier, where hydroponics and aeroponics are utilised in farms to produce yields faster (Grag, 2014). Furthermore, VF can also be integrated into aquaponics (Chaudhry & Mishra, 2019). There are three types of VF. The first one is Hydroponics, commonly used growing system in a vertical farm. Hydroponics involves growing plants in the nutrient solutions as a growing medium (Birkby, 2016; Al-Kodmany, 2018). The plant roots are immersed in the nutrient solution, which is monitored and circulated regularly to ensure that the proper chemical composition is maintained (Birkby, 2016). Secondly, aeroponic is the practice of growing plants with their root systems floating in the air and a nutrient solution sprayed at the roots to keep a constant film of nutrients and moisture (He, 2013). Lastly, aquaponic is the method of cultivating plants and fish in the same system that relies on the biotic relationship between fish and bacteria (Santos et al., 2021). Beacham et al. (2019) mentioned that the VF system can be categorised into two; multiple of levels of traditional horizontal growing platform and the crops are grown in a vertical surface (Beacham et al. 2019).

Figure 1



Sources: Beacham et al. (2019)

Figure 1 shows representation types of VF, where (a) multiple layers of horizontal growing surfaces in a stacked horizontal system, (b) the use of controlled-environment facilities, (c) multi-floor towers in which each level is separated from the surrounding (e) a stacked horizontal VF system, balconies (d) Green walls, on the sides of the buildings, other vertical surfaces and (f) cylindrical growth units along with the vertical arrangement of the plant (Beacham et al., 2019). Practically, vertical farms can be built almost anywhere, and with the global warming where extreme temperature or adverse weather conditions, farmers can be guaranteed of cultivating crops at ease (Miller, 2020). Kalantari et al. (2018) presented a successful vertical city farm worldwide such as the US, Canada, Singapore, South Korea, Japan, Holland, Sweden, and China that can be found in figure 2.

N	Name	Location	Height	Type of Building	Products	Area	Technology	year	Website
1	The Plant Vertical Farm	Chicago, IL	3story	Existing building in 19 century	Wide variety of edible crops includes an artisanal brewery, kombucha brewery, mushroom farm, and bakery, Tilapia	100,000 sq.ft	-Aquaponics systems and fish breeding areas - Hydroponic -Recycling waste to energy - Using biogas from an anaerobic digester -Natural sun energy	2013	www.plantchicago.com
	S ky Greens Farms	Singapore	9 m	New	leafy green vegetables	600 m	-Aeroponuic system -Low carbon hydraulic water-driven -Natural sun energy	2009	www.skygreens.appsfly.com
	V ertiCrop TM	Vancouver, Canada		Rooftop of existing building	Leafy greens, micro greens, and strawberries	50*75 Sq.ft, 120 racks with 24 growing trays on each rack = 16-acre farm.	-Fully automated system - Closed loop conveyor hydroponic -Room temperature, lighting, fertilization, irrigation and recapturing of the water being used - Natural and artificial light	2009	www.verticrop.com
4	Republic of South Korea VF	South Korea	3 story	New	leafy green vegetables ,almost wheat, and corn	450 m²	-Renewable resources like geothermal and solar -Automated rack system - LED	2011	www.cityfarmer.info/
5	Nuvege plant factory	Japan (Kyoto)	4 story		Leafy green vegetables	30,000 horizontal sq.ft 57,000 sq.ft of vertical growing space	-Automated rack system -LED grow lights -Hydroponics		www.nuvege.com
6	Plantlab VF	Den Bosch, Holland	3 story under-ground	Existing building	every imaginable crop, including beans, corn, cucumbers, tomatoes, and strawberries		-Without the use of daylight - Advanced LED -Aeroponic and hydroponic	2011	www.plantlab.nl/
7	Vertical Harvest plans2	Jackson Wyoming, USA	3 story	New	tomatoes, strawberries, lettuce, and micro greens	4500 sq.ft. footprint into 18,000 sq.ft., or four times the growing area	-Recirculating hydroponic methods - LED	2012	www.verticalharvestjackson.com/
8	Planned Vertical Farm	Linkoping, Sweden	17 story	New	Asian leafy green vegetables		**-Aeroponic** -Hydroponic -Using waste products in the process - Natural lighting	2012	www.plantagon.com
9	Green Sense Farms	-First farm in : Portage, Indiana -Shenzhen, china		New	-Micro Greens -Baby Greens -Herbs -Lettuces	20,000 sq./ft	-Using stacking vertical towers -Using automated computer controls, which provide the precise amount of light, nutrients, water, temperature, and humidity - Minimize waste, and recycle water technique	- 2014 -2016	http://www.greensensefarms.com
0	**A eroFarms**	Newark, New Jersey	9 m	New	**250 different types of herbs and greens grow like kale, arugula, and mizuna.**	**20 ,000-sq/ft with 35 rows and 12 levels of vertically grown**	-Without any soil, pesticides, or sunlight. -Crops sit on stacked trays outfitted - LED lights -Using Sensors that track the growing process. - Recycle water technique	2012	http://aerofarms.com/

Figure 2: Details some of the vertical farms around the world Sources: Kalantari et al., (2018)

Vertical Farming has the potential to produce crop all year round in a controlled environment, eliminating the cost of transportation, improving food safety and biosecurity, and reducing reduced inputs such as water supply, pesticides, herbicides, and fertilisers (Benke & Tomkins, 2017). Furthermore, it also alleviates pressure on agricultural lands by farming vertically rather than horizontally, thus incorporating soil-free growing systems can appeal to urban environments (Beacham et al., 2019). In 2020, the market size of VF was valued at $3.24 billion and is projected to reach $24.11 billion by the year 2030 (Allied Market Research, 2021). Therefore, these agricultural technologies will be redefining the food industry in the years to come. Vertical Farming has been identified as an essential tool for managing future food security and is gaining popularity throughout several urban cities due to its beneficial role in the agriculture sector (Oliviera et al., 2020; Chatterjee et al., 2020). Therefore, it is important to study the potential of VF in Brunei, where it ensures the highest yield per hectare compared to traditional farming.

3. Issues Related to Farming

Food Security

The Food and Agriculture Organization (2008) defined food security as "all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". There are three main aspects that food security relies on food availability, food access and food quality (Eigenbrod & Gruda, 2015). Despite the increased global food production in the past decades, more than 750 million people still suffer from undernourishment, mainly in developing countries (FAO, 2021). Food security in developing countries suffers the most from the current food production due to population increase alongside the intensifying environmental catastrophic events such as floods, drought, extreme temperatures and rainfall (Ahmet et al., 2017). It is expected that climate change would lead to changes in ideal crop varieties, seasonal conditions, extreme weather events such as high temperature, heavy rainfall and atmospheric conditions such as CO2 (Lin et al., 2022). Furthermore, the issue of food insecurity is not only caused by the shortage of food supply but also a lack of purchasing power and access at national and household levels (Ahmed et al., 2017). As a result of the decrease in food supply brought on by climate change, consumers have to bear additional costs for obtaining food, thus reducing their access to it (Liu et al., 2022). Moreover, the need of food security interventions, such as food relief and subsidised food production, must be targeted to minimise food insecurity in these areas (Buye, 2021). Such factors can impact food security, including unsustainable economic growth, wars, trade imbalances, natural resource scarcity, gender inequity, inadequate education, and poor health (Buye, 2021).

Urbanisation

Urbanisation is "the process of which a large number of people become permanently concentrated in a relatively small area, forming cities" (Britannica, 2021). According to the UN (2018), the world's rural population has stagnated; however, it is expected that the world's urban population will continue to increase a further seven billion to urban cities. Furthermore, urbanisation is expected to be more rapid in developing than in developed countries (Lal, 2020). For example, UNESCAP (2016) reported that urbanisation in Malaysia accounted for 75.2% of its population living in urban areas in 2016. Therefore, urbanisation would stimulate the local food supply, which involves improvements in infrastructure that allow fresh goods to be available and sold in towns and cities. The Business Research Company (2020), in the Vertical Farming Global Market Report 2022, states that rapid urbanisation is expected to boost the growth of the vertical farming market. Urbanisation increases the total cropland area and decreases the rural population, resulting in a higher per-capita cropland area of rural dwellers and, as a result, a larger farm size (The Business Research Company). The state of urbanisation in Brunei has been increasing in the period of 2011-2021. According to Statista, the share of urban population in Brunei Darussalam in 2021 is estimated at 78.55%, highest value of share during the year.

Soil

Food availability is determined by soil health: if our soils are healthy, we can produce nutritious, high-quality food and animal feed (Spanner, 2015). As a result, the healthiest soils yield the most beneficial and abundant food supplies making them an essential asset to food security (Spanner, 2015; Sindelar, 2015). Soil supports plants growth and contributes to the preservation of natural and planted vegetation, such as forest and grassland, as well as the wide range of crops species and varieties cultivated or managed for food, fibre, fodder, fuel, medicinal products to climate, landscape, and soil type, as well as societal needs (FAO, 2022). Soil erosion is known to be a significant widespread form of land degradation (Dragović & Vulević, 2021). While soil erosion naturally happens in all climates and continents, unsustainable human activities such as intensive agriculture, deforestation, overgrazing, and inappropriate land use considerably accelerate soil erosion (FAO, 2022). Furthermore, it affects soil health and productivity by clearing the fertile topsoil and exposing the remaining the soil (FAO, 2022). Therefore, it reduces agricultural productivity, degrades ecosystem functions, and intensifies hydrogeological risks such as floods and landslides, which would cause a significant loss in biodiversity and damage to the urban infrastructures (FAO, 2022). According to Liu and Hanlon (2019), in acidic soils, the bioavailability of nutrients such as Ca, Mg and molybdenum (Mo) is often low and may negatively affect vegetable production. In addition, the elements of metal toxicity such as aluminium (Al), Iron (Fe), (Mn) and Copper (Cu) are usually found in acidic soils at pH lower than five, which have more excellent solubility than the crop nutrient requirements (CNRs) (Liu & Hanlon, 2019). Moreover, plant diseases are usually associated with soil pH. For example, the clubroot disease of mustard cabbage caused by Plasmodiophora brassicae is a widespread disease when soil pH is lower than 5.7 (Liu & Hanlon, 2019).

A study by Grealish et al. (2008), it has come to known that Brunei's soils acidity is high, with pH values ranging from 4.2 to 4.9. Due to aluminium (Al) and manganese (Mn) toxicity and deficiencies in micronutrients such as calcium (Ca), magnesium (Mg), potassium (K) and others, it affects crop production. For most crops, the requirement of the soil must be maintained at a pH above 5.5 (Grealish et al., 2008). Furthermore, Brunei's climate, landscape and soils predisposed much of the country to waterlog due to high rainfall, shallow groundwater (typically less than 0.5m from the surface), perch water table (overlying unsaturated soil), poor surface drainage and convergent runoff (Grealish et al., 2008). In Brunei, commonly does farming on steep land and the soils in Brunei are typically sandy, deep and well drained (Grealish et al., 2008). Thus, it encourages infiltration and lowers the risk of erosion (Grealish et al., 2008). Therefore, these challenges call for venturing into vertical farming to ease the pressure on soil besides contributing to the agricultural economy of Brunei in a non-conventional manner.

Traditional Farming

Traditional farming is a form of agriculture practice in which plants are grown in the soil on the land (Avgoustaki & Xydis, 2020). Soil is an essential component of agriculture since it is the source of the nutrients such as nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S) that are required to grow crops to almost all food-producing plants (FAO and ITPS, 2015; Sindelar, 2015; Spanner, 2015). It is estimated that the traditional farming contributes 95% of the food produced directly or indirectly on the soils (Spanner, 2015). Traditional food production systems have provided food solutions for people since the beginning of human history. The intensification of traditional farming practices and land usage has resulted in a decrease in organic matter content in agricultural soils in many countries (FAO and ITPS, 2015). Furthermore, farmers that engage in traditional farming faced a myriad of challenges, such as weather catastrophes, lengthy working hours, inconsistent yield, crop venerability to pest and disease, and low return on investment (Sreedhar & Kumar, 2020). Globally, traditional farming uses 70% of the fresh water (World Bank, 2020). According to Coyle & Ellison (2017), traditional farming uses 91% water for lettuce compared to vertical farming and greenhouses. Thus, traditional farming has been firmly blamed for contributing to biodiversity loss, soil erosion, an increase in water and atmospheric pollution and groundwater where a high level of nitrate in the soil resulting leaching and gentrification due to inefficient and excessive usage of synthetic fertilisers and pesticides (FAO & ITPS, 2015; Rahman et al., 2015; Varanasi, 2019). The usage of pesticides has globally increased by approximately two million tonnes per year (De et al., 2014). In Southeast Asia, the overuse of pesticides has caused the pre-harvest agricultural soil to fail and the residual pesticides gave adverse effects not only on the health of consumers and farmers, but also environmental damage and trade opportunities (Aisyah et al., 2019; Laili & Aisyah, 2020).

With a projected global population projected to exceed 10 billion and a further 70% in food production in 30 years, as well as compounded competition for land and water resources and the impact of climate change, the current and future food security hinges on our ability to increase yields and good quality using the soils that are already under production (Spanner, 2015).

Ageing farmers and youth in agriculture

A country's future depends on the youth, who play an essential role in its development (Phyo, 2018). However, according to the World Bank (2022), the global unemployment of youth ageing 15-24 accounts for 17.2%. It is argued that most of the labour in traditional farming consists of ageing farmers. The proportion of ageing farmers is significant and increasing. A study by Heide-Ottosen et al. (2014) revealed that farmers over 55 years old in sub-Saharan Africa are 7.1%, 12.1% in Asia, 25.3% in the Caribbean and 12.3% in Latin America. In Brunei, the country is also facing ageing labour in the agriculture sector. Kon (2021) reported that one of the major concerns of the MPRT is that Brunei is facing a shortage of farmers, therefore hindering the growth of agriculture. In Brunei, data from DEPS (2021) suggest that Bruneian farmers aged over 50 years account for 60.7% of total labour in the agricultural industry. According to DEPS (2021), the data shows that Brunei's agriculture sector employs the minor employment (2,899 persons) of 2% compared to other sectors, industry (51,475 persons) of 28 per cent and services (162,512 persons) of 90 per cent. The migratory status shows that locals involved in the agricultural sector are 2,356 persons while foreigners are 543 persons. Furthermore, the involvement of youth aged between 20 and 39 in the agricultural sector is 724, contributing approximately 0.40% of the labour force. In 2016, Suria Zainuddin, the head of the agricultural extension division at the MPRT, mentioned that the ministry pledged to involve and recruit young farmers as most of the current farmers are ageing.

Dhindsa & Hamdilah (2015) investigated the societal perceptions in Brunei, specifically of the lower secondary agricultural students, including their teachers and parents, towards agriculture. The findings showed that the respondents believed that agriculture is critical to the country's ability to supply food, jobs, and economic stability. Also, the education of agriculture in schools is critical for developing agricultural skills, providing information on agriculture-related occupations, and preparing children for a sustainable future. The study suggested early exposure to agriculture through the school curriculum would improve student awareness. In Thailand, the Department of Agricultural Extension established a programme called ‘Young Smart Farmer’. The objective of the programme is to promote the youth in the agronomic networks, replacing more than 50% of retired farmers. The programme intends to create fresh agricultural ‘young blood’ to reach the maximum agricultural capability by utilising technology to increase yields and other commercial factors such as production capacity, management and farm marketing. Furthermore, the department recognised the value of using digitalised technologies for cultivation purposes to increase yield quality and develop a broad strategy to increase profit growth, whether for domestic consumption or exports (Bangkok Post, 2019).

In Brunei, one of the initiatives that have been made to increase participation and attract youth in agriculture is ‘Project Rintis’. The Department of Agriculture and Agrifood and the Minister of Primary Resource and Tourism provide agricultural lands for entrepreneurs to engage in farming on a 2-year contract. Each farm will have an agriculture yield target (MPRT, 2021b). Farms that can meet the yield target within the first two years of operations will have opportunities for expansion on-site (MPRT, 2021b). Since the program’s establishment, 104 growers were offered land for various vegetable farming such as chilli, tomato, cucumber and others (MPRT, 2021b). Furthermore, out of 104 growers, 49 were from the youth (MPRT, 2021b). Furthermore, since the expansion program was introduced, 44 growers have been offered site expansion to increase agricultural production (MPRT,2021b). Out of 44 growers, 11 growers were from the youth (MPRT, 2021b). However, Musa et al. (2020) described that the major problems for the farmers in Brunei such as lack of financial support, lack of infrastructure and technology and lack of exposure. Finding shows that acquiring financial support for start-up businesses is very challenging in Brunei due to no capital market and stock exchange, therefore, some farmers have to explore other options such as borrowing money from friends and relatives and others pursue different options to develop their farm business. Another finding, farmers have to deal with poor infrastructure where there is no proper irrigation and drainage system, and the utilisation of machinery and new technology in farming in Brunei is still inadequate compare to other nations (Musa et al., 2020).

Urban farming

Chatterjee et al. (2020) defined Urban Farming (UF) as "the production of agricultural goods (crops) and livestock goods within urban areas like cities and towns". UF contributes to the sustainability of cities in various ways, such as improving food supply, health conditions, local economy, social integrations, and environmental sustainability (Chatterjee et al., 2020; Orsini et al., 2013). Kozai (2015) mentioned that UF indicates that a city's economic development has reached a higher level than other agricultural practices, however, it also makes an intensive use of resources such as capital, facilities, technology and labour. Past literature by Zezza & Tasciotti (2010) argued that UF does not appear to be a significant urban economic activity because several countries have a substantial share of their urban population that depends on farming or livestock for their livelihoods. However, Orsini et al. (2013) mentioned that UF has the potential to become a regular feature of most cities, both in developing and developed countries. Specht et al. (2014) introduced Zero-Farming (Z-farming), which includes rooftop gardens, rooftop greenhouses, indoor farms, and other building-related forms to tackle future urban food production. The author concluded that z-farming has a good opportunity in environmental, social, and economic respects (Specht et al., 2014). However, this food production strategy is only for a very dense cities such as China and Singapore, where space for ground-based agriculture is a limited resource (Specht et al, 2014). Crawford (2018) reported that urban agriculture could have the potential to yield up to 10% of food crops; where researchers analysed using Google's Earth software that urban agriculture, if fully implemented in cities, could produce approximately 180 million metric tonnes of food a year hence be good news of driving force for the sustainability for the future. Eigenbrod & Gruda (2015) stressed that implementing UF in cities could achieve a grander scale in food security; however, it must be taken into account that both urban and rural agriculture achieve global food security. UF contributes around 20 per cent of the world food production and plays a vital role in achieving food security during a global crisis such as the Coronavirus pandemic (Lal, 2020).

Therefore, urban food production on a large scale could alleviate some pressure from rural agriculture. Literature by Sengodan (2022) showed that the current successful results of UF ventures in Malaysia, Singapore and Thailand have shown a positive contribution to the planning and evolution of VF in a tropical climate. Suparworko & Taufani (2016) studied the structure design of UF on vertical buildings in Indonesia. The result of the study showed that the method can be used effectively in vertical surfaces on buildings.

Vertical Farming

Vertical farming is regarded as the best solution to the challenges of agricultural food production, climate change and resource depletion (Wilderman, 2020). It is a revolutionary plant production system which allows high-quality fruits and vegetables to be produced locally for rapidly expanding cities (Kumar et al., 2020). Vertical farms integrated with modern technologies will enable the cultivation of crops within urban areas (Januszkiewicz et al., 2017). Due to its multiple harvests per year and higher plant density, a vertical farm produces more than 80 times as much as an open field traditional farming (Wilderman, 2020). Furthermore, that vertical farming could achieve 13.8 times more as a yield ratio to occupied growing floor area. (Touliatos et al., 2016). It also uses 18 times less water using a semi-closed loop water system, has lower freshwater pollution rates (eutrophication is reduced by 70–90% due to minor use of excessive fertilisers), and significantly reduces transport distance, which reduces CO2 (Wilderman, 2020).

He (2015) argues producing food in a small-scale vegetable production using soil, hydroponic and aquaponic in rooftop and vertical farm cannot meet the requirement in a densely populated and land scare cities such as Singapore, in addition, the consequences of climate change made farming more difficult. Furthermore, urban farming such as vertical farming requires a large scale of research and innovation in order tackle the problems the food security, human nutrition and environment sustainability (O'Sullivan et al., 2019). Banerjee & Adenauer (2014) describes regarding the general structure of a sky-high vertical farm. The author insisted that it requires an area of 0.93 ha, consist of 37 multiples levels where 25 levels are used for crop production, 3 levels for aquaculture, 3 levels of same distributions are used for environment management, 2 levels located below the basement for waste management (Banerjee & Adenauer, 2014). Furthermore, 1 level used for plant germination, sowing and cleaning growth trays, another level for is used for packing and processing the crops or fish, and the last level is used for selling products (Banerjee & Adenauer, 2014). The designated structure of the vertical farm is 167.5 meters in height and both length and width are 44 meters, hence the aspect ratio of 3.81(Banerjee & Adenauer, 2014). In addition, the vertical farm requires a huge space elevator in the centre of the building for the forklift truck to do harvesting and transporting waste down to other levels (Banerjee & Adenauer, 2014). The designed vertical farm requires more than 200,000 water to be able to do daily operation and 14,000 of water is used and leave designed vertical farm with the water waste and the waste water can be recycle back to the directly to the plants using water-recycling system (Banerjee & Adenauer, 2014).

Moghimi & Asiabanpour (2021) claimed that the cost of VF can be costly due to energy and highly labour intensive. Banerjee & Adenaeuer (2014) discussed the cost analysis of the designed system of the vertical aquaponic farm. The study indicated that a vertical farm requires a high cost for building, equipment, water and electricity. On the bright side, with an area of 0.25 ha, crop production alone could increase 500 times the yield expected. Regarding the study of acceptance of the VF, several works of literature have been conducted in Southeast Asian countries like Singapore and Malaysia. Ares et al. (2021) literature conducted a multi-method study on consumer attitudes to vertical farming, specifically on indoor plant factories with artificial lighting in China, Singapore, the United Kingdom (UK), and the United States of America (USA). The study's findings revealed a positive attitude toward VF among consumers in the four countries. The author recommends that future research needs to be extended to other countries and different information on VF be presented to consumers. Kalantari & Akhyani (2021) conducted mix-method research, which involves collecting, analysing, and interpreting qualitative and quantitative data on community acceptance in the field of VF based in Kuala Lumpur, Malaysia. The result of the study revealed that analysis from the past literature differed from the eight factors (Perceived Benefits, Perceived Risk, Location, Demographics characteristics, Value and Belief, Trust, Fairness, and Knowledge), which were then identified, and a new framework was developed. The study's findings are shown to positively contribute to knowledge generation, stakeholder network establishment, new project implementation, and improvement of the general perception of VF. Furthermore, the author mentioned that the findings provide a starting point to expand the body of knowledge on VF from a social perspective.

4. Types of vertical farming systems

There are three types of growing systems in vertical farming- hydroponics, aeroponics and aquaponics. Primarily, hydroponics is a growing method that is commonly used in vertical farming. It is a method of growing plants in a water-based, nutrient-rich solution' (Jan et al., 2021) that are 'free from the soil' (Birky, 2016) through 'water channels equipped with the pump and irrigation systems, according to grower's need' (MarketsandMarkets, 2021). According to MarketsandMarkets' Market Research Report (SE 3992), the hydroponics segment in the vertical farming market will maintain its dominance over the forecast period due to its ease of installation and cost-effective vertical farm setup. The central hydroponic system utilised for cultivating leafy vegetables, in general, are the deep flow technique (DFT) and nutrient film technique (NFT) (Sahira et al., 2021). In a study by Majid et al. (2021), hydroponics contributes to higher yield and nutritional quality in a short amount of time than soil-based systems ($P < 0.05$). Using NFT can save 64% of water consumption (Majid et al., 2021). The author claimed that DFT is the most promising system for adoption under protected agriculture due to its simplicity, ease of operation, higher yield, economic feasibility, and nutritionally produced. For example, a Study by Shahira et al. (2021) describes hydroponic farming in Indonesia, Syafa Farm, located in West Java, Bandung Regency, for commercial purposes of growing water spinach (Ipomoea Aquatica). The result indicated the farm able to yield 100 kg per month. The author summarised that the farm's general hydroponic water spinach farming is feasible to run and continue its business operation. Meanwhile, aquaponics is a 'process of growing plants and fish together in one system where the system relies on the biotic relationship between fish and bacteria' (Santos et al., 2021). Fish that are raised in aquaponics demand a good quality of water condition, where parameters such as ammonia, dissolved oxygen, pH level, temperature and turbidity should be in the optimal range and the water and nutrients from the fish waste can be recycle, which would make aquaponic environmentally friendly and profitable (He, 2015; Santos et al., 2021).

Lastly, aeroponics is an innovative indoor growing method which involves 'spraying the nutrient-rich solution onto plants root periodically''. The main difference between hydroponics and aeroponics systems is that hydroponics utilises water as a growing medium, while aeroponics has no medium (Al-Kodmany, 2018). Aeroponics makes harvesting more accessible and provides higher yields (Al-Kodmany, 2018). Furthermore, to achieve the best result, aquaponics requires 'precision sensing technology and strict dosing regimen' (Wong et al., 2020). A study by He (2017) has successfully managed to produce various types of temperate and subtropical vegetables in Singapore using a light emitting diode (LED) integrated vertical aeroponics farming system (VAF) all year round. The author concluded that LED integrated VAF system would reduce Singapore's reliance on vegetable imports and promote food security.

Popular crops in vertical farming

Vertical farming has been recognized for their ability to grow premium leafy vegetables and microgreens especially in indoor. A study by He (2019) shows that integrated vertical aeroponic farming has successfully grow premium vegetables such as Chinese broccoli (B. alboglabra), Na Bai (B. chinensis L.), wild rocket (Eruca sativa), mizuna (B. juncea var. japonica), red and green leaves lettuce (L. sativa), ice plants (M. crystallinum), red- and green-leaved Chinese Basil (Perilla frutescens), kale (B. oleracea, cvs. Curly kale; Kale Toscano and Borecole red), and microgreen such as sweet basil (Ocimum basilicum), red and green Chinese Basil (Perilla frutescens). Furthermore, it is possible to grow high valued fruits such as tomatoes (S. lycopersicum), cucumbers (C. sativus), cantalopue (C. melo), Bell peppers (C. annuum), and strawberries (F. × ananassa). However, it requires different nutrients ratios and may require hand-pollination (ZipGrow, 2022).

Technologies in Vertical Farming

The concept of indoor vertical farming has attracted much interest worldwide, whether for domestic or commercial use (Yusof et al., 2017). VF provides the best offer growing conditions to plant using with modern technologies during the processes from seeding to harvest (Yesil & Tatar, 2020). One of the features indoor VF is the use of artificial light such as light-emitting diode (LED) technology. Literature by Gomez & Izzo (2018) reviewed of key studies focused on increasing efficiency of crop production with LEDs. Light sources are essential for plant growth, and with the use of LED technology in indoor vertical farming, it stimulates the growth of plants by utilising the electromagnetic spectrum to generate photosynthesis and chlorophyll content with low power density per unit growth area (kW m-2) (Yusof et al., 2017; Gomez & Izzo, 2018). Study by He (2015) mentioned that adopting LED in VF could promote consistence growth and optimal usage for limited space by shortening the growth cycle, thus reducing the vegetable in cost effective manner. The author identified the combination, duration, and intensities of LED lighting for optimal growth. The study showed that the combination of blue and red LED increased light-saturated photosynthetic carbon dioxide assimilation rate, stomatal conductance and crop productivity, increased crop rotation and thus land use efficiency. Furthermore, crops grown under LED-integrated VAF systems can grow twice as fast (He, 2015).

Following the literature of He (2017), the LED integrated vertical aeroponic farming (VAF) system can be used indoors and in the greenhouse. The newly VAF system was designed to increase the production of vegetables using scientific approaches and a limited space environment. The author outlines that the critical success of the VAF system is the provision of a low-energy input engineering solution, the use of LEDs which contributes to maximising crop productivity. The findings show that the VAF system successfully grows leafy vegetables and microgreens. The author concludes it is necessary for a small country like Singapore, where the city is dense and can produce all types of vegetables all year round. The study suggests that their LED integrated VAF systems are among the most effective farming systems. However, the author stressed that further economic analysis studies should be conducted before concluding the feasibility and sustainability of VAF for commercial growers in Singapore. Kozai's (2015) describes Japan's plant factories with artificial lighting (PFAL). In 2014 there are 165 PFALs were used for commercial production in Japan. Spread Co., Ltd is the largest PFAL operated in Kyoto, producing 23,000 leaf lettuces head daily. Another PFAL, Mirai Co., Ltd, is an indoor multi-level vertical farm comprising 25,000 square meters (Shimamura, 2016). The Japanese company produces approximately 10,000 lettuce per day and uses 40 per cent less energy, 80 per cent less food waste, and 99 per cent less water usage than outdoor fields (Shimamura, 2016; Kohlstedt, 2015). Another feature of technologies that is used in indoor vertical farming is the Internet of Things (IoT). The current and prospect of IoT can influence people's life making a well-informed decision (Doshi et al., 2019). The application of the IoT in VF can improve the trend of agriculture sector in application of information technology and support the farmers to gain control when approached by threats and lowering the probability of dangerous pesticides and unsafe chemical in their plantation (Ismail & Thamrin, 2018). Furthermore, it allows farmers to take action in a quickly manner to protect their plant, regardless the farmer's location, and has the capability to be economical and lowering crop loss (Ismail & Thamrin, 2018; Doshi et al., 2019). Chin and Audah (2017) demonstrate a prototype of a VF monitoring system called 'BeagleBone Black' (BBB) using the IoT where the system design involves sensors attached to the VF structure, transmitting data to BBB, using Sierra Wireless Module coordinated with BBB to provide a network to the Telco services and a BBB microcontroller to manage all data from sensors via an analogue input (AIN) pin. The result of the experiment was a success that the sensor was functioning well, and manage to record data to Thinkspeak IoT and provided a real-time monitoring system for VF.

Another technique, Ruengittinum et al. (2017) proposed a Hydroponic Farming Ecosystem (HFE), utilising IoT devices in an android application. The study aims to support non-professional farmers with limited farming knowledge and people interested in vertical planting. The study experimented for four trials, revealing that all tests showed promising results. While, Ismail & Thamrin, (2018) proposed the application of IoT in VF in controlled environment where the farmer able to monitor their plants through online application to check the status of soil moisture and the ability to control water pipe to supply water to the plants when needed. The author concludes that the proposed design system able to control water supply to the plants and reduce the water usage and recycle the excess water to the reservoir water storage for watering process.

5. Conclusion

VF is an innovative agricultural farming method used in urban agriculture to increase the agricultural production. Indoor VF offers the best growing condition for crops all year round using latest technologies such LED, providing high quality and quantity agricultural products with minimal land and water usage. However, the big challenges may face in introducing it in Brunei is the need for skilled labour and capital intensive. Literature by Lubna et al. (2022) mentioned that vertical farming is a heavy labour intensive compared to traditional farming. Thus, the reliance on human labour is crucial. Domestic labour is desirable compared to traditional farms that hire seasonal labour where vertical farm does operate all year round. Furthermore, most vertical farms are located in urban areas; therefore, a more significant domestic labour force is needed (Lubna et al., 2022).

However, Wood et al. (2020) argues domestic labours from urban areas lack experience and training in managing a vertical farm. Due to the necessity of extensive labour, training programmes such as farming techniques, integrated pest management, food safety and handling, and data collection are required (Lubna et al., 2020). Lubna et al. (2022) argues that having no skilled labour, relying on untrained and inexperienced employees might pose a significant danger to a new vertical farm. Therefore, supervisors must create an open culture of communication in the workplace, allowing new employees to communicate information about problems on the farm, potential inefficiencies, and issues that require a more informed viewpoint. Therefore, developing human capital is a vital step to promote the practice of VF. It must be started from school education and trainings. Up skilling training for the existing farmers and workers will also help this idea and initiative.

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