ASM Sc. J., 20(2), 2025
https://doi.org/10.32802/asmscj.2025.1621

A Preliminary Study on the Current Status and Development of Commercial Aquaponics Farms in Malaysia

Q.S.C. Kiu[1], C.Y. Teoh[1,2*] and A.L. Ooi[1,2]

[1]*Department of Agricultural and Food Science, Faculty of Science, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia*

[2]*Centre for Agriculture and Food Research, Universiti Tunku Abdul Rahman, Jalan Universiti, Bandar Barat, 31900 Kampar, Perak, Malaysia*

A survey was conducted to collect information about commercial aquaponics farms in Malaysia to provide insight into their operating status and to promote aquaculture sustainability. A total of 13 aquaponics farms from Selangor (9), Pulau Pinang (2) and Sarawak (2) participated in this survey. Farm general information, crop, fish and aquaponics system, financial input and output, and farm challenges of each aquaponics farm were summarised. Aquaponics farms are mainly located in urban areas where 84.6% of the farms were intermediate farms (>1076 ft^2–≤5382 ft^2) and large farms (>5382 ft^2). The most produced crops and fish by these aquaponics farms were leafy vegetables and tilapia respectively. Aquaponics farmers spent an average of RM 75.44/ft^2 on the initial capital while RM 16.44/ft^2 on the annual expenses. On average, crop production value was threefold higher than fish production value produced by these aquaponics farms. Plant pests and diseases, pH instability and nutrient deficiencies in the aquaponics system as well as financial issues were some of the main challenges faced by the aquaponics farmers.

Keywords: aquaponics; aquaculture; tilapia; sustainability

I. INTRODUCTION

Aquaponics is an agricultural practice that combines the principles of aquaculture and hydroponics, and it has gained a good deal of attention worldwide (Pattillo *et al.*, 2022). It integrates a recirculating aquaculture system (RAS) with hydroponic to culture aquatic organisms and plants in a recirculating unit. In the aquaponics system, effluent is channelled from the fish tank to the plant tank and used as a nutrient source after the conversion of ammonia to nitrate. The water is then recycled back to the fish tank. This mechanism contributes to the treatment of aquaculture waste and minimises the environmental impacts caused by fish wastewater. Besides that, the aquaponics system also improves land and water management, economic viability, increases food productivity, influences social education, and promotes farm diversification (Somerville *et al.*, 2014; Rizal *et al.*, 2017; Lennard & Goddek, 2019). It has become one of the technology-intensive innovations recommended by FAO (2020) for aquaculture sustainability.

Previous studies reported that aquaponics improved the survival rate and growth performance of the Nile tilapia (*Oreochromis niloticus*) and rainbow trout (*Oncorhynchus mykiss*) (Effendi *et al.*, 2017; Setiadi *et al.*, 2018; Atique *et al.*, 2022). Aquaponically grown fish had significantly higher weight gain, lower mortality rate and lower FCR compared to those cultured in RAS due to water quality enhancement that comes with higher dissolved oxygen (DO), lower total ammonia nitrogen (TAN) and nitrite concentration in the culture water (Effendi *et al.*, 2017; Setiadi *et al.*, 2018; Atique, *et al.*, 2022). Aquaponics practitioners grow mostly leafy vegetables and herbs in the aquaponics systems (Pattilo *et al.*, 2022).

*Corresponding author's e-mail: cyteoh@utar.edu.my

Some surveys were conducted to review and document the status of aquaponics development in different regions, including two global surveys (Love *et al.*, 2015; Pattillo *et al.*, 2022), Europe (Villarroel *et al.*, 2016), South Africa (Mchunu, *et al.*, 2018), Philippines (Bosma *et al.*, 2017) and Czechia (Tůmová *et al.*, 2020). Although these studies reported that aquaponics is a rapidly emerging agricultural technology that comes with various benefits, there is still a lack of information about the status of commercial aquaponics farms in Malaysia. Malaysia has many different aquaculture systems, in which most farmers are still using the pond culture (Department of Fisheries, 2023). Implementation on modern agricultural technologies and sustainable agricultural practices are highlighted in the Malaysia National Agrofood Policy 2.0 (2021-2030). Employing modern farming technology, such as aquaponics, would be one of the substantial methods to improve the productivity in aquaculture production (Othman 2010; Lennard & Goddek, 2019).

With the improvement on tilapia growth performance in aquaponics (Effendi *et al.*, 2017; Setiadi *et al.*, 2018), implementation of aquaponics by farmers in Malaysia could enhance the aquaculture production as tilapia is the most cultured freshwater fish species in the country. In 2021, the production and retail sale of tilapia was 37,609.45 tonnes and RM 574,788.64 (Department of Fisheries, 2022). Moreover, consumers in Malaysia are also reported with high intention on purchasing aquaponics' products, giving an indicator of a great potential local market for the aquaponics industry (Tamin *et al.*, 2015).

As more studies are focusing on the biology and technology of aquaponics, aquaponics' aspect in the agricultural industry and market should also be investigated to further develop aquaponics as a sustainable farming technology in the future (Junge *et al.*, 2017). Hence, the authors have sought to document the descriptive information about the development stage of aquaponics farms in Malaysia. This study aims to provide an insight into the commercial aquaponics farms in Malaysia through a survey, including the variety and production value of aquaponics products (crop and fish), potential selling market and aquaponics farm challenges. It is also to evaluate the commercial status of aquaponics and to promote its development in Malaysia as a key towards aquaculture sustainability. Additionally, there is no data or information recorded by any Malaysian agencies which is related to aquaponics on fish and crop farming. Providing information about commercial aquaponics operations may encourage more farmers to explore aquaponics, thereby fostering sustainable food production in the country.

II. MATERIALS AND METHOD

The authors obtained ethical approval for this research project from the institute, Universiti Tunku Abdul Rahman (UTAR) (Re: U/SERC/18/2022).

A. Questionnaire

Questions reflected in the survey were divided into four main sections with subsections (modified from Bosma *et al.*, 2017; Tůmová *et al.*, 2020; Pattillo *et al.*, 2022), which included (A) General information of the aquaponics farm: ownership and operation duration (year), location, size (ft^2), farm type, and organic certification, (B) Crop, fish and aquaponics system: crop species including type of hydroponic, application on pesticide and fertiliser, fish species and stocking density (fish L^{-1}), fish and plant ratio, application on IoT and production cycle of crop and fish, (C) Financial input and output of the aquaponics farm: initial capital (RM/ft^2), annual expenses (included electricity and water, storage and packaging, transportation, labour cost, fish fingerlings, fish feeds, plant seeds, fertilisers and pesticides) (RM), annual crop production value (RM/ft^2), annual fish production value (RM/ft^2), market place and farm main income and (D) Farm challenges. All questions were prepared in trilingual setting: English, Bahasa Melayu and Mandarin using an online Google Form. The questionnaire was proofread by the authors before data collection to ensure its legibility (Tůmová *et al.*, 2020).

B. Data Collection and Analysis

This survey aimed to collect descriptive information from the commercial aquaponics operations in Malaysia in which fish and crops grown using in the aquaponics system are sold. A purposive sampling method was used to collect the survey data. Social media platforms, such as Facebook, Instagram, and WhatsApp were used to search for potential respondents. Browsing Google search engine was also used to search for qualified candidates (Mchunu *et al.*, 2018; Tůmová *et al.*, 2020; Pattillo e*t al.*, 2022). Only 13 aquaponic farms participated in this survey. The farmers were interviewed and responded to the provided questionnaires through phone calls, WhatsApp, Google Meet, Microsoft Teams, and Facebook Messenger by the authors. Collected information was summarised and presented in graphs and pie charts using Microsoft Excel.

III. RESULTS

A. General Information of Aquaponics Farms

A total of 13 aquaponics farms participated in this survey study.

1. Ownership and Operation Duration

Figure 1 shows the general information collected from aquaponics farms participating in this survey. Among the respondents, two aquaponics farms were no longer operating. Both farms had operated for 2 years (Year 2020 to 2022). In terms of farm ownership, 54% of the aquaponics farms operated as a company, 38% of the farms were sole ownership and 8% operated in partnership. Twenty-three percent of the surveyed farms operated for 6 years, 8% operated for 4 years while 69% operated for 3 years or less.

2. Location, size (ft^2), farm type and organic certification

Among the 13 aquaponics farms, nine farms were in Selangor while two farms were in Pulau Pinang and Sarawak (Figure 1). Most of the farms (85%) were in urban areas while the rest were in rural areas. Farm size was categorised according to Tůmová *et al.* (2020), including domestic (≤ 538 ft^2), small scale (>538 ft^2 – ≤1076 ft^2), intermediate scale (>1076 ft^2 – ≤5382 ft^2), and large scale (>5382 ft^2). The surveyed aquaponics farms consist of intermediate size (53.8%), followed by large scale (31.8%), small scale (7.7%), and domestic (7.7%). The largest aquaponics farm size was 113,256 ft^2 while the smallest aquaponics farm was 330 ft^2. Most of the aquaponics farms (92%) had a greenhouse to operate their aquaponics systems while only one farm had both indoor and outdoor aquaponics setup with an open-air cover. To date, none of the surveyed farms have obtained organic certification.

B. Crop, Fish and Aquaponics System

1. Crop in Aquaponics

Leafy vegetables were the most grown crop in the aquaponics system (100%) (Figure 2A). Various types of leafy vegetables were cultivated in aquaponics farms surveyed which included bak choy, lettuce, spinach, salad greens, choy sum and kale. Herbs, particularly mint and basil were the second most cultivated crop in the farms surveyed (31%). Other vegetables planted in the aquaponics system were melon (Cucurbitaceae family) (24%), chili (15%), cucumber (15%), cherry tomato (15%), azolla (8%), eggplant 8%), snake gourd (8%) and okra (8%). Sixty-two percent of the aquaponics farms utilised deep water culture (DWC) and vertical towers in their hydroponic systems (Figure 2B).

All aquaponics farms surveyed used different types of fertilisers in their aquaponics systems. Sixty-nine percent of the farms used commercial liquid fertiliser in their aquaponics systems (Figure 2C). Epsom salt and chelated iron such as ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA) and organic certified ethylenediamine-N,N'-bis(2-hydroxyphenylacetic acid) (EDDHA) were also used as fertilisers by the aquaponics farmers. Based on the survey, 77% of the farms applied pesticides on their plant crops to prevent plant pests and diseases. Some farmers (50%) used commercial organic pesticides while some aquaponics farmers (40%) used self-formulated organic pesticides (neem oil, wood vinegar and a mixture of chili and garlic water) (Figure 2D).

2. Fish in Aquaponics

Figure 2E shows that all aquaponics farms cultured red hybrid tilapia (*Oreochromis* sp.), followed by *patin* (*Pangasius* spp.) (23%), jade perch (*Scortum barcoo*) (23%), bighead carp (*Hypophthalmichthys nobilis*) (8%) and lemon

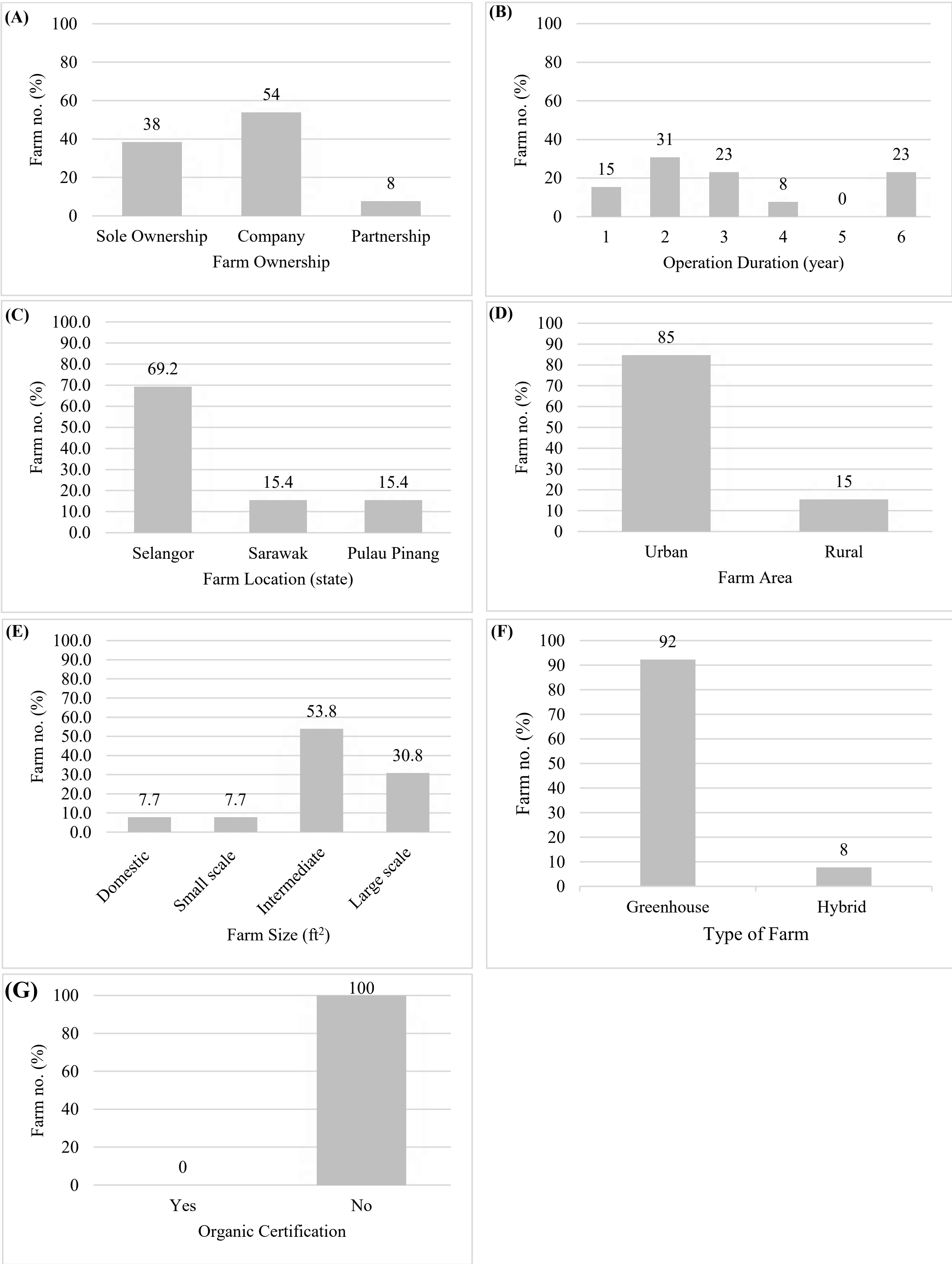

Figure 1. General information of aquaponics farms: (A) Farm ownership, (B) Farm operation duration (year), (C) Farm location (state), (D) Farm area, (E) Farm size (ft^2), (F) Farm type, and (G) Farm organic certification.

bard (golden belly barb, *krai* or *kerai*) (*Hypsibarbus* sp.) (8%). The fish stocking density used by 31% of the farms was 0.04 fish/L and the fish: crop ratio varied from 1 fish: 12 crops to 5 fish: 3 crops (Figure 2G). Five farms did not provide this information.

3. Production Cycle and IoT Application

As shown in Figure 2.I, 46% of the surveyed aquaponics farms would harvest their aquaponics fish in 6 months, while 23% of farms would harvest in 8 months. Leafy vegetables grown using aquaponics would reach marketable size in the range of 28 days to 40 days (Figure 2J). One farm did not sell the plant crops grown from the aquaponics system. Only 38% of the farms were equipped with IoT applications, such as using sensors on water level, water quality, air temperature and air humidity (Figure 2H).

C. Financial Input and Output of Aquaponics Farms

1. Initial Capital, Annual Expenses, Annual Crop and Fish Production Value

As shown in Figure 3A, the initial capital used to set up the aquaponics farms varied among the 13 surveyed farms, but the results do not indicate that the larger the farm size, the higher the initial capital would be required for the establishment of an aquaponics farm in Malaysia. A large-scale farm (>5382 ft^2) was reported to use a low initial capital (RM 2.17/ft^2) while an intermediate farm (>1076 ft^2 – ≤5382 ft^2) would need a high initial capital (RM 266.67/ft^2) to set up the aquaponics farm. For example, results collected from this survey show that the largest farm (113,256 ft^2) only required RM 18.54/ft^2 for setup at the initial stage. Large-scale farms (≥4,800 ft^2) needed a lower initial capital compared to farm size which was less than 4,800 ft^2. On average, aquaponics farm owners in this study spent around RM 75.44/ft^2 on the initial capital of the farm setup.

The highest annual expense of the aquaponics farm in this study was RM 50.00/ft^2 from a small-scale farm (>538 ft^2 – ≤1076 ft^2) while the lowest amount (RM 0.33/ft^2) was from a large-scale farm (>5382 ft^2) (Figure 3B). The largest farm (113,256 ft^2) only required RM 0.38/ft^2 for its annual expenses. On average the annual expenses of the aquaponics farms in this study was RM 16.44/ft^2.

In this study, the highest annual crop production value was RM 125.00/ft^2 produced by a small-scale farm (>538 ft^2 – ≤1076 ft^2) while the lowest annual crop production value was RM 0.60/ft^2, produced by a large-scale farm (>5382 ft^2). The highest annual fish production value was RM 16.00/ft^2, produced by an intermediate-size farm (>1076 ft^2 – ≤5382 ft^2) while the lowest annual fish production value was RM 0.21/ft^2, produced by a large-scale farm (>5382 ft^2). On average, the annual crop production value was RM 20.59/ft^2 while the annual fish production value was RM 6.76/ft^2 reported from the aquaponics farms in this study.

2. Market Place and Farm Business Status of Aquaponics Farms

In this survey, 69% of the farms sold their aquaponics' products (crop and fish) directly to the consumers (Figure 4). Other users were restaurants or café (31%), grocery shops (15%), communities or residential areas (15%), fresh markets (15%) and hypermarkets (8%).

Some of the farms (15%) sold their products (fish and crop) to other aquaponics farms or marketing agencies which then resold the produce to other consumers. The majority of the aquaponic farms (69%) were not only selling their cultivated products as the main income but were also involved in various other aquaponics businesses. These included the sale of aquaponics system setup, aquaponics equipment and fertilisers, as well as providing consultancy, training, and education.

D. Farm Challenges

The biggest challenge faced by the aquaponics farm based on this survey (Figure 5) was plant pests and diseases (92%) This is followed by financial issues (77%), nutrient imbalance, pH instability (62%), marketing (46%), lack of skilful workers (46%) and fish pests and diseases (46%). Other challenges faced by the aquaponics farms included the lack of labour force (38%), unstable electric supply (23%), weather and climate change, technical problems of their aquaponics systems (23%), postharvest problems (15%), sourcing good quality fish fingerlings and crop seeds (8%).

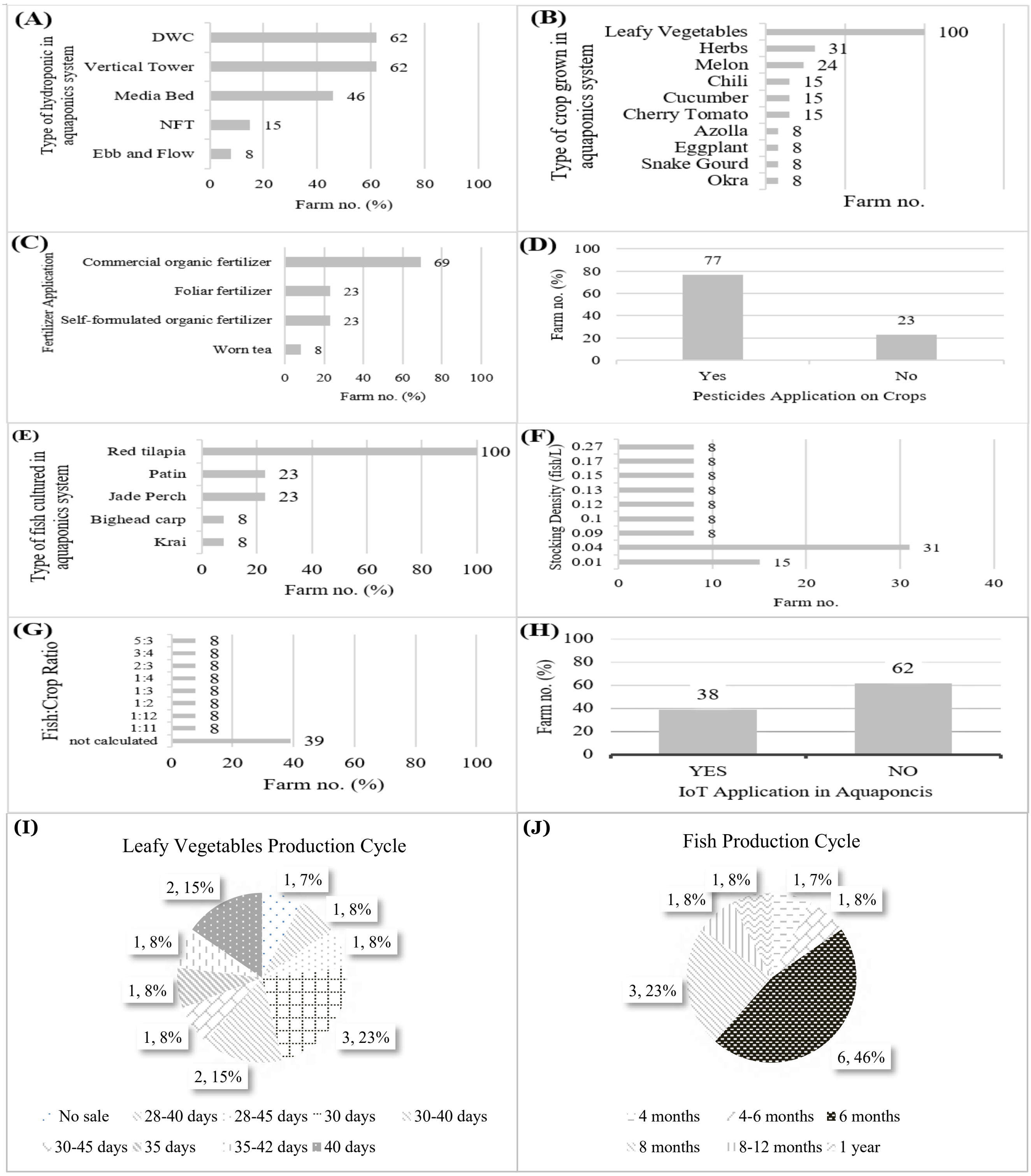

Figure 2. Information about the crop, fish and aquaponics system in Malaysia: (A) Type of crop grown in aquaponics, (B) Type of hydroponic applied in aquaponics, (C) Fertiliser application in the culture water, (D) Pesticides application on crops, (E) Type of fish grown in aquaponics, (F) Fish stocking density (fish/L), (G) Fish: crop ratio, (H) IoT application in aquaponics, (I) Fish production cycle and (J) Leafy vegetables production cycle.

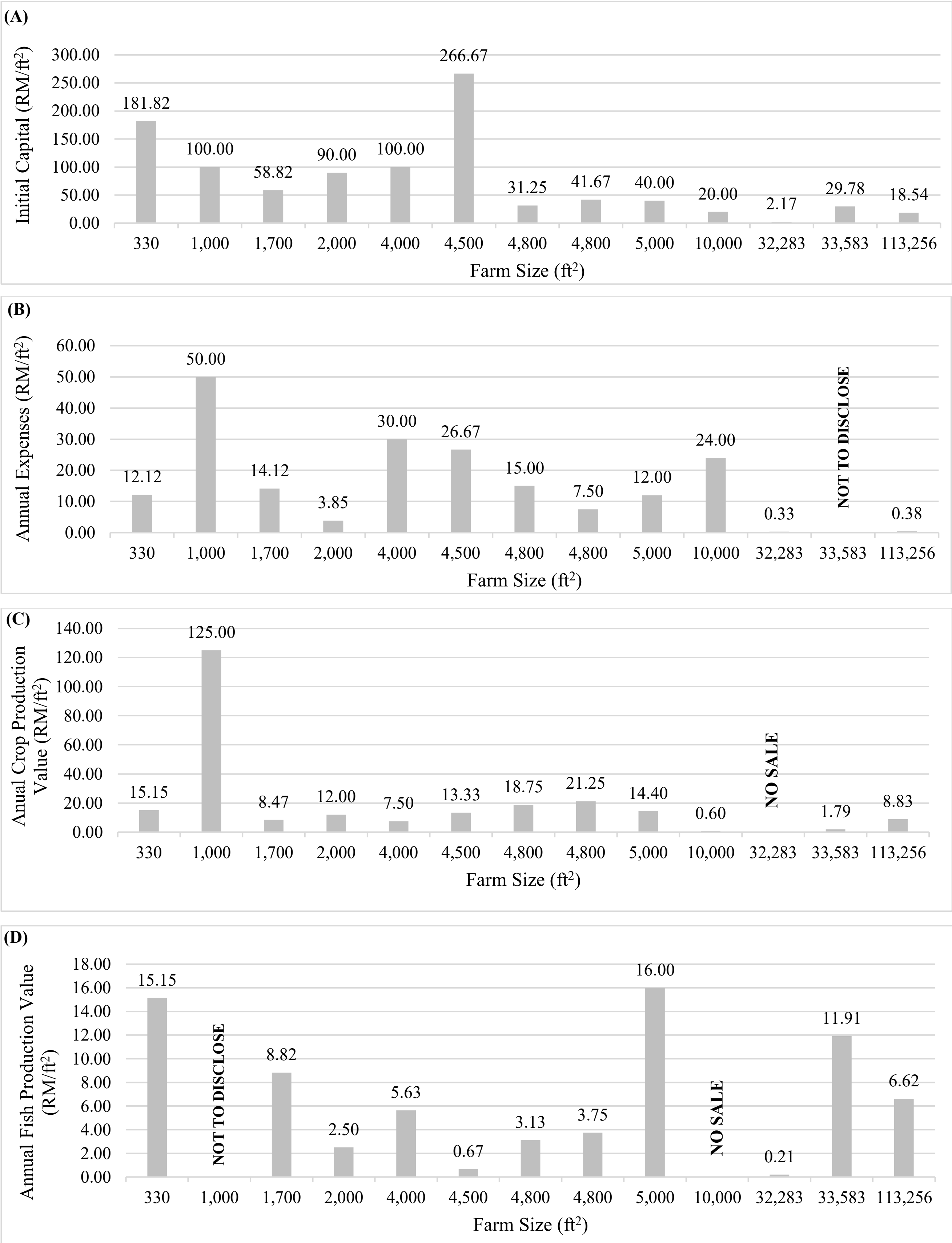

Figure 3. Financial input and output of aquaponics farm in Malaysia: (A) Initial capital of aquaponics farms, (B) Annual expenses of aquaponics farms, (C) Annual crop production value (RM/ft^2) and (D) Annual fish production value (RM/ft^2).

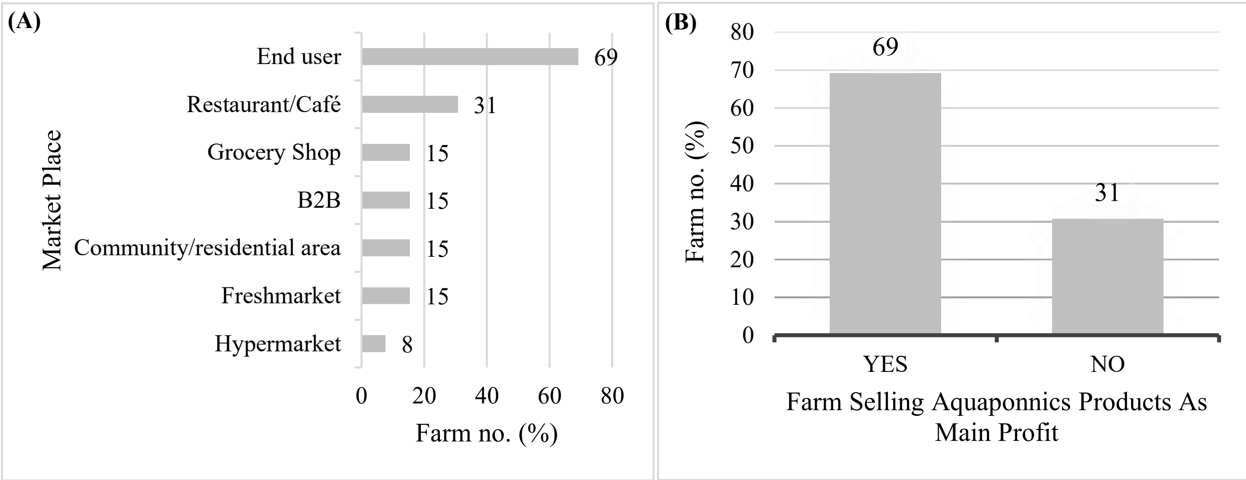

Figure 4. Marketing of aquaponics products by the surveyed farms: (A) Market place for aquaponics products and (B) Aquaponics product sales as the main income.

IV. DISCUSSION

A. Aquaponics Farms in Malaysia

The number of farms practicing aquaponics in this study was small, reflecting the status of aquaponics as an emerging farming technique in Malaysia. Similar observations have been reported in South Africa (Mchunu *et al.*, 2018) and Europe (Villarroel *et al.*, 2016). The application of aquaponics is much lower in farms as compared to other farming methods in fish and crop cultivation. This might be due to the challenges faced when establishing and operating an aquaponics farm as a business as compared to applying it as a hobby (Love *et al.*, 2015; Pattillo *et al.*, 2022). Another potential reason might be the lack of knowledge in developing a profitable commercial farm as aquaponics itself requires scientific knowledge on culturing both crops and fish in a system (Love *et al.*, 2015; Tůmová *et al.*, 2020).

In the present study, two aquaponics farms (small-scale and large-scale) were no longer operating as both farmers claimed that their harvested products were not profitable.

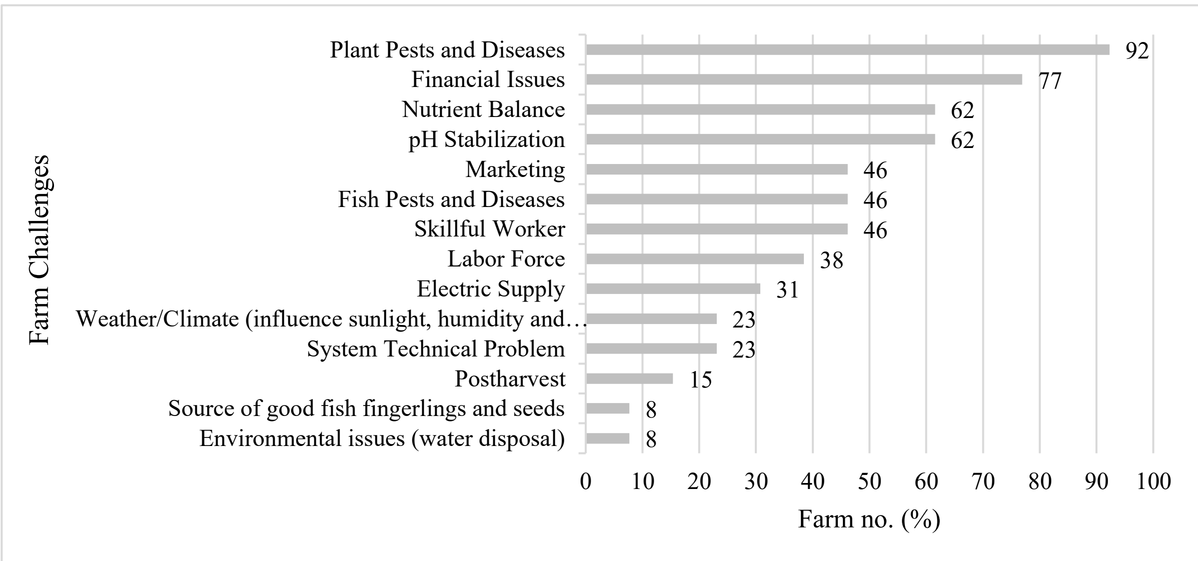

Figure 5. Farm challenges faced by aquaponics farmers in Malaysia.

Operation duration of both farms started from 2020 to 2022 within the period of COVID-19 pandemic and Movement Control Order (MCO) in Malaysia. The pandemic and MCO had brought a lot of challenges to the farmers such as the reduction in domestic demand, problems in logistic and supply chain management during the pandemic (Waiho *et al.*, 2020; Azra *et al.*, 2021).

Most aquaponics farms are located in Selangor (69%) which might be due to its economic advantage derived from a larger population. Urban area (85%) with great market demand for aquaponics products and lower transportation distance are also some of the criteria for farmers in selecting their aquaponics farm location (Bosma *et al.*, 2017). It also shows that farmers prefer to establish their aquaponics system in the greenhouse which might be more suitable for a tropical climate in Malaysia. Indoor aquaponics was not a choice for the farmers due to the high cost of lighting instalment, although indoor aquaponics could provide a more controlled culturing environment (Niu & Masabni, 2018).

In the survey conducted, the involvement of marketing agencies (15%) and farms deriving their main income from direct product sales (31%) suggests an awareness of consumer demand. Understanding market trends and consumer preferences becomes crucial for farms seeking to optimise their sales strategies. The diversification of income sources among aquaponics farms (69%) indicates a proactive strategy for economic resilience and risk mitigation. These implications collectively highlight the dynamic nature of the aquaponics industry, emphasising the importance of adaptability, innovation, and strategic planning for sustained success and growth.

All aquaponics farms in this study do not have organic certification from any agencies (see Figure 1G). However, all farmers in this study declare that their aquaponics products are pesticide-free and provide more health benefits compared to other fish and crop produced from conventional farms. Aquaponics products are often labelled as organic produce for better pricing in the market which makes the production more economically viable (Quagrainie *et al.*, 2017). However, aquaponics farms in this study are not organic certified and most of them use pesticides (77%) and fertilisers (100%) in their aquaponics system. This raises concern of mislabelling aquaponics products as organic produce.

In fact, aquaponics farms in Malaysia may face difficulties to qualify for organic certification (myORGANIC) because the organic certification recognised by the government is only applicable for soil farming, at the moment (Ibrahim *et al.*, 2016; DOA, 2023). This requirement is similar to the international standards for organic certification. As more modern agricultural technologies are invented nowadays, including hydroponics and aquaponics, agricultural policy on organic farming should be improvised to compete with the current development trend in agriculture. This situation has also occurred in the United States and European Union as neither aquaponics nor hydroponics is eligible for organic certification due to using non-soil farming methods (Kledal, König & Matulić, 2019). Much remains to be done to obtain recognition by the government and international agencies (Rahmat *et al.*, 2021), especially on these modern farming technologies. On the other hand, aquaponics farmers should investigate the pesticides and fertilisers application in their systems to achieve the standard of producing organic products.

B. Crop, Fish and System in Malaysian Aquaponics

1. Crop in Aquaponics

In this study, the most grown crop in the aquaponics system was leafy vegetables. The results were similar to the previous studies in global surveys (Love *et al.*, 2015; Pattillo *et al.*, 2022), Europe (Villarroel *et al.*, 2016) and South Africa (Mchunu *et al.*, 2018). Although leafy vegetables are not the most-value crop among the crop species grown in the aquaponics system in Malaysia, most of the aquaponics farms raise leafy vegetables (*bak choy*, lettuce, and spinach) because of their lower nutrient requirements and short cultivation duration compared to fruity vegetables (Mchunu *et al.*, 2018). Additionally, the size of leafy vegetables allows them to be grown in high density in an aquaponics system (Mchunu *et al.*, 2018).

In this study, herbs were the second most grown crop due to its high market value and demand. In Europe, herbs were the most grown crop in the aquaponics system in 58% of the farms, followed by lettuce grown in 47% of the farms (Villarroel *et al.*, 2016). Herbs such as mint and basil might have similar agronomic requirements as leafy vegetables making both crop species the main choices grown in the aquaponics system in Malaysia. Other recommendations on aquaponics crop species would be the microgreens and ornamental plants (Villarroel *et al.*, 2016; Mchunu *et al.*, 2018; Pattillo *et al.*, 2022), which were not grown by any aquaponics farms in Malaysia.

DWC and vertical towers were the most applied hydroponic methods in the aquaponics systems of the surveyed farms, constituting 62% (see Figure 2B). Compared to other methods, DWC is more space-saving and less construction work when it comes to a large-scale commercial aquaponics farm (Gosh & Chowdhury, 2019). Moreover, DWC is easy to clean and more flexible in transporting the crop from farm to market during the cultivation and harvesting period (Pickens *et al.*, 2016). Besides, most aquaponics farms use vertical towers which are built by the same aquaponics company selling their aquaponics system. Hence, the design and setup for the vertical towers were well-modified to suit the aquaponics system in the farm. Like DWC, the vertical tower is space efficient, but it may have clogging problems and rely on the water pump (Pattillo, 2017).

All aquaponics farms in this study apply fertiliser to their crops as aquaponics could lead to nutrient deficiency for plant crops (Yep & Zheng, 2019). Addition of synthetic and organic fertilisers such as foliar spray and organic liquid fertiliser in the aquaponics system would meet the nutrient requirements of plant crop for growth (Rakocy *et al.*, 2004; Roosta, 2014; Atique *et al.*, 2022). The addition of Epsom salt and chelated iron such as EDTA, DTPA and organic certified EDDHA were also applied to the aquaponics systems to supply available iron for plant nutrients. The water in the aquaponics system is insufficient to support the crop growth, for example leafy vegetables and herbs. Plant nutrients that are insufficient in aquaponics include phosphorus, potassium, calcium, magnesium and iron (Yep & Zheng, 2019). Hence, fertilizer application fulfils the growth requirement of plant crops which is an important routine in aquaponics farms.

It is not surprising that aquaponics farms would apply pesticides on their planted crop as plant pests and disease problems are encountered in aquaponics farms. No specific plant pests and diseases were identified by the farmers as they may be lack of knowledge to identify them. However, plant pests and disease problems have rarely been reported in any aquaponics survey studies previously. This topic should receive greater attention since aquaponics is deemed to grow organic produce. Although there was one aquaponics farm using synthetic pesticides in this study, it was only applied at the earlier stage of plant growth to prevent pest outbreaks. Nevertheless, pesticide application in aquaponics goes against the organic regulation and this action may cause aquaponics products unable to be labelled as organic products (Kledal *et al.*, 2019; Yep & Zheng, 2019).

2. Fish in Aquaponics

The most grown fish in the aquaponics system was the red hybrid tilapia (*Oreochromis* sp.), and it was grown in all the aquaponics farms in this study. Similar results were also found in previous studies (Love *et al.*, 2015; Villarroel *et al.*, 2016; Mchunu *et al.*, 2018; Pattillo *et al.*, 2022). Tilapia fish was also the most cultured fish species in the whole aquaculture sector in Malaysia with the production of 37,609.45 tonnes and RM 574,788.64 in 2021 (Department of Fisheries, 2022). Tilapia is selected as the main fish choice to be grown in aquaponics is attributed to its high growth rate, high tolerance to a wide range of water quality and able to adapt in high stocking density (Pinho *et al.*, 2021). Nonetheless, high frequency of culturing the same fish species would decrease the fish productivity and limit the fish choice produced by aquaponics (Pinho *et al.*, 2021).

Aquaponics farmers also cultured other fish species such as *patin* and jade perch that have greater market value than tilapia. However, among the cultured fish species, non-native fish species (tilapia, jade perch and bighead carp) might cause the spread of invasive species and threaten the native species population and wild ecosystem. *Tilapia nilotica* was reported to colonise the streams in Selangor state and became a potential threat to the native fish species in food hunting and survival ability (Ahmad *et al.*, 2020). Thus, more alternative native fish species should be explored with the aim of promoting the cultivation of native freshwater fish species in Malaysia. Fish stocking density is important in operating aquaponics as understocking might provide insufficient nutrients for crop growth while overstocking might waste the excess nutrients in the aquaponics system to maximise crop production. In this study, the stocking density most frequently used by farmers was 0.04 fish/L (31%). This stocking density of 0.04 fish/L is within the range of 0.04 fish/L to 0.06 fish/L, which was used in previous studies with different fish sizes ranged from 2.67 g to 125.00 g (Setiadi *et al.*, 2018; Saufie *et al.*, 2020; Tawaha *et al.*, 2021; Atique *et al.*, 2022).

In the present study, aquaponics farms have different fish: crop ratios (see Figure 2G). Some aquaponics farmers determine the fish: crop ratio by referring to the growth condition of the fish and crop which was also reported in a study in Czechia (Tůmová *et al.*, 2020). According to Shete *et al.* (2015), the optimum ratio for aquaponics is 1 fish to 2 crops which optimises the production of both fish and crops to achieve their optimal growth performance in the system. Besides fish: crop ratio, fish feed to crop ratio is another alternative method to calculate the optimal quantities of fish and crop in an aquaponics system (Bailey & Ferrarezi, 2017). Calculation on the fish and crop ratio is important in countries with limited area and resources to maximise the fish and crop production in aquaponics (Somerville *et al.*, 2014; Shete *et al.*, 2015).

3. Production cycle and IoT application

The marketable fish size was determined individually by each surveyed aquaponics farm, and it varied among the farms. After six months of the production cycle, the fish grown in aquaponics had reached a weight of 300 g and were predominantly sold to grocery shops, fresh markets, and consumers. Furthermore, in this study, aquaponics farmers extended the growth duration of their fish to one year. Consequently, the fish, when reaching a weight of 0.8 kg to 1 kg, were sold to local restaurants. On the other hand, leafy vegetable production was within the range of 28 days to 40 days to reach marketable size, depending on the variety of crops. Regarding IoT applications, only some farmers use sensors, cloud storage, and user interfaces for data collection. The results showed that IoT application was not commonly implemented by most of the aquaponics farms which might be ascribed to the high capital and maintenance costs of the IoT application. Implementation of IoT in aquaponics could aid the farmers in plant pests and diseases monitoring (Lin *et al.*, 2022), the health of the crop and fish monitoring (Alselek *et al.*, 2022) and water parameters monitoring and regulating (Narvios *et al.*, 2022; Dawa *et al.*, 2022).

C. Financial Input and Output of Aquaponics Farms

1. Initial Capital, Annual Expenses, Annual Crop and Fish Production Value

According to the study conducted by Quagrainie *et al.* (2017), the total initial capital for a small farm was $65,000, a medium farm was $125,000 and a large-scale farm was $250,000 in the United States. Compared to the present survey (Figure 3A), the average initial capital to establish an aquaponics farm in Malaysia (RM 75.44/ft^2) was cheaper whereas the initial capital for a small-scale aquaponics farm only ranged from RM 100 to RM 181.82 per ft^2. Large-scale farms (ranging from RM 2.17 to RM 29.78 per ft^2) in Malaysia were also cheaper than the investment required to build a commercial aquaponics farm in Hawaii (Tokunaga *et al.*, 2015) and Czechia (Tůmová *et al.*, 2020). Lower capital required in the country is mainly due to the relatively affordable construction and material costs in Malaysia than those developed countries. Moreover, 85% of the aquaponics farms in this study were in an intermediate and large-scale farm size (Figure 1E), hence, the construction cost might be lower when the building materials are purchased in bulk at their wholesale price.

Annual expenses recorded in the present survey included the production and labour costs. Annual expenses for small-scale aquaponics farms were higher than those for bigger farm sizes. This could be due to larger farms having the benefit of placing bulk orders for fish fingerlings, fish feed, plant seeds, fertilisers, and pesticides, securing wholesale prices that are lower than the smaller quantities purchased by small-scale farms. While costs for electricity, water, and labour may rise in proportion to the size of the farm, a significant factor leading to higher annual expenses for smaller aquaponics farms could be the elevated purchase prices associated with smaller quantities. Economic analysis can be conducted on aquaponics farms in Malaysia to obtain a statistical result in future studies.

Average crop production (RM 20.59/ft^2) was two-fold more profitable than average fish production (RM 6.76/ft^2) that are produced by the aquaponics farms in this study. The same situation was reported in other studies as crop production is more profitable than fish production in aquaponics (Tokunaga *et al.*, 2015; Quagrainie *et al.*, 2017;

Bosma *et al.*, 2017; Bailey & Ferrarezi *et al.*, 2017). This might be due to the cultivation of low-value fish species such as tilapia, which was grown by most of the aquaponics farms. Low-value fish species would cause the profit of an aquaponics farm to rely on crop production. This will result in a non-profit aquaponics commercial farm (Bosma *et al.*, 2017). Choices could be made by rearing high-value fish species such as jade perch (*S. barcoo*) or other high-value native fish species to improve the fish production value (Bosma *et al.*, 2017; Pinho *et al.*, 2021). Only one native fish species (*krai*, *Hypsibarbus* sp.) was cultured in aquaponics farms in this study. More high-value Malaysian native fish species could be selected such as *kelah* (*Tor* spp.) and *jelawat* (*Leptobarbus hoevenii*) (Department of Fisheries, 2022), which might improve the fish production value in aquaponics. However, there is a need to explore the cultivation of these indigenous fishes, considering the uncertainties associated with adoption and the unforeseen factors that might arise during their cultivation in aquaponics. This includes understanding the potential impact on their growth performance and the water quality parameters of the aquaponics system.

Another recommendation would be using ornamental fishes in the aquaponic systems which are not used by any farmers in this study. Ornamental fish were also grown in aquaponics in other regions (Love *et al.*, 2015; Villarroel *et al.*, 2016; Mchunu *et al.*, 2018; Tůmová *et al.*, 2020; Pattillo *et al.*, 2022). Malaysian aquaponics farms could breed and culture ornamental fish such as koi or goldfish (Cyprinidae) which can fetch a higher value than the consumable fish species to improve the fish production value (Pattillo *et al.*, 2022). Undoubtedly, the growth of the aquarium industry in Malaysia can be a potential market for aquaponics farmers to sell their ornamental fish for more profits (Mohamand *et al.*, 2022), not to mention that ornamental fish is one of the main contributors to aquaculture exports (Department of Fisheries, 2022).

3. Market place and farm business status

Direct selling aquaponics products to the consumers is more profitable for the aquaponics farms as the profit margin is greater compared to selling them to other marketing platforms. A study conducted by Tamin *et al.* (2015) stated that Malaysians have a high intention of purchasing aquaponics products. Direct selling to consumers provides farmers a better chance to promote their aquaponics products personally. Besides, selling fish and crops grown through aquaponics to restaurants or cafes could command higher prices, as the products are used in dishes or delicacies. Farmers who could not directly sell their aquaponics products would be involved in other businesses that are related to aquaponics to support their operation. Similar to the study conducted by Pattilo *et al.* (2022), commercial aquaponics producers would not only sell their fish and crops, but incorporate aquaponics with agritourism, educational opportunities, and non-food products to generate income for aquaponics farms. Villarroel *et al.* (2016) found that only 12% of the aquaponics farms in Europe sold only crops that grew from their system while 24% of aquaponics farms sold materials and supplies, and 65% of them provided aquaponics training and education for profit. An aquaponics farm that sells only crops and fish would face difficulty in maintaining the farm operations. Therefore, farmers are suggested to diversify their products and services to support the economic viability of aquaponics in their farms.

D. Farm Challenges

Major challenges faced by the surveyed aquaponics farms in this study were plant pests and diseases, farm financial issues, nutrient imbalance, and pH instability. In Czechia, large-scale commercial aquaponics farms face plant pest problems and nutrient deficiencies which cause great losses in the production of crops (Tůmová *et al.*, 2020). To prevent the problem of plant pests and diseases, farmers should adopt standard biosecurity measures at their greenhouses and use the correct methods to monitor the insect pests, plant bacteria, and viruses in their aquaponics system by using IoT applications with disease monitoring sensors (Lin *et al.*, 2022) and bio-pesticides or biological control agents that suitable to be applied on aquaponics (Suárez-Cáceres *et al.*, 2021; Folorunso *et al.*, 2022).

Furthermore, Yep and Zheng (2019) reported that problems like nutrient imbalance and instability of pH in the culture water had also caused concern to the aquaponics farmers in Malaysia. Insufficient nutrient supply in aquaponics is caused by nutrient sources from fish faeces and feed which do not provide adequate amounts of phosphorus, potassium, and other micronutrients for plant growth. Maintaining the water pH within the optimal range for various components is a significant consideration in aquaponics. This is particularly important because the use of fertilisers and the action of water changes in the aquaponics system can influence the water pH. The optimal pH ranges for different components must have distinct requirements: fish growth (6.5-7.0), nitrifying bacteria like *Nitrobacter*, *Nitrosomonas*, and *Nitrospira* (7.0-8.3), and nutrient absorption by plants (5.8-6.2) (Yep & Zheng, 2019). Moreover, challenges faced by aquaponics farms extend beyond pH concerns, encompassing financial issues stemming from factors like crop and fish production value, the cultivation of low-value fish species, and limited market sources for selling aquaponics products at favourable prices.

V. CONCLUSION

The present study reflects the development status of aquaponics in Malaysia. Aquaponics is not the main choice for Malaysian farmers to practice crop and fish cultivation due to various farm challenges. Most crop and fish species grown in aquaponics in Malaysia were similar to the findings reported in other regions. Differences were recorded regarding the aquaponics system setup, farm location and size, financial input, and output of the farms. On average, aquaponics farmers spent RM 75.44/ft^2 on the initial capital of the farm setup while RM 16.44/ft^2 on the farm annual expenses. Besides, the value of average crop production (RM 20.59/ ft^2) was higher than the fish production (RM 6.76/ ft^2) produced by aquaponics farms in Malaysia. Aquaponics farms in Malaysia should pay a great deal of attention to their farm's economic viability in order to support the operation of the commercial business.

Future research should investigate each aspect in this study further which include economic feasibility and solutions to each challenge faced by the aquaponics farms in Malaysia. Besides, a survey on the consumer perspective towards aquaponics products in different perspectives such as consumer knowledge towards aquaponics, financial consideration, and food safety could be conducted. A related study can also be conducted to understand the consumer's attitude toward aquaponics products and promote aquaponics as a sustainable farming method to the consumer knowledge. Aquaponics is a sustainable farming method that should be widely developed for sustainable agricultural production.

VI. ACKNOWLEDGEMENT

This study was financed by Universiti Tunku Abdul Rahman Research Fund (UTARRF) and awarded to the corresponding author by the Institute Postgraduate Studies Research, UTAR, Malaysia (IPSR/RMC/UTARRF/2021-C2/T04). The authors are grateful to all the aquaponics farmers who agree to provide valuable on-farm information about the industry.

VII. REFERENCES

Ahmad, AK, Nur-Hazwani, MNR, Omar, SAS, Aweng, ER & Taweel, A 2020, 'Preliminary study on invasive fish species diffusion in selected Malaysian freshwater ecosystems', *Pakistan Journal of Biological Sciences*, vol. 23, pp. 1374-1379.

Alarcón-Silvas, SG, León-Cañedo, JA, Fierro-Sañudo, JF, Ramírez-Rochín, J, Fregoso-López, MG, Frías-Espericueta, MG, Osuna-Martínez, CC & Páez-Osuna, F 2021, 'Water quality, water usage, nutrient use efficiency and growth of shrimp *Litopenaeus vannamei* in an integrated aquaponics system with basil *Ocimum basilicum*', *Aquaculture*, vol. 543, p. 737023.

Alselek, M, Alcaraz-Calero, JM, Segura-Garcia, J & Wang, Q 2022, 'Water IoT monitoring system for aquaponics health and fishery applications', *Sensors*, vol. 22, no. 19, p. 7679.

Atique, F, Lindholm-Lehto, P & Pirhonen, J 2022, 'Is aquaponics beneficial in terms of fish and plant growth and water quality in comparison to separate recirculating aquaculture and hydroponic systems?', *Water*, vol. 14, p. 1447.

Azra, MN, Kasan, NA, Othman, R, Noor, GAGR, Mazelan, S, Jamari, ZB, Sarà, G & Ikhwanuddin, M 2021, 'Impact of COVID-19 on aquaculture sector in Malaysia: Findings from the first national survey', *Aquaculture Reports*, vol. 19, p. 100568.

Bailey, DS & Ferrarezi, RS 2017, 'Valuation of vegetable crops produced in the UVI commercial aquaponics system', *Aquaculture Reports*, vol. 7, pp. 77-82.

Bosma, RH, Lacambra, L, Landstra, Y, Perini, C, Poulie, J, Schwaner, MJ & Yin, Y 2017, 'The financial feasibility of producing fish and vegetables through aquaponics', *Aquaculture Engineering*, vol. 78, pp. 146-154.

Dawa, M, Lausa, SM & Tibom, MR 2022, 'Internet of Things (IoT) based aquaponics management system adaptive to climate change', *AIP Conference Proceedings*, vol. 2502, p. 050004.

Department of Agriculture (DOA) 2023, *Malaysian Organic Certification Scheme (myORGANIC)*, viewed 25 November 2023, < https://www.doa.gov.my/index.php/pages/view/377>.

Department of Fisheries (DOF) 2022, *Annual Fisheries Statistics*, viewed 6 January 2023, < https://www.dof.gov.my/en/resources/fisheries-statistics-i/>.

Effendi, H, Wahyuningsih, S & Wardiatno, Y 2017, 'The use of nile tilapia (*Oreochromis niloticus*) cultivation wastewater for the production of romaine lettuce (*Lactuca sativa L.* var. *longifolia*) in water recirculation system', *Applied Water Science*, vol. 7, pp. 3055-3063.

Folorunso, EA, Bohatá, A, Kavkova, M, Gebauer, R & Mraz, J 2022, 'Potential use of entomopathogenic and mycoparasitic fungi against powdery milder in aquaponics', *Frontiers of Marine Science*, vol. 9, no. 7, p. 992715.

Food and Agriculture Organization (FAO) 2017, *The future of food and agriculture - Trends and challenges*, Food and Agriculture Organization of the United Nations, Rome.

Food and Agriculture Organization (FAO) 2020, *The state of world fisheries and aquaculture 2020: Sustainability in action*, Food and Agriculture Organization of United Nations, Rome.

Gosh, K & Chowdhury, S 2019, 'Review of aquaponics system: Searching for a technically feasible and economically profitable aquaponics system', *Journal of Agricultural, Environmental and Consumer Science*, vol. 19, pp. 5-13.

Hao, Y, Ding, K, Xu, Y, Tang. Y, Liu, D & Li, G 2020, 'States, trends, and future of aquaponics research', *Sustainability*, vol. 12, pp. 1-14.

Irbahim, IZ, Wahab, MAMA & Suhaimee, S 2016, *Organic Agriculture in Malaysia*, viewed 25 November 2023, <https://ap.fftc.org.tw/article/1010#:~:text=In%20Malaysia%2C%20organic%20agriculture%20have,wild%20mushrooms%20and%20bamboo%20shoots>.

Junge, R, König, B, Villarroel, M, Komives, T & Jijakli, MH 2017, 'Strategic points in aquaponics', *Water*, vol. 9, no. 3, p. 182.

Kledal, PR, König, B & Matulić, D 2019, *Aquaponics: The ugly duckling in organic regulation*, Springer, Denmark.

KÖnig, B, Junge, R, Bittsansky, A, Villarroel, M & Komives, T 2016, 'On the sustainability of aquaponics', *Ecocycles*, vol. 2, no. 1, pp. 26-32.

Lennard, W & Goddek, S 2019, *Aquaponics: The basics*, Springer, Cham.

Lin, WL, Wang, SC, Chen, LS, Lin, TL & Lee, JL 2022, 'Green care achievement based on aquaponics combined with human-computer interaction', *Applied Sciences*, vol. 12, no. 19, p. 9809.

Love, DC, Fry, JP, Genello, L, Hill, ES, Frederick, JA, Li, X & Semmens, K 2015, 'An international survey of aquaponics practitioners', *PLoSONE*, vol. 9, no. 7, p. e102662.

Mchunu, N, Lagerwall, G & Senzanje, A 2018, 'Aquaponics in South Africa: results of a national survey', *Aquaculture Reports*, vol. 12, pp. 12-19.

Mohamand, ABM, Siti, NA, Mohd, IZ & Shahreza, S 2022, 'Aquascape ornamental industry in Malaysia: A perspective review', *IOP Conference Series: Earth and Environmental Science*, vol. 860, no. 1, p. 012044.

Narvios, WM, Cesa, CKN, Batayola, FF, Bolo, K, Verdida, SM & Nguyen, YQ 2022, 'Smart aquaponics system for a small-scale farmer for highly urbanized settler', *AIP Conference Proceeding*, vol. 2502, p. 05001.

Niu, G & Masabni, J 2018, 'Plant production in controlled environments', *Horticulturae*, vol. 4, no. 4, p. 28.

Pattillo, DA 2017, *An overview of aquaponic systems: Hydroponic components*, North Central Regional Aquaculture Center, Iowa.

Pattillo, DA, Hager, JV, Cline, DJ, Roy, LA & Hanson, TR 2022, 'System design and production practices of aquaponics stakeholders', *PLoS ONE*, vol. 17, no. 4, p. e0266475.

Pickens, JM, Danaher, J & Wells, D 2016, *Greenhouse crops and cropping systems for commercial aquaponics*, Southern Regional Aquaculture Center Publication, Mississippi.

Pinho, SM, David, LH, Garcia, F, Keesman, KJ, Portella, MC & Goddek, S 2021, 'South American fish species suitable for aquaponics: a review', *Aquaculture International*, vol. 29, pp. 1427-1449.

Pinho, SM, Flores, RMV, David, LH, Emerenciano, MGC, Quagrainie, KK & Portella, MC 2021, 'Economic comparison between conventional aquaponics and FLOCponics systems', *Aquaculture*, vol. 552, p. 737987.

Quagrainie, KK, Flores, RMVF, Kim, H & McClain, V 2017, 'Economic analysis of aquaponics and hydroponics production in the U.S. Midwest', *Journal of Applied Aquaculture*, vol. 30, no. 1, pp. 1-14.

Rahmat, SR, Khan, HH, Badaruddin, RFR, Mohamad, MF & Samsurijan, MS 2021, 'A review of organic agriculture industry in Malaysia and gross margin between organic and conventional plantation', *Journal of Contemporary Issues in Business and Government*, vol. 27, no. 3, pp. 329-338.

Rakocy, JE, Shultz, RC, Bailey, DS & Thoman, ES 2004, 'Aquaponic production of tilapia and basil: Comparing a batch and staggered cropping system', *Acta Horticulturae*, vol. 648, pp. 63-69.

Rizal, A, Dhahiyat, Y, Zahidah, Andriani, Y, Handaka, AA & Sahidin, A 2018, 'The economic and social benefits of an aquaponic system for the integrated production of fish and water plants', *IOP Conference Series: Earth and Environmental Science*, vol. 137, p. 012098.

Roosta, HR 2014, 'Effects of foliar spray of K on mint, radish, parsley and coriander plants in aquaponic system', *Journal of Plant Nutrition*, vol. 37, pp. 2236-2254.

Saufie, S, Estim, A, Shaleh, SRM & Mustafa, S 2020, 'Production efficiency of green beans integrated with tilapia in a circular farming system of media-filled aquaponics', *Spanish Journal of Agricultural Research*, vol. 18, no. 3, p. e0611.

Setiadi, E, Widyastuti, YR & Prihadi, TH 2018, 'Water quality, survival, and growth of red tilapia, *Oreochromis niloticus* cultured in aquaponics system', *E3S Web of Conferences*, vol. 47, p. 02006.

Shete, AP, Verma, AK, Chadha, NK, Prakash, C & Chandrakant, MH 2015, 'A comparative study on fish to plant component ratio in recirculating aquaponic system with common carp and mint', *Journal of Environment and Bio-Sciences*, vol. 29, no. 2, pp. 323-329.

Somerville, C, Cohen, M, Pantanella, E, Stankus, A & Lovatelli, A 2014, *Small-Scale Aquaponic Food Production*, Food and Agriculture Organization of the United Nations, Rome.

Suárez-Cáceres, GP, Pérez-Urrestarazu, L, Avilés, M, Borrero, C, Eguíbar, JRL & Fernández-Cabanás, VM 2021, 'Susceptibility to water-borne plant diseases of hydroponic vs. aquaponics systems', *Aquaculture*, vol. 544, p. 737093.

Tamin, M, Haruun, A, Estim, A, Saufie, S & Obong, S 2015, 'Consumer acceptance towards aquaponics products', *IOSR Journal of Business and Management*, vol. 17, no. 8, pp. 49-64.

Tawaha, AR, Wahab, PEM, Jaafar, H, Zuan, ATK & Hassan, MZ 2021, 'Effects of fish stocking density on water quality, growth performance of tilapia and yield of butterhead lettuce grown in decoupled recirculation aquaponic systems', *Journal of Ecological Engineering*, vol. 22, no. 1, pp. 8-19.

Tokunaga, K, Tamaru, C, Ako, H & Leung, P 2015, 'Economics of small-scale commercial aquaponics in Hawaii', *Journal of the World Aquaculture Society*, vol. 46, no. 1, pp. 20-31.

Tůmová, V, Klímová, A & Kalousa, L 2020, 'Status quo of commercial aquaponics in Czechia: A misleading public image?', *Aquaculture Reports*, vol. 18, p. 100508.

Villarroel, M, Junge, R, Komives, T, K¨onig, B, Plaza, I, Bitts´anszky, A & Joly, A 2016, 'Survey of aquaponics in Europe', *Water*, vol. 8, no. 10, p. 468.

Waiho, K, Fazhan, H, Ishak, SD, Kasan, NA, Liew, HJ, Norainy, MH & Ikhwanuddin, M 2020, 'Potential impacts of COVID-19 on the aquaculture sector of Malaysia and its coping strategies', *Aquaculture Reports*, vol. 18, p. 100450.

Yep, B & Zheng, YB 2019, 'Aquaponics trends and challenges – a review', *Journal of Cleaner Production*, vol. 228, pp. 1586-1599.