ENTREPRENEURS AND CONSUMERS PERSPECTIVE ON AQUAPONICS AND ITS POTENTIAL APPLICATION ON *Tor tambroides* AND *Leptobarbus hoevenii* IN MALAYSIA

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FACULTY OF SCIENCE
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APRIL 2024

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By

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A dissertation submitted to the Department of Agricultural and Food Science
Faculty of Science
Universiti Tunku Abdul Rahman
in partial fulfillment of the requirements for the degree of
Master of Science

April 2024

ABSTRACT

Entrepreneurs and consumers perspective on aquaponics and its potential application on *Tor tambroides* and *Leptobarbus hoevenii* in Malaysia

Colin Kiu Qi Song

Aquaponics is a sustainable farming method that integrates hydroponics and aquaculture while aquaponics farming can enhance fish diversity and boost fish production in Malaysian aquaculture. Documenting local entrepreneurs and consumer perspective have not done previously, which are pivotal to promote the development and commercialization of aquaponics in Malaysia. Besides, investigating the potential application of aquaponics on culturing *Tor tambroides* and *Leptobarbus hoevenii* are also important to improve their productivity within the nation. Two surveys were conducted to investigate the development status of aquaponics operations and consumer perspectives on aquaponics. Additionally, a fish rearing experiment was carried out on two selected high-value native fish species in Malaysia within aquaponics systems. The first survey contains information on the operation and production of 13 commercial aquaponics farms in Malaysia. These aquaponics farms' most produced crop and fish were leafy vegetables (e.g. lettuce, salad greens, kale and bak choy) 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, the crop value was threefold higher than the fish value produced by these aquaponics farms. Plant pests and diseases, financial issues, pH stabilization and nutrient deficiencies were the main challenges faced by these farmers. The second survey was conducted to determine consumers' perceptions and knowledge of aquaponics and its products. Consumers had less experience in practicing aquaponics and purchasing aquaponics products. They had a positive attitude towards the benefits provided by aquaponics and its products but held a neutral attitude towards purchasing and spending more on aquaponics products. A 3 × 2 (fish species × culture system) factorial design experiment was conducted to compare the productivity of empurau (*Tor tambroides*), jelawat (*Leptobarbus hoevenii*) and red hybrid tilapia (*Oreochromis* sp., control) cultured in recirculating aquaculture system (RAS) and aquaponics system. Growth performance, feed conversion ratio and survival rate of fish were evaluated. The water quality of all tanks was determined throughout the 70-day experiment. Growth performance of empurau and jelawat in weight gain: empurau in aquaponics (390.99%) vs. RAS (390.99%), and jelawat in aquaponics (1111.84%) vs. RAS (1134.89%). For FCR, empurau in aquaponics (2.30) vs. RAS (2.62), and jelawat in aquaponics (1.68) vs. RAS (1.74) were observed in aquaponics as compared to RAS. The result holds the potential to enhance fish production and its diversity, along with promoting aquaponics as a sustainable farming approach to culturing Malaysian indigenous fish species. In summary, aquaponics is still an emerging practice in Malaysia with a promising consumer market. Aquaponics requires more exposures and promotions within the nation to guarantee a continuous development in the future of Malaysian aquaculture.

ACKNOWLEDGEMENTS

I wish to express my greatest appreciation to my supervisor, Ts. Dr. Teoh Chaiw Yee, who guided this project. She is supportive, has patience, and gives insightful comments on my work. I also wish to express my greatest gratitude to my co-supervisor, Dr. Ooi Ai Lin, who provided guidance and advice for my work. Additionally, I wish to thank Universiti Tunku Abdul Rahman for providing the research fund (UTARRF) to complete this research project.

I want to express my heartfelt gratitude to all of the aquaponics farms and respondents who participated in the surveys. I am thankful to all of them for spending their precious time. Without their involvement, it would be impossible to complete the survey. Their kindness and helpfulness are highly appreciated.

Finally, to my beloved family members, my father, mother and younger siblings, I would like to thank them for supporting and encouraging me to complete my research. Their understanding and prayers are very much appreciated.

APPROVAL SHEET

This dissertation entitled "**Entrepreneurs and consumers perspective on aquaponics and its potential application on *Tor tambroides* and *Leptobarbus hoevenii* in Malaysia**" was prepared by COLIN KIU QI SONG and submitted as partial fulfillment of the requirements for the degree of Master of Science at Universiti Tunku Abdul Rahman.

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It is hereby certified that ______***COLIN KIU QI SONG***______________ (ID No: __***22ADM00993***_____) has completed this dissertation entitled "Investigation on the current aquaponics status and its potential application for high value native fish species in Malaysia" under the supervision of Ts. Dr. TEOH CHAIW YEE (Supervisor) from the Department of Agricultural and Food Science, Faculty of Science, and Dr. OOI AI LIN (Co-Supervisor) from the Department of Agricultural and Food Science, Faculty of Science.

I understand that University will upload a softcopy of my dissertation in pdf format into UTAR Institutional Repository, which may be made accessible to UTAR community and public.

Yours truly,

COLIN KIU

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(*Colin Kiu Qi Song*)

DECLARATION

I hereby declare that the dissertation is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UTAR or other institutions.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
Ca	Calcium
CO_2	Carbon dioxide
DO	Dissolved oxygen
DOF	Department of Fisheries
DPTA	Diethylenetriamine pentaacetate
DWC	Deep water culture
EDDHA	Ethylenediamine-N,N'-bis(2-hydroxyphenylacetic acid)
EDTA	Ethylenediaminetetraacetic acid
FAO	Food and Agriculture Organization
FCR	Feed conversion ratio
Fe	Iron
GIFT	Genetically Improved Farmed Tilapia
IoT	Internet of Things
K	Potassium
Mg	Magnesium
myGAP	Malaysian Good Agricultural Practices
myOrganic	Malaysian Organic Certification Scheme
NFT	Nutrient film technique
NH_3-N	Ammonia
NO_2^-	Nitrite
NO_3^-	Nitrate

P	Phosphorus
RAS	Recirculating aquaculture system
USA	United States of America

CHAPTER 1

INTRODUCTION

Aquaponics is an agricultural practice that combines the principles of aquaculture and hydroponics in a closed-loop system. It has gained a fair amount of attention worldwide (Pattillo, et al., 2022). It integrates a recirculating aquaculture system (RAS) with hydroponics to culture aquatic organisms and plants in a recirculating unit. In the system of aquaponics, effluent is channeled 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 benefits in aquaculture waste treatment, land and water management. It can increase food productivity, reduce environmental impacts and be economically feasible. It can also give impact in social education and generate farm diversification (Somerville, et al., 2014; Rizal, et al., 2017; Lennard and Goddek, 2019). All these benefits have driven the development of aquaponics which is one of the global emerging technologies (Hao, et al., 2020; Pattillo, et al., 2022).

As the world population is growing, water conservation to secure water resources is one of the challenges in aquaculture (FAO, 2021). Besides, improving food productivity is also essential to achieving zero hunger as one of the sustainable development goals (SDGs) listed by the United Nations. Concerns regarding resource scarcity and food safety are raised due to limited resources and a growing human population. Furthermore, untreated waste water produced by aquaculture activities which is released into the environment has also raised concerns about the environmental impacts that it may cause. Harmful waste released by fish farms will accumulate in the environment and cause nutrient loading as the waste water contains metabolic waste products and uneaten feeds from fish cultivation (Granada et al. 2015).

The advantages of aquaponics are greatly reflected in water conservation. Compared to RAS and hydroponic systems, aquaponics system has higher water use efficiency that consumes only 0.3 to 5.0% of the water from the system daily (Yep and Zheng, 2019; Alarcón-Silvas, et al., 2021). Recycling the waste water from aquaculture can be achieved in the aquaponics system as the grown crops can absorb the nutrients from the waste water after the degradation of the toxic substances by bacteria. This waste recycling function has gained aquaponics its importance in aquaculture wastewater remediation and lowering the environmental impacts compared to conventional aquaculture (Suárez-Cáceres et al. 2021; Estim et al. 2023). The system treats the waste water produced during fish cultivation, which has also conserved and secured the water resources for plant cultivation as water conservation is one of the challenges in aquaculture listed by FAO (2017).

Hence, aquaponics is perceived as a more sustainable farming method and a technology-intensive innovation to produce agricultural products (fish and crops) recommended by FAO (2020) towards aquaculture sustainability. This is mainly due to its great deal of advantages such as high water efficiency (Yep and Zheng, 2019), producing more than one type of food in a system (Lennard and Goddek, 2019), reducing the release of waste water into the environment and mitigating negative environmental impacts caused by conventional aquaculture farms (Suárez-Cáceres, et al., 2021; Estim, et al., 2023). Urbanization is a challenge to agriculture in competing land utilization. Aquaponics systems can be operated in urban areas. Hence, urbanization has driven aquaponics to meet local market demand and increase food availability in urban areas. It has great potential to produce food and shorten the food supply chain within the urban areas (Goddek, et al., 2015).

Additionally, aquaponics has attracted many practitioners globally to developing aquaponics on a commercial scale (Bosma, et al. 2017; Tůmová, Klímová and Kalousa et al. 2020; Pattillo et al. 2022). There are also educators and hobbyists practicing aquaponics in both rural and urban areas globally (Love et al. 2015; Pattilo et al. 2022). As more studies are focusing on the biology and technology of aquaponics, consumers aspects in the agricultural industry and market should be investigated to further develop aquaponics as a sustainable farming technology (Junge, et al., 2017). In Malaysia, there is a lack of information on the status of aquaponics, especially on the commercial aquaponics farm. There are many different aquaculture systems in Malaysia where most are pond culture (DOF, 2022). Implementation of 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 which comes with various benefits, would be one of the substantial methods to improve the productivity in aquaculture production (Othman, 2010; Lennard and Goddek, 2019). Aquaponics products produced by aquaponics operations have been sold to aquaponics consumers, especially on the fish and crops grown using aquaponics systems. In Malaysia, Tamin, et al. (2015) have elaborated four variables: perceived knowledge, relative advantage, subjective norm and compatibility that affect Malaysian consumers to purchase aquaponics products with a significant positive relationship. This shows that there is a potential local market for aquaponics in Malaysia.

On the other hand, previous studies reported that aquaponics improved the survival rate and growth performance of the cultured fish species (Effendi, et al., 2017; Setiadi, et al., 2018; Atique, et al., 2022). It has been shown that 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 came 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). Improved growth performance of tilapia using aquaponics are also reported by Effendi, et al. (2017) and Setiadi, et al. (2018). With these benefits, farmers in Malaysia practicing aquaponics could enhance tilapia production as tilapia is the most cultured freshwater fish species in Malaysia with the production reaching 37,609.45 tonnes and retail sale of RM 574,788.64 in 2021 (DOF, 2022).

Nevertheless, only a few fish species, particularly tilapia, have been observed to be popular in aquaponics (Love, et al., 2015; Villarroel, et al., 2016;

Mchunu, et al., 2018; Pattillo, et al., 2022). Additionally, crop production in aquaponics is more profitable compared to fish production in aquaponics as Bosma, et al. (2017) reported an aquaponics farm that primarily cultured low-value fish species like tilapia could not be successful in the Philippines. In many locations, tilapia and catfish are exotic fish species that may not be well accepted by consumers in all markets, such as Vietnam (Mapenzi, et al., 2020), Tanzania (Madsen, et al., 2015), South America (Pinho, et al., 2021), China (Zhong, et al., 2016) and Malaysia (Rahim, et al., 2013; Ariffin, et al., 2019; Ahmad, et al., 2020). Therefore, native fish species appear to be a viable option to meet local market demand and increase the variety of fish in aquaponics (Pinho, et al., 2021). Growing native fish species could also help tomad prevent the spread of exotic species, which could endanger the native population in the wild. For example, tilapia (*Tilapia nilotica*) is described as an introduced species that has invaded the nation's local streams (Ahmad, et al., 2020). Not only that, African catfish (*Clarias gariepinus*) and broadhead catfish (*C. macrocephalus*) are invasive catfish species in Malaysia introduced through aquaculture (Rahim, et al., 2013; Ariffin, et al., 2019). Adoption of native species in aquaponics may help to tap into the international market and boost species diversification in aquaculture production.

Selection on the native fish species in aquaculture should have certain criteria. Considering that the aquaponics system in this study will be implemented with RAS, the native fish species should have the capability to grow in intensive RAS (Yep and Zheng, 2019; Pinho, et al., 2021). Selected native fish species for aquaponics should have high market acceptance and high market value in the local area (Pinho, et al., 2021). This is to balance the value of fish production with the crop plant production in aquaponics. In addition, introducing native fish species into aquaponics may consider the aspect of improving their growth performance to increase their production yield.

Native freshwater fish species growing in aquaponics are not thoroughly researched, despite the fact that they could become an alternative to common fish species grown in aquaponics (Pinho, et al., 2021). Freshwater fish that are natively found in Malaysia, such as empurau (*Tor tambroides*) and jelawat (*Leptobarbus hoevenii*) have high market value and demand locally (Bosma, et al., 2017; Amirrudin and Zakaria-Ismail, 2014; DOF, 2022; Lau, et al., 2023). However, empurau and jelawat are rarely cultivated in aquaponics.

As aquaponics can be considered as a sustainable food production and has the potential to be developed widely in Malaysia, it is important to investigate the current development status of aquaponics and their consumers in Malaysia. Hence, in the present study, two surveys (survey I and survey II) were conducted on aquaponics operations in Malaysia and consumers' perceptions on aquaponics products (fish and crops). The first survey (survey I) aims to document the descriptive information about the development stage of commercial aquaponics farms in Malaysia, including the variety and production value of aquaponics products (crops and fish), potential selling market and aquaponics farm challenges. It was also aimed to evaluate the commercial status of aquaponics and to promote its development in Malaysia as a key towards aquaculture sustainability. There is no data recorded by any Malaysian agencies which is related to aquaponics on fish and crop culturing methods. Providing information on commercial operations can encourage more farmers to venture into aquaponics as it could promote sustainable food production in the country.

The second survey (survey II) aims to investigate Malaysian consumers on their demographic information, experience, perception and knowledge of aquaponics and its products (fish and crop). To determine the consumer preferences and economic considerations on aquaponics products, it could precede the commercial investment in aquaponics by enhancing the producers understanding of the basic trends and structure of the potential consumer markets in Malaysia (Greenfeld, et al., 2020). Considering the fish variety produced by aquaponics is limited to a few species (Pinho, et al., 2021), the perception among Malaysian consumers of native fish species grown using aquaponics was also conducted in the second survey. It is crucial to know the consumers' acceptance of a new product (native fish species cultured using aquaponics) before launching into a new market (Tamin, et al., 2015). It is also important to document this information from the consumers' point of view as it would be the key factor affecting the commercialization of aquaponics production and their economic sustainability (Suárez-Cáceres, et al., 2021).

Subsequently, another objective of this study is to investigate the growth performance, survival rate and FCR of empurau, jelawat and the most popular aquaponics fish species, red hybrid tilapia (*Oreochromis* sp.) cultured in aquaponics as compared to the RAS system, with the goal of determining the viability of native fish species, empurau and jelawat produced in aquaponics.

Water qualities and water use efficiency were also examined among different fish species cultured in the two experimental culture systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Aquaculture

Aquaculture, the farming of aquatic organisms, is a global practice that spans across continents and diverse environments. It serves as a critical contributor to the global food supply, providing a wide range of food products to meet the dietary needs of a growing global population worldwide (Young, et al., 2019; Troell, et al., 2023). Aquaculture practices can be found in virtually every corner of the world, from inland freshwater ponds and raceways to coastal marine environments and land-based recirculating systems. This global reach allows the production of a diverse array of species, including fish, shellfish and aquatic plants (Young, et al., 2019), from saltwater, brackish water to freshwater species (Kurniawan, et al., 2021). The global aquaculture sector has grown an average of 10% annually from 2016 to 2020 (Kurniawan, et al., 2021), which has played a crucial role in food security, economic development and the preservation of aquatic biodiversity (Young, et al., 2019).

By 2050, as the world's population is projected to reach 9.7 billion and the global demand for animal proteins may rise to 88%, food consumption at this level will exceed the guidelines for healthy eating (Troell, et al., 2023). In this context, feeding a growing population with a healthy and sustainable diet is one of the greatest challenges. Aquaculture holds a huge potential to overcome this problem while aquaculture can also contribute substantially to the SDGs in the aspect of eradicating poverty and hunger, improving health and nutrition, providing livelihoods and sources of incomes, and securing environmental resources, including water, land and biodiversity (Troell, et al., 2023). In this regard, sustainable aquaculture which involves cultivation and harvesting of aquatic organisms in a responsible and environmentally friendly manner is essential to meet the growing global food demand while ensuring the resilience of aquatic ecosystems in the long term. As a sustainable farming method, aquaponics is also listed as one of the potentials to continue contributing positively to Agenda 2030 SDGs (Troell, et al., 2023).

2.1.1 Aquaculture in Malaysia

Over the past 150 years, aquaculture in Malaysia had remarkably improved in its culturing technique, cultured species, and national income contribution (Kurniawan, et al., 2021). According to the Annual Fisheries Statistics 2022, aquaculture in Malaysia is not only culturing aquatic organisms in freshwater, but also involves brackish water and marine culture (DOF, 2023). Aquaculture systems in Malaysia include freshwater ponds and cages, ex-mining pools, cement tanks, canvas tanks, pen culture and indoor RAS (DOF, 2021; DOF, 2023). Pond culture with brackish water has the highest production value in 2022, followed by sea cage culture and freshwater pond culture (Table 2.1). The aquaculture in Malaysia is still dominated by sea cage cultures, followed by extensive and intensive pond systems (FAO, 2021).

Table 2.1: Wholesale and retail value of aquaculture production by the top three aquaculture systems in Malaysia, referring to the Annual Fisheries Statistics 2022

Culture System	Wholesale (RM)	Retail value (RM)
Ponds culture in brackish water	1,924 millions	2,399 millions
Sea cages	660 millions	787 millions
Pond culture in freshwater	509 millions	690 millions

Aquaculture has emerged as a vital economic sector in Malaysia, making a noteworthy contribution to the national Gross Domestic Product (GDP), accounting for 0.2% of it (FAO, 2016). In 2019, Malaysia's fisheries sector represented 1.1% of the worldwide total, with aquaculture contributing 0.4%. This contributed to an 8.9% growth in the national agricultural GDP and generated 1.75 million job opportunities for Malaysians. According to the National Agro-Food Policy (NAFP) spanning from 2011 to 2020, the aquaculture industry has been designated as a high value endeavor, and it is anticipated to expand by 8.6% over the 9 years (Chong, 2023).

The aquaculture sector in Malaysia has excelled in generating high value products to cater to local demands and has even ventured into overseas exports as commodities (FAO, 2016), such as on bivalve, mollusks, shrimps, giant tiger prawns, and marine fish (DOF, 2022). Additionally, aquaculture is part of a government initiative aimed at reducing poverty among coastal communities

(Solaymani and Kari, 2014). Government oversight has demonstrated remarkable success in enhancing the well-being of coastal households. Currently, the government is prioritizing research and practical efforts to increase aquaculture production to meet the annual demand (Kurniawan, et al., 2021).

Despite its numerous advantages, aquaculture in Malaysia is still grappling with environmental challenges. The substantial production of fish necessitates land use modification to establish aquaculture sites (Kurniawan, et al., 2021). This has led to the allocation of more than 20,000 hectares of land and coastal areas in Malaysia, with plans for an additional 40,000 hectares as an investment in the aquaculture sector. This investment, anticipated to fulfill demands until 2040, is a government priority (Isa, et al., 2020). Given the rapidly growing number of freshwater aquacultures, there is a growing concern about the management of freshwater resources (Gephart, et al., 2017). Ensuring a secure supply of freshwater for the population without conflicting with the needs of the aquaculture sector is crucial to avoid hindering its growth in the future (Kurniawan, et al., 2021).

2.1.2 RAS

Sustainable aquaculture, which entails producing food while conserving natural resources, can only be realized by adopting production systems that minimize their ecological footprint. The challenges hindering the growth of traditional cage-based and flow-through aquaculture systems include constraints on expansion and new site allocation due to competition with various other uses and interests, limited availability of freshwater, and concerns about pollution. Consequently, European nations, particularly those with existing aquaculture operations like the United Kingdom, Ireland, Italy and Norway, have actively advocated for RAS as a viable solution and opportunity for advancing the aquaculture industry (Badiola, Mendiola and Bostock, 2012). In Malaysia, RAS is also practiced by local aquaculture farmers, mainly applied in cement tanks, fiber tanks and canvas tanks intensively (DOF, 2023; Chong, 2023).

RAS offers the potential to diminish water consumption, enhance waste handling, and optimize nutrient recycling. RAS was originally developed as a technology for intensive fish farming. Recycling culture water in RAS makes it recycle as much as 90-99% of the water by utilizing various components (Badiola, Mendiola and Bostock, 2012). By doing so, they grant the operator a higher degree of control over environmental and water quality factors, thus facilitating the creation of optimal conditions for fish cultivation. However, it is important to acknowledge that RAS comes with significant drawbacks, including substantial capital and operational costs, the need for meticulous management, and challenges in disease treatment (Badiola, Mendiola and Bostock, 2012; Chong, 2023). Furthermore, the continuous recycling of water necessitates constant pumping of new intake water, which leads to increased electricity expenses. Consequently, RAS systems are intricate entities, characterized by their integration of technology and biology, necessitating ongoing performance monitoring ((Badiola, Mendiola and Bostock, 2012).

RAS is a water-saving tool that allows for the harmonization of intensive fish production with environmental sustainability due to its water recycling ability. Reducing the release of waste water from fish cultivation can overcome one of the aquaculture challenges in Malaysia, which is environmental pollution (Chong, 2023). Wide development of RAS can become one of the advances in aquaculture that promotes SDGs, hence, developing Malaysian aquaculture towards sustainable aquaculture farming.

2.2 Aquaponics

The term “Aquaponics” originated from the word combination of aquaculture and hydroponic, which means cooperation of aquatic animals (commonly fish) and plant cultivation in a system (Yep and Zheng, 2019). The history of aquaponics can be traced back to 1,500 years ago in China (Jones, 2000). Farmers stacked the duck’s cages above a stream that connected to their rice field. Leftover feeds and duck feces would drop into the stream as the food source of the cultured fish, including some finfish and catfish. After all, anything that was uneaten by the fish flowed into the rice field, becoming the nutrients for the crops to grow (Jones, 2000). Another aquaponics concept recorded in the past was the ‘Chinampas' system made by the Aztecs in approximately 1,000 A.C., located in Mexico (Acquacoltura Italia, 2016). “Chinampas” is a floating raft that is artificially made from reeds, covered by the muddy soils from the Lake of Texaco. The invention of these “Chinampas” is due to the poor soil conditions in the living area of the Aztecs. The Aztecs had succeeded in farming eventually as the crops grew their roots through the

“Chinampas” and absorbed water and nutrients from the lake (Acquacoltura Italia, 2016). This concept is similar to the deep water culture (DWC) applied in both hydroponics and aquaponics nowadays.

Current aquaponics system is composed of a hydroponic and a RAS (Goddek, et al. 2016; Pinho, et al., 2022). There are three main organisms in aquaponics: fish or other aquatic organisms, plant and nitrifying bacteria (Yep and Zheng, 2019). Yet, the system design of aquaponics can be varied on the hydroponic section and also the sequence of each section (Figure 2.1 and 2.2).

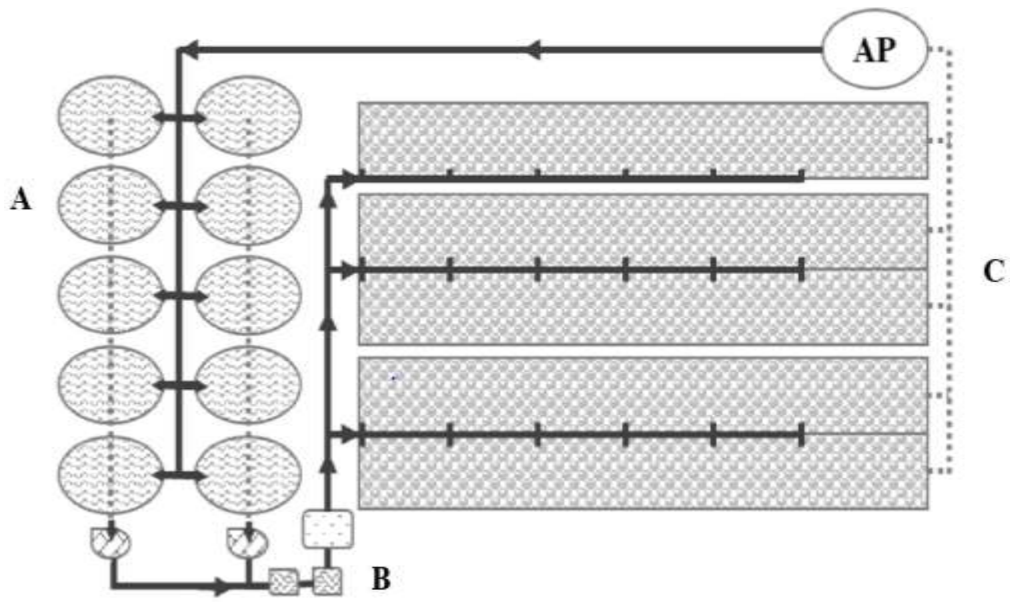


Figure 2.1: Aquaponics system built by Pinho, et al. (2022) with (A) culture tank, (B) physical and biological filtration and (C) hydroponic. DWC is applied in this system. AP stands for aquaponics. Arrow heads show the direction of the water flow.

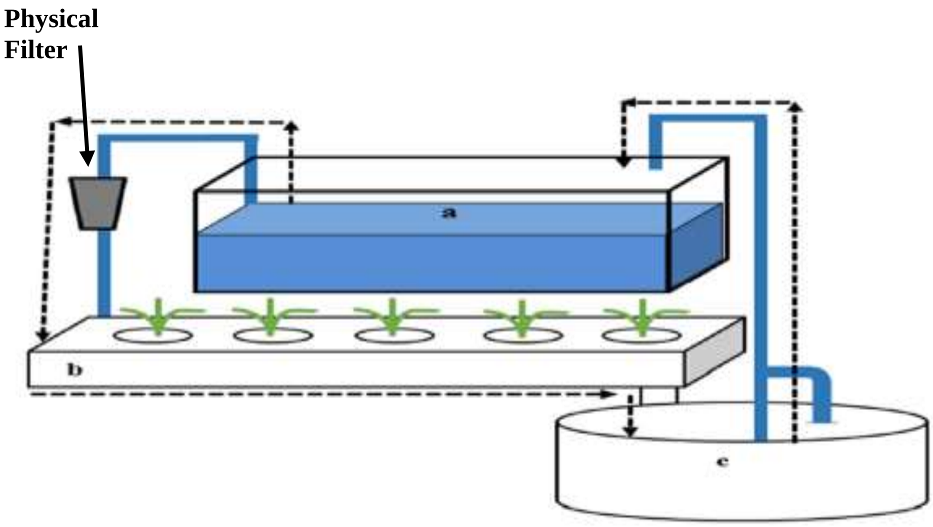


Figure 2.2: Aquaponics system built by Effendi, Wahyuningsih and Wardiatno (2017) with (a) culture tank, (b) hydroponic and (c) filtering section. Sequence of this aquaponics system is different from Figure 2.1. Nutrient film technique (NFT) is applied in this system

2.2.1 Types of Aquaponics Systems

Traditionally, aquaponics is recycling the water in a one loop system, labeled as a coupled aquaponics system. The culture water in a coupled aquaponics system flows through each section of the system like a RAS (Kledal, König and Matulić, 2019). Additionally, a decoupled aquaponics system is invented to solve the problem of nutrient deficiency and pH imbalance in aquaponics system (Goddek, et al., 2016). Decoupled aquaponics system separates fish tank and hydroponics into two parts and each part has their own loop of water supply (Monsees, Kloas, and Wuertz, 2017; Kledal, König and Matulić, 2019). The culture water from the fish tank flows to the hydroponic section, but the effluent is not flowing back to the fish tank. Separating the water body from the fish tank and hydroponics removes the dependency between fish and crop production as extra fertilizers can be added to the hydroponic section (Kledal, König and Matulić, 2019). Monsees, Kloas, and Wuertz (2017) reported that the fruit yield from a decoupled aquaculture system was 39% higher than coupled aquaculture system. Besides, fish production from both systems showed no significant difference in growth performance FCR. Yet, debates between both coupled and decoupled aquaponics systems exist as there is not a consensus about the status of a decoupled aquaponics system to be categorized as an aquaponics or just a nutrient supplying method from the aquaculture effluent with extra nutrient supplements (Junge, et al., 2017).

Moreover, there are more inventions added to the aquaponics to improve the system, such as incorporating biofloc technology in aquaponics to improve fish growth performance (Pinho, et al., 2021) and implementing the application of Internet of Things (IoT) to monitor the water quality, nutrients concentration, fish stock and plant condition, as well as the pest infection on both plant and fish in the aquaponics system (Khaoula, et al., 2021).

2.2.2 Types of Hydroponics in Aquaponics

According to Love, et al. (2014) and Pattillo, et al. (2022), there are seven types of hydroponic setup in aquaponics systems, including DWC, media beds, nutrient film technique (NFT), drip irrigation, vertical towers, wicking beds and Dutch buckets (see Figure 2.3). The three most common hydroponic setups in aquaponics are DWC or floating rafts, NFT and media begs (Love, et al., 2015; Kledal, König and Matulić, 2019; Pattillo, et al., 2022).

For DWC, crops are planted on a platform or raft that floats on the surface of the cultural water. The roots of crops are fully submerged in the cultural water. These roots could carry out the function of regulating water temperature, controlling pH fluctuations, and functioning as a biofilter and water buffer in the whole aquaponics system (Kledal, König and Matulić, 2019). DWC is the top choice for aquaponics operators because it is space-saving and less construction work when it comes to a large-scale commercial aquaponics farm (Gosh and Chowdhury, 2019).

In the NFT system, a film of culture water is constantly supplied to the hydroponic channel, giving the roots only partially submerged in the culture water. The problem of NFT is requiring more construction materials than DWC with piping, however, water used in aquaponics with NFT is lower than DWC (Gosh and Chowdhury, 2019). NFT setup is also limited to crops with small root systems such as leafy vegetables (Duarte, et al., 2015). In addition, certain small-scale aquaponics use media beg to grow crops, mostly with clay pebbles. In these methods, water is flowing through the media beg continuously, or using “Ebb and Flow” technique (flooding and draining) on the planting media. However, clogging is a serious problem in the media because it hinders the water flow through the hydroponic section, hence it is seldom used by large-scale commercial operations (Lennard and Leonard, 2006). Moreover, aquaponics practitioners also conduct other hydroponic methods, such as drip irrigation, vertical tower, wicking beds and Dutch buckets, or the combination of any two hydroponic methods (Love, et al., 2015).

Figure 2.3: Six types of hydroponic setups in aquaponics systems. (Adapted from Love, et al. (2014))

2.2.3 Water Quality in Aquaponics

Aquaponics produces good water quality for fish cultivation, mainly by maintaining a low ammonia concentration and a stable pH in the culture water. Aquaponics has been reported to improve the growth performance and survival rate of fish as compared to conventional aquaculture using RAS due to the improvement in water quality. Previous studies have reported that Nile tilapia (*Oreochromis niloticus*) grown in aquaponics showed better survival rate and growth performance due to enhanced water quality including higher dissolved oxygen (DO), lower total ammonia nitrogen (TAN) and nitrite concentrations compared to RAS (Effendi, et al., 2017; Setiadi, et al., 2018). Likewise, rainbow trout (*Oncorhynchus mykiss*) cultured in aquaponics also showed a lower FCR and higher specific growth rate (SGR) than those grown in RAS due to better water quality in aquaponics (Atique, et al., 2022). In this regard, good water quality can improve the growth performance of cultured fish and aquaponics farming.

Ammonia (NH_3) is one of the parameters that affect the water quality in fish cultivation. Maintaining zero or low NH_3 concentration in the culture water is essential for fish growth. High NH_3 concentration causes the reverse diffusion of NH_3 molecules from the culture water into the blood which has inhibited the excretion of NH_3 from the fish body (Hargreaves and Kucuk, 2001). Upon accumulation in the bloodstream, NH_3 can permeate cell membranes and lead to NH_3 toxicity, disrupting enzyme function and ultimately resulting in the death of fish (Colt, 2006; Abd El-Hack, et al., 2022). The internal build-up of NH_3

induces stress responses in fish which are energy demanding, competing with the energy consumption that is normally used up for fish growth, ingestion and digestion (Paust, et al., 2011), and immune functions (Wendelaar Bonga, 1997; Abd El-Hack, et al., 2022). A study conducted by Rahmati, et al. (2022) also reported that increasing NH_3 concentration has a significant effect on increasing fish stress indices of the cortisol and glucose level which lead to death in tilapia. Previous studies have reported the function of aquaponics in ammonia removal for better water quality for the growth of tilapia (Effendi, et al., 2017; Setiadi, et al., 2018).

Other than that, aquaponics can stabilize the water pH throughout the fish cultivation period. Low water pH in the fish tank is due to the release of carbon dioxide (CO_2) by the living organisms in the systems such as fish and bacteria (Effendi, et al., 2017). CO_2 reacts with the water molecules and forms carbonic acid that drops the pH level in the fish tank (Makhdom, et al., 2017). Besides, the process of nitrification composes the fish metabolic wastes and organic waste materials in the fish tank and releases hydrogen ions into the water column. This process has also reduced the pH level due to the hydrogen ions acidifying the water environment (Dediu, et al., 2011). Aquaponics always results in a more stable pH similar to the finding reported by Makhdom, et al. (2017) and Atique, et al. (2022). The reason for a more neutral and stable water pH is attributed to the presence of crop plants that buffered the pH of the culture water in aquaponics. This is because crop plants exchange the ions of hydrogen and hydroxide in their roots during the nitrate absorption from the culture water in aquaponics. During the process, plant roots uptake cation and excrete anion that cause the root medium to remain alkaline to neutralize the acidic culture water in aquaponics (Makhdom, et al., 2017). Another reason for constant pH in aquaponics might be because of the anoxic parts in the biological filters that form the process of denitrification and alkalinity recovery (Makhdom, et al., 2017). A stable water pH may also be the reason that improves the fish growth performance and survival rate in aquaponics compared to RAS (Makhdom, et al., 2017; Atique, et al., 2022).

2.3 Status of Aquaponic Development

There were some surveys 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, Klímová and Kalousa, et al., 2020).

2.3.1 Aquaponic Development Status in Different Regions

Referring to Table 2.2, an international survey conducted by Love, et al. (2015) reported that most aquaponics practitioners were practicing aquaponics as a hobby (84%), while only 11.7% engaged in the commercial scale of aquaponics operations. Aquaponics has also gained popularity as the number of aquaponics systems increased from 121 to 661 in the 2000s to 2013 (Love, et al., 2015). Pattillo, et al. (2022) conducted another international survey on aquaponics practitioners, showing that aquaponics practitioners have shifted from hobbyists

Table 2.2: Aquaponics status in different regions

Locations/ Regions	Number of Respondents	Descriptions	References
Global regions: International survey	Total: 809 respondents 80% were Americans. Only 1 Malaysian was involved in this survey.	84.0%: Practising aquaponics as a hobby. 11.7%: Engaged in commercial aquaponics. Aquaponics has gained its popularity: the number of aquaponics systems increased from 121 to 661 in the 2000s to 2013.	Love, et al. (2015)
Global regions: International survey	Total: 378 respondents 80% were Americans. No Malaysians were involved.	Aquaponics practitioners have shifted from hobbyists (11.7%) to producers (41%), from 2014 to 2020.	Pattillo, et al. (2022)
Czechia	Total: 148 respondents	60.81%: Hobbyists 16.89%: Educational and research purposes 10.14%: Aquaponics services 9.46%: Self-supply 2.7%: Engaged in commercial aquaponics Total annual aquaponics production in Czechia: 3000 kg of fish and 276 kg of crops.	Tůmová, Klímová and Kalousa (2020)

(11.7%) to producers (41%), from 2014 to 2020, which indicated the development of aquaponics towards commercialization. Both surveys conducted by Love, et al. (2015) and Pattillo, et al. (2022) were mainly participated in by Americans (80% among 809 respondents and 84% among 378 respondents), which could not represent the global aquaponics practitioners.

In Czechia, most of the aquaponics practitioners were hobbyists (60.81%), followed by those building aquaponics for educational and research purposes (16.89%), providing services related to aquaponics (10.14%) and self-supply (9.46%) (Tůmová, Klímová and Kalousa, 2020). Among the 148 respondents from Czechia, only 2.7% were commercializing aquaponics into agricultural products. Moreover, total annual aquaponics production in Czechia could reach 3000 kg of fish and 276 kg of crops grown using aquaponics (Tůmová, Klímová and Kalousa, 2020). However, the authors also stated that the aquaponics industry is still a nonprofit sector with a misleading public image while positive trends in aquaponics are only found on the Internet. Besides, Villarroel, et al. (2016) reported that most aquaponics practitioners from 21 European countries set up aquaponics for educational and research purposes in the universities (42.6%) and vocational schools (8.8%) while there was only 19.1% from commercial aquaponics operations. Not only that, most of them were not having aquaponics as their main income source (80.4%). Villarroel, et al. (2016) also stated that the research base in aquaponics in Europe is still stronger than those aquaponics activities for profit gaining.

A different situation is observed in South Africa as aquaponics is still not practiced by many. According to Mchunu, et al. (2018), only 44 aquaponics operations in South Africa had built aquaponics system previously and most of the systems were in small scale, 39% respondents developed aquaponics as their hobby while 36% for self-supply and 25% for commercial purposes. Aquaponics in South Africa can be considered as an emerging practice while most of the aquaponics practitioners have limited knowledge of aquaponics (Mchunu, et al., 2018).

The results observed in Czechia (Tůmová, Klímová and Kalousa, 2020), Europe (Villarroel, et al., 2016) and South Africa (Mchunu, et al., 2018) show that aquaponics practitioners are practicing aquaponics mainly as a hobby and for some are for research and educational purposes only. Only minority operated the aquaponics commercially. Currently, there is still a lack of studies on the aquaponics status in Asia.

2.3.2 Type of Crops Cultured in Aquaponics

The international survey conducted by Love, et al. (2015) listed out the most cultured crop in aquaponics were basil, tomatoes, and salad greens (Table 2.3). Another type of crops that are grown by aquaponics practitioners include herbs, peppers, lettuce, cucumbers, kale, chard, strawberries, beans and peas, *bak choy*, broccoli, cabbage, onions, squash, watercress, beets, melons, ornamental plants, collard greens, okra, cauliflower, taro, corn, eggplant, celery and leeks (Love, et al., 2015).

In another global survey conducted by Pattillo, et al. (2022), common crops grown in aquaponics include lettuce (83%), leafy greens (81%), followed

Table 2.3: Type of crops grown in aquaponics reported in the previous studies

Locations/Regions	No. of Respondents	Type of Crops Cultured in Aquaponics	References
International Survey	809	70%: Basil 69%: Tomatoes 64%: Salad greens	Love, et al. (2015)
International Survey	378	83%: Lettuce 81%: Leafy greens 73%: Basil 58%: Tomatoes 44%: Peppers 43%: Herbs	Pattillo, et al. (2022)
Twenty European Countries	68	58%: Herbs 47%: Lettuce 32%: Tomatoes	Villarroel, et al. (2016)
South Africa	44	75%: Leafy vegetables 50%: Basil 46%: Herbs 32%: Peppers 25%: Cucumbers 18%: Ornamental plants 16%: Beans and peas 16%: Tomatoes 9%: Carrots 7%: Cut flowers	Mchunu, et al. (2018)

by basil (73%), tomatoes (58%), peppers (44%), and herbs (43%). Other than that, cucumber (35%), strawberries (32%), microgreens (31%), chives (31%), flowers (18%), eggplant (17%) and cannabis (6%) were also grown. Both surveys conducted by Love, et al. (2015) and Pattillo, et al. (2022) showed that leafy vegetables (lettuce, salad greens, kale and *bak choy*) are some of the main choices of crops to be grown in aquaponics. This might be due to their lower nutrient requirements and short cultivation duration (Love, et al., 2015;

Mchunu, et al., 2018). Besides, leafy vegetables can also be grown in high density in an aquaponics system due to their smaller size compared to fruity crops (Mchunu, et al., 2018).

In Europe, herbs were the most grown crop in the aquaponics system observed in 58% of the farms, followed by lettuce which was observed in 47% of the farms (Villarroel, et al., 2016). Leafy vegetables were also observed as the most commonly grown crop (75%) in aquaponics in South Africa (Mchunu, et al., 2018), followed by basil (50%), herbs (46%), peppers (32%), cucumbers (25%), ornamental plants (18%), beans and peas (16%), tomatoes (16%), carrots (9%) and cut flowers (7%). To conclude, lettuce and leafy vegetables are the three most commonly cultured crops in aquaponics (Table 2.3).

2.3.3 Type of Fish Cultured in Aquaponics

Only certain fish species have high adoption in aquaponics. Limited fish choice has affected the productivity and the diversification of fish production in aquaponics (Pinho, et al., 2021). A review study on the challenges and trends of aquaponics conducted by Yep and Zheng (2019) also indicated that the most successful fish species grown in aquaponics are Nile tilapia, carp and African catfish. Meanwhile, Nile tilapia is also the most commonly cultured fish species due to its ability to tolerate a wide range of water quality, able to grow in high stocking density and fast growing (Yep and Zheng, 2019). Another international survey conducted by Love, et al. (2015) reported that 50% of the commercial aquaponics operations cultured two aquatic organisms while 30% of them cultured at least three aquatic organisms in their aquaponics system. Commercial operations had embraced *Tilapia* spp. with high adoption rate of 69%., followed by ornamental fishes, such as *koi*, goldfish and tropical ornamental fish (43%) and catfish from the order Siluriformes (25%) (Love, et al., 2015). Similar findings are reported in Europe (Villarroel, et al., 2016), South Africa (Mchunu, et al., 2018) and another international survey conducted by Pattillo, et al. (2022). Particularly, tilapia is the most cultured fish species in aquaponics, according to the previous studies (Table 2.4).

Other fish species that are cultured in aquaponics include Jade perch (*Scortum barcoo*), African catfish, and ornamental fish such as *koi* fish (Pattillo, et al., 2022). Yet this data could not represent the variety of fish species reared in Malaysia's aquaponics because there is only one Malaysian among the respondents. There is a lack of comprehensive documentation regarding the cultured fish species in Malaysian aquaponics. This hinders the assessment of fish production and the determination of potential market opportunities in line with the current stage of aquaponics development.

Moreover, a limited variety of fish options has impacted the production of fish in aquaponics, as the profit derived from these limited fish species (tilapia and catfish) was reflected by minimal production value (Engle, 2015; Bailey and Ferrarezi, 2017). When comparing crop production and fish production in aquaponics, crop production contributes 3.6 times more than fish production (Rakocy, et al., 2004). According to Bosma et al. (2017), cultivating

Table 2.4: Type of fish grown in aquaponics reported in the previous studies

Locations/ Regions	No. of Respondents	Type of fish Cultured in Aquaponics	References
Review Study	-	Nile tilapia, carp and African are the most commonly cultured fish species in aquaponics.	Yep and Zheng (2019)
International Survey	809 respondents	69%: Tilapia spp. 43%: Ornamental fish such as *koi*, goldfish and tropical fish 25%: catfish from the order Siluriformes	Love, et al. (2015)
International Survey	378 respondents	57%: Tilapia 37%: Ornamental fish such as *koi* and goldfish Other fish species: 1. Jade perch 2. Catfish (*Ictaluridae*) 3. Bluegill 4. Sunfishes (*Centrarchidae*) 5. Trout and salmon (*Salmonidae*) 6. Crayfish, prawn and shrimp (*Crustacea*) 7. Striped bass (*Moronidae*) 8. Baitfish (*Cyprinidae*), perch 9. Walleye (*Percidae*) 10. Largemouth bass (*Centrarchidae*) 11. Common or grass carp (*Cyprinidae*) 12. Barramundi (*Latidae*)	Pattillo, et al. (2022)
Twenty European Countries	68 respondents	27%: Tilapia 10%: Catfish 8%: Ornamental Fish 7%: Trout 4%: Bass 2%: Perch	Villarroel, et al. (2016)
South Africa	44 aquaponics operators	82%: Tilapia 30%: Trout 18% Barbel/Catfish 16%: Ornamental Fish 2%: Bass 2%: Bluegill	Mchunu, et al. (2018)

low-value fish species like catfish proved insufficient for maintaining a profitable aquaponics farm in the Philippines. The authors suggested that focusing solely on high value fish species, such as Jade perch, is crucial for enhancing profits in aquaponics fish production.

Furthermore, the most commonly cultured fish species in aquaponics, Nile tilapia and catfish are not widely accepted in the global markets (Pinho, et al., 2021). The reason that concerns the consumers is that tilapia available in the market is high dependence on the use of antibiotics (Roriz, et al., 2017) and steroid hormones for high yield production (Golan and Lavevi-Sivan, 2014; Joshi, et al., 2019). Catfish at marketable sizes are reported to contain significant levels of heavy metals due to their traditional farming practices, which involve using water from polluted rivers like the Mekong Delta in Vietnam (Mapenzi, et al., 2020) and Lake Rukwa in Tanzania (Madsen, et al., 2015). The harmful residues of these heavy metals deposited in the fish flesh pose a lethal threat to human consumption. Thus, exploring alternative fish species for aquaponics should focus on enhancing fish production value and diversifying the range of aquaponics products. This approach aims to increase food availability in alignment with consumer preferences.

2.3.4 Consumer Perspective on Aquaponics

Many studies have been conducted on consumer acceptance, attitudes, preferences and willingness to purchase aquaponics products such as in Alberta in Canada (Savidov and Brooks, 2004), Berlin, Germany (Specht, et al., 2016), Romania (Zugravu, et al., 2016), European countries (Miličić, et al., 2017), Minnesota, United States of America (USA) (Short, et al., 2017), Australia and Israel (Greenfeld, et al., 2020), Spain and Latin America (Suárez-Cáceres, et al., 2021) (Table 2.5). Information obtained from both sellers and consumers on aquaponics and its products is crucial for the development of this sustainable farming method. In a survey conducted in Spain and Latin America, approximately 60% of the 636 participants demonstrated a high knowledge of aquaponics and expressed great interest in it as a sustainable method of food production. Particularly, the motivations to consume aquaponics products were mainly focused on the food quality, taste, and the absence of pesticides or chemical residues (Suárez-Cáceres, et al., 2021). Furthermore, consumers' willingness to pay higher prices for aquaponics products is influenced by various factors, including their household income, environmental concerns, a preference for purchasing organic products, and familiarity with aquaponics (Suárez-Cáceres, et al., 2021).

Besides, another survey conducted in Minnesota also reported that only about one-third of respondents had previously heard of aquaponics (Short, et al., 2017). Consumers in this survey also tended to be generally neutral or favorable to aquaponics. Moreover, the main issue that affects consumers' decision to purchase aquaponics products is the price (36%), however, most of the consumers tended to believe in the positive impact of aquaponics on the environment (87.5%) (Short, et al., 2017). Another survey conducted by Greenfeld, et al. (2020) demonstrated that 56% of the Australians and only 17% of the Israelis were familiar with aquaponics (Greenfeld, et al., 2020). By acknowledging the added value of aquaponics products, only 17–30% in both Australia and Israel would prefer to buy them, while the majority of the

Table 2.5: Consumer perspective on aquaponics in different regions

Locations/ Regions	Descriptions	References
20 European Countries	Total respondents: 68 50%: Never heard about aquaponics 17%: Willing to pay more for aquaponics' products.	Miličić, et al. (2017)
Spain and Latin America	Total respondents: 636 Approximately 60%: High knowledge of aquaponics and expressed great interest in it as a sustainable method of food production.	Suárez-Cáceres, et al. (2021)
Minnesota	Total respondents: 450 Main issues affecting consumers' decision on purchasing aquaponics products: 1. Price (36%) 2. Food safety (36%) Most of the consumers tended to believe the positive impact of aquaponics to the environment (87.5%).	Short, et al. (2015)
Australia and Israel	Australia: 321 respondents Israel : 200 respondents 56% of the Australians and 17% of the Israelis were familiar with aquaponics. Only 17-30% of them would prefer to buy aquaponics products after knowing the added value.	Greenfeld, et al. (2020)
Malaysia	Total respondents: 390 Malaysians from urban and rural areas showed positive intentions to purchase aquaponics products.	Tamin, et al. (2015)

respondents were not convinced of consuming aquaponically grown products over conventional products even after knowing their added values, mainly due to the high price of aquaponics products that caused a holdback on this matter (Greenfeld, et al., 2020).

In Malaysia, consumers have a high intention of purchasing aquaponics products, which could be an indicator of a potential local market to aquaponics farmers (Tamin, et al., 2015). Yet there is no related study about consumer perception and knowledge of aquaponics products in Malaysia formerly, despite Tamin, et al. (2015) has reported a positive intention of Malaysian consumers to purchase aquaponics products. The survey conducted by Tamin, et al., (2015) primarily concentrated on urban areas such as Kuala Lumpur, Johor Bahru, and Kota Kinabalu, as well as rural areas including Kota Belud, Ranau, Parit Jawa, Ayer Hitam, and Simpang Renggam. However, it did not provide comprehensive coverage for every state in Malaysia. It is crucial to know the consumers' acceptance of a new product (native fish species cultured using aquaponics) before launching into a new market (Tamin, et al., 2015). It is also important to document this information from Malaysian consumers as it would be the key factor affecting the commercialization of aquaponics production and their economic sustainability (Suárez-Cáceres, et al., 2021).

2.4 Potential Native Freshwater Fish Species Culture Using Aquaponics

In 2022, tilapia recorded the highest production in Malaysia with a total of 32,140.46 tonnes (DOF, 2023). With this great production amount, it is difficult to avoid the introduction of tilapia fish to the wild environment (Ahmad, et al., 2020). Ahmad, et al. (2020) reported that tilapia (*T. nilotica*) was described as an introduced species that invaded the local streams in Malaysia. Promoting the cultivation of native fish species is imperative to prevent the spread of exotic species, which could endanger the native population in the wild (Ahmad, et al., 2020; Cheok and Soo, 2021). While promoting aquaponics, introducing Malaysian native fish species to be cultured using aquaponics is also necessary to achieve high production value as an alternative to tilapia (Pinho, et al., 2022). Selection of the native fish species should have certain criteria. Native fish species should have the ability to grow in intensive RAS that can tolerate high stocking density and a wide range of water conditions as RAS is applied in the aquaponics system (Yep and Zheng, 2019; Pinho, et al., 2021). Selected native fish species for aquaponics would prefer to have high market acceptance and high market value in the local area (Pinho, et al., 2021), in order to cover the cost of fish production and crop production in aquaponics. In addition, introduction of native fish species into aquaponics should also consider the aspect of improving their growth performance in order to increase their production yield (Effendi, et al., 2017; Setiadi, et al., 2018).

2.4.1 Native Freshwater Fish Species in Malaysia

Malaysia is a tropical nation with a wide variety of aquatic ecosystems, including oceans, estuaries, rivers, streams, lakes and ponds. Within these aquatic ecosystems, there are many native freshwater fish species found in Malaysia. Across the nation, 385 freshwater fish species belonging to 49 families have been documented with Perak having the greatest number of native freshwater fish species assemblage (230) (Table 2.6). In terms of species, the

Table 2.6: Number of native freshwater fish species documented in Malaysia (Cheok and Soo, 2021)

State	Number of Species
West Malaysia	
Kedah	55
Penang	7
Perak	230
Kelantan	65
Terengganu	56
Pahang	139
Selangor	68
Negeri Sembilan	17
Johor	100
East Malaysia	
Sabah	74
Sarawak	97

Cyprinidae family dominates Malaysia's rivers and streams with 88 known species, followed by Danionidae (44), Osphronemidae (21) and Bagridae (27). Family Cyprinidae dominates Malaysian lotic habitats because it is the largest family of freshwater fishes as well (Cheok and Soo, 2021).

The high abundance and diversity of native freshwater fish species in Malaysia has also encouraged the cultivation of these species due to their high market value and demand. A total of 11 native fish species are cultured in Malaysia (Table 2.7) (Annual Fisheries Statistics, 2022). Among them, *jelawat* had the highest aquaculture production (3,076.54 tonnes), followed by *toman* (350.22 tonnes) and *lampan sungai* (92.13 tonnes) in 2022.

Table 2.7: Aquaculture production of different native fish species in Malaysia, reported by Annual Fisheries Statistics 2022

Native Fish Species	Production (tonnes)
Jelawat (River Carp)	3,076.54
Kalui (Giant Gourami)	3.19
Kelah (River Carp)	4.29
Ketutu (Marble Goby)	30.22
Lampan Sungai (River Carp)	92.13
Patin (River Catfish) *including all patin species	20,861.92
Tenggalan (Carp/ Barb)	0.75
Toman (Giant Snakehead)	350.22

2.4.2 Empurau (*Tor tambroides*)

Although local fish species have great production values in Malaysia, they are rarely cultivated in aquaponics. Native fish species growing in aquaponics are not thoroughly studied, despite the fact that they could become an alternative to common fish species grown in aquaponics (Pinho et al. 2021). The selection of native fish species could be based on those with high market value and demand (Bosma et al. 2017), such as empurau (*Tor tambroides*) (DOF, 2023; Lau et al. 2023).

T. tambroides is one of the high value native freshwater fish in Malaysia from the Cyprinidae family. It is locally known as empurau, Malaysian Mahseer or kelah. Empurau gains its reputation on its good taste and flesh texture. It is well known as the most expensive native fish in Malaysia, both in the food and ornamental fish industry (Ng, 2004; Khai, et al., 2015; Rodgers, 2019). In Sabah, *Tor* spp. appears to be a keystone species for s state-level program in the 12th Malaysia Plan within 2021-2025, which aims to promote a sustainable *Tor* aquaculture industry in this state (Biun, et al., 2021). Besides, empurau had been cultured in aquaponics by Alias, et al. (2022) for the nursery of fish fries. Hence, empurau has the potential to be cultivated using the aquaponic system.

The price of the fish fillet of empurau ranged from RM 550 to RM 2,000 per kg between the year 2014 to 2019 (Chua, 2014; Rodgers, 2019). According to Annual Fisheries Statistics 2022, commercial production of empurau is listed in the category named kelah, as RM 1,931,480 in 2019 and the value increased to RM 2,247,560 in 2022 (DOF, 2023). However, the production might have included other *Tor* spp. and *Neolissochilus* spp. which are natively found in Malaysia, such as *T. tambra*, *T. douronensis*, *N. soroides* and *N. hendersoni* (Table 2.8). There are many studies conducted for improving its growth performance by enhancing feed nutrition and captive breeding, but culturing empurau in aquaponics has not been investigated. Aquaponics can be a potential method for improving its growth performance as well as increasing the fish production value in aquaponics. Aquaponics can also provide better water quality for fish growth as empurau is highly sensitive to poor water quality (Khai, et al., 2015).

Table 2.8: Type of kelah natively found in Malaysia

Type of kelah in Malaysia	Scientific Name	References
Kelah merah	*T. tambroides* *T. tambra*	Watson, et al., 2016; Jaafar, et al., 2021
Kelah biru	*T. douronensis*	Ahmad, 2014; Jaafar, et al., 2021
Kelah hijau	*N. soroides* *N. hendersoni*	Khai, et al., 2014; Watson, et al., 2016

2.4.3 Jelawat (*Leptorbarbus hovenii*)

L. hoevenii, also known as jelawat or the Sultan fish, is one of the high market value freshwater species and has high availability in the local markets (DOF, 2023). It can grow up to 60 cm in length and belongs to the family Cyprinidae that is native to Malaysia (Farahiyah, et al., 2017). Jelawat is also a potential native fish species that can be cultured using aquaponics as an alternative to tilapia.

The marketable size of jelawat could cost up to RM 320 per kg in 2014, which is one of the most expensive freshwater fish species in Malaysia (Chua, 2014). Like empurau, research on jelawat species, is mainly focused on its feed nutrition and captive breeding. Both species also had high production values documented in the Annual Fisheries Statistics 2022 (DOF, 2023). Commercial production of jelawat was RM 853,550 in 2019 and the value increased to RM 50,886,770 in 2022 (DOF, 2023). Referring to Annual Fisheries Statistics 2022

(Table 2.9), jelawat production and its retail value are higher than empurau in Malaysia (DOF, 2023). Cultivating jelawat using aquaponics can enhance the fish production value as a high value native fish species.

Table 2.9: Aquaculture production (tonnes) and retail value (RM) of kelah, jelawat and tilapias in Malaysia in 2022. Data from Annual Fisheries Statistics (DOF, 2023)

Freshwater Fish Species	Production (Tonnes)	Retail Value (RM)
Kelah	4.29	2,247,560
Jelawat	3,076.54	50,886,770
Genetically improved farmed tilapia (GIFT)	3,863.34	55,791,100
Red tilapia	27,926.90	43,267,410
Black tilapia	350.22	1,588,966,000

CHAPTER 3

METHODOLOGY

This study involved two surveys (Section 3.1 and 3.2) and one fish cultivation experiment (Section 3.3). The first survey (Survey I) targeted local aquaponics operations while the second survey (Survey II) targeted Malaysian consumers. The fish rearing experiment was performed to cultivate *empurau*, *jelawat* and red hybrid tilapia.

3.1 Survey on Aquaponics Operation (Survey I)

The aim of this survey was to collect descriptive data from commercial operations in Malaysia that sell fish and crops cultivated using aquaponics systems.

3.1.1 Questionnaire Preparation (Aquaponics Operation)

Text questions reflected in the survey were divided into four main sections with subsections, which included (A) General information about the aquaponics farm, (B) Crop, fish and aquaponics system, (C) Financial input and output of the aquaponics farm and (D) Farm challenges (modified from Bosma, et al., 2017; Tůmová, Klímová and Kalousa, et al., 2020; Pattillo, et al., 2022). The main sections and subsections are listed below:

(A) General information of the aquaponics farm: ownership and operation duration (year), location, size (ft^2), farm type, and organic certification. The farm size was categorized according to Tůmová, Klímová and Kalousa, et al. (2020), including domestic ($\leq 538\ ft^2$), small scale ($>538\ ft^2 - \leq 1076\ ft^2$), intermediate scale ($>1076\ ft^2 - \leq 5382\ ft^2$) and large scale ($>5382\ ft^2$).

(B) Crop, fish and aquaponics system: crop species including type of hydroponics, application on pesticide and fertilizer, 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), annual expenses (included electricity and water, storage and packaging, transportation, labor cost, fish fingerlings, fish feeds, plant seeds, fertilizers and pesticides) (RM), annual crop yield (RM), annual fish yield (RM), market place and farm main income.

(D) Challenges faced by aquaponics farmers.

All questions were prepared using trilingual: English, Bahasa Melayu and Mandarin using an online Google Form (Appendix A). The questionnaire was proofread by the authors before starting the data collection to ensure its legibility (Tůmová, Klímová and Kalousa, et al., 2020). This survey was approved by Universiti Tunku Abdul Rahman and granted under the ethical clearance (Re: U/SERC/18/2022).

3.1.2 Data Collection and Analysis I (Aquaponics Operation)

A purposive sampling method was used to collect the survey data. Social media platforms, such as Facebook, Instagram and WhatsApp were used to source potential respondents. A Google search engine was also used to source for qualified candidates (Mchunu, et al., 2018; Tůmová, Klímová and Kalousa, et al., 2020; Pattillo, et al., 2022). Collected information was summarized and presented in graphs and pie charts by using Microsoft Excel.

Due to limited resources and the absence of records from government and non-government agencies providing the exact number of aquaponics farms in Malaysia, this survey only collected data from 13 aquaponics farms that were willing to participate.

3.2 Survey on Consumers of Aquaponics Products (Survey II)

This survey was targeting Malaysian consumers to investigate their experience, perception and knowledge of aquaponics and its products. Besides, consumers' perspectives on native fish species grown using aquaponics were also collected in this survey.

3.2.1 Questionnaire Preparation (Survey II)

An online survey was prepared in three languages: English, Bahasa Melayu and Mandarin using Google Forms for the consumers to respond anonymously.

Questionnaires consisted of closed-ended and multiple-choice questions with predefined answers. Likert scale questions from “strongly disagree” to “strongly agree” scale were used to provide additional valuable material to the interpretation of the overall results. The first section of Survey II was set to acquire the demographic information of the respondents. The second section inquired about the consumer’s experience with aquaponics systems whether they have purchased aquaponics products (fish and crops), and also their perception and knowledge of aquaponics and its products (fish and crops). The last section focused on the consumer’s perspective on the native fish species cultured using aquaponics systems (Appendix B).

A pilot study involving thirty respondents was conducted using a convenience sampling method. The value for the Cronbach Alpha was 0.72 which is practical and acceptable (Tamin, et al., 2015).

3.2.2 Data Collection and Analysis II (Survey II)

According to the Department of Statistics Malaysia (2022), Malaysia has an estimated population of 32.7 million in 2022. At a 95% confidence interval and 5% margin of error, the representative sample size of the Survey II was 385 (Checkmarket, 2022). Therefore, 385 respondents were drawn from six regions in East and West Malaysia to participate in Survey II, encompassing the Northern Region, East Coast Region, Central Region, Southern Region, Sarawak, and Sabah. Social media platforms, such as Facebook, Instagram and WhatsApp were used to search for respondents and the survey link was shared through the respective platform or email. A snowball sampling method was conducted to collect the survey data (Suárez-Cáceres, et al., 2021).

Descriptive analysis was used to perform the data using Statistical Product and Service Solutions (SPSS) (IBM SPSS Statistics for Windows, version 26, (IBM Corp., Armonk, N.Y., USA)) and Microsoft Excel. Spearman's correlation test was performed to measure the relationship between age, educational level, income level and residential region with the consumer perception and knowledge of aquaponics and its products (fish and crop), and consumer perspective of native fish species cultured using aquaponics. Interpretation of the strength of the correlation between the variables was according to the thumb rule of coefficient value with five levels of correlation (Schober, Boer and Schwarte, 2018).

3.3 Fish Cultivation Experiment

After conducting Survey I and Survey II, a 3 × 2 (fish species × culture system) factorial design fish cultivation experiment was carried out. Three experimental fish species were cultured in both aquaponics and RAS: empurau, jelawat and red hybrid tilapia (control fish species). In this fish cultivation experiment, there were six treatments, each with three corresponding replicates: aquaponics culturing red hybrid tilapia, aquaponics culturing empurau, aquaponics culturing jelawat, RAS culturing red hybrid tilapia, RAS culturing empurau and RAS culturing *jelawat* (Table 3.1).

Table 3.1: Six treatments (fish species × culture system) were conducted in the fish cultivation experiment

System / Species	Aquaponics	RAS
Red hybrid tilapia (control)	Aquaponics culturing red hybrid tilapia	RAS culturing red hybrid tilapia
Empurau	Aquaponics culturing empurau	RAS culturing empurau
Jelawat	Aquaponics culturing jelawat	RAS culturing jelawat.

3.3.1 Experimental Tank Setup

Aquaponics systems were setup (see Figure 3.1 and Figure 3.2) (modified from Effendi, et al., 2017; Setiadi, et al., 2018) and placed in the Aquaculture Facilities (AQF), Universiti Tunku Abdul Rahman (UTAR), located at 4◦34'N, 101◦14'E. Glass tanks with 90 L capacity each (30 × 70 × 46 cm^3) were used as the fish tank and hydroponic tank in the aquaponic system. For the aquaponics system, the water was channeled from the fish tank to the filtering section consisting of mechanical (cotton and sponge filter) and biological filters (ceramic rings and bio balls) for large residue removal and nitrification. Then, the water was flown to the hydroponic tank and pumped back to the fish tank. Two units of water pump (7-Watt, maximum water flow 570 L/hour) were installed at the fish and hydroponic tanks each. Air stones were provided for both fish and hydroponic tanks to increase the DO. RAS setup was similar with the aquaponics system excluding the hydroponic tank and the water was recycled between the fish tank and filtering section. In total, there were 18 systems in this experiment: nine aquaponics systems and nine RAS. The water source used in this experiment were the de-chlorinated tap water.

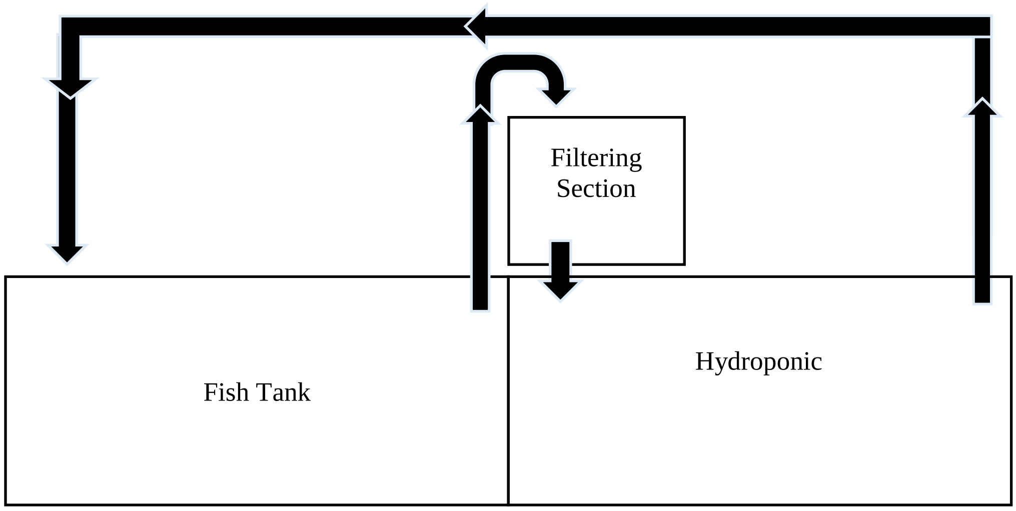


Figure 3.1: Side view of the aquaponics system setup. Black arrows indicate the water flow of the whole system

Figure 3.2: Front view of three sets aquaponics system that cultured empurau, jelawat and red hybrid tilapia

3.3.2 Fish and Crop Cultivation

Fingerlings of each species were obtained from the local hatchery suppliers. Upon arrival, fishes underwent acclimation for one month with twice feeding daily in the AQF before the commencement of cultivation experiment. Commercial nitrifying bacteria (Qiuyu, Malaysia) were added 2 capsules into both aquaponics and RAS tanks a week prior to the experiment to kick start the nitrifying process. Fish stocking density was 0.04 fish/L (Setiadi, et al., 2018; Saufie, et al., 2020), as the tanks were filled up to 80 L with 4 fish per tank. For each species, four healthy and similar size fish were selected and distributed into their respective tanks. At the commencement of the cultivation experiment, the initial average weight of the fishes was recorded in which 2.80 ± 0.04 g for red hybrid tilapia, 2.63 ± 0.04 g for empurau and 2.68 ± 0.05 g for jelawat. Meanwhile, initial water quality parameters were recorded for both RAS and aquaponics tanks (Table 4.6). Commercial fish pellets with 35% crude protein and 1.5 mm diameter (Cargill, AquaFocus Prestarter 6383) were used as the feed. Fishes were fed until apparent satiation twice per day (09:00 and 17:00 h) for 70 days. Besides, the water quality parameters were monitored (Tawaha, et al., 2021) throughout the experiment (see section 3.3.3). Weekly water change was done to all RAS tanks to maintain its water quality. Water was added to offset the evapotranspiration loss in aquaponics tanks.

Bak choy (*Brassica rapa*) were grown as the experimental crop in this fish cultivation experiment. Seed of the bak choy was germinated on the germinating sponge and grown for three weeks before transplanting into the hydroponic section for each experimental aquaponics tank (see Figure 3.3). DWC was used whereby roots of the seedlings were submerged into the culture water for nutrient absorption. Transplantation of bak choy seedlings were done three weeks after fish distribution into the experimental tank. Fish to plant ratio was set as 1:1, hence, each aquaponics consisted of four bak choy seedlings in total. Hydroponic fertilizer (CityFarm Malaysia, hydroponic AB liquid fertilizer) consisting of nitrogen (22.5%), phosphorus pentoxide (9%), potassium oxide (37%), calcium oxide (26%), magnesium oxide (3%), sulphur oxide (13%), boron (0.02%), copper-ethylenediaminetetraacetic acid (EDTA, (0.004%), iron-EDTA (1.32%), iron-diethylenetriamine pentaacetate (DPTA, 0.14%), iron-ethylenediamine-*N*,*N'*-bis(2-hydroxyphenylacetic acid) (EDDHA, 0.01%), manganese-EDTA (0.033%), molybdenum (0.003%) and zinc-EDTA (0.021%) was supplemented to provide adequate nutrients for the plants grown in aquaponics (Villarroel, et al., 2016; Monsees, et al., 2017; Yep and Zheng, 2019; Tawaha, et al., 2021; Fischer, et al., 2021; Meena, et al., 2023). Fertilizer supplement was applied whenever signs of nutritional deficiency observed on the crops grown in aquaponics. Each aquaponics system was equipped with a commercial plant grow light LED lamp (48:24, white:red) with a photosynthetic photon flux of 200 mol/m and a 12-h photoperiod (see Figure 3.4).

3.3.3 Data Collection and Analysis III

After 70 days of cultivation, all experimental fishes were individually weighed. Fish growth performance was analysed based on weight gain (WG, %) and specific growth rate (SGR, %/day) of fish. Fish survival rate (%) and FCR were also evaluated for all experimental treatments (Effendi et al., 2017; Tawaha et al. 2021).

Figure 3.3: Bak choy seedlings germinated after three weeks and ready to transplant to the aquaponics systems

Figure 3.4: Bak choy planted at the hydroponic section in each aquaponics systems using DWC under the plant grow light

The formulae used are shown as follows:

$$\text{WG (\%)} = \frac{Final\ wet\ weight\ (g) - Initial\ wet\ weight\ (g)}{Initial\ wet\ weight\ (g)} \times 100\%$$

$$\text{SGR} = \frac{ln\,[final\ wet\ weight\ (g)] - lnln\,[initial\ wet\ weight\ (g)]}{Duration\ (days)} \times 100\%$$

$$\text{Survival rate (\%)} = \frac{Final\ number\ of\ fish}{Initial\ number\ of\ fish} \times 100\%$$

$$\text{FCR} = \frac{Total\ feed\ given\ in\ dry\ weight\ (g)}{Total\ wet\ weight\ gain\ of\ fish\ (g)}$$

Measurements of the physical and chemical water quality parameters were carried out throughout the experiment. Water temperature (ºC), pH and dissolved oxygen (DO, mg/L) were measured on a daily basis using a portable pH meter (HI8424, HANNA instruments, USA) and portable DO meter (ECDO1101, EUTECH, Singapore). Chemical water parameters including ammonia-nitrogen (NH_3-N), nitrite (NO_2^-) and nitrate (NO_3^-) were measured in mg/L every three days using API freshwater master test kit, and the data were validated using multiparameter spectrophotometer (HI83399, HANNA instruments, USA) once a week or when the concentration exceeded detection limit of the test kit; while phosphate (P), potassium (K), calcium (Ca), magnesium (Mg) and iron (Fe) were measured in mg/L on a biweekly basis for each treatment using the same multiparameter spectrophotometer (Tawaha, et al., 2021). Weekly and total water usage (L) for all experimental tanks were recorded for water efficiency comparison.

Within 70 days of fish cultivation, two batches of bak choy were planted and harvested at a 35 day interval in aquaponics treatments, and the total supplementation of fertilizer (mL) was recorded. After harvesting, the plant roots were removed before weighing. Fresh crop yield (g) was determined by measuring total fresh weight (g) of the bak choy harvested from each aquaponics treatment, including the stem and leaves, and relative growth rate (%) of the bak choy was evaluated with the formula shown below (Effendi, et al., 2017):

Relative growth rate (%) = $\frac{ln\,[final\;wet\;weight\;(g)] - lnln\,[initial\;wet\;weight\;(g)]}{Duration\;(days)} \times 100\%$

All data were presented as mean ± standard deviation and subjected to the analysis of variance (ANOVA) using SPSS 27.0 (SPSS Inc., Chicago, USA). T-test was used to analyze the difference of initial water quality between RAS and aquaponics systems. One-way ANOVA was used to determine if significant differences occurred on the nutrient supplementation, crop yield and relative growth rate of *bak choy* across aquaponics treatments. Two-way ANOVA was applied to determine the effects of fish species, culture method and their interaction in final fish body weight, WG, SGR, survival rate and FCR of the fishes, the water quality parameters and water usage across all experimental treatments. Differences among means were determined by Duncan's Multiple Range test and considered to be significant at the level of 0.05.

CHAPTER 4

RESULTS

4.1 Survey on Aquaponics Operations (Survey I)

Survey I included four sections: general information, crop, fish and aquaponics systems, financial input and output, and the challenges faced by the surveyed aquaponics farms. A total of 13 local aquaponics farms participated in the Survey I.

4.1.1 General Information of Aquaponics Farms

General information about each aquaponics farm was tabulated and presented in graphs, including their ownership, operational duration, farm location and size, farm type and organic certification.

4.1.1.1 Ownership and Operation Duration

Figure 4.1 shows the general information collected from aquaponics farms participating in Survey I. Among the surveyed aquaponics farms, two aquaponics farms were no longer operated. 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. In terms of operation duration, 23% of the aquaponics farms operated for 6 years, 8% operated for 4 years and 69% operated for 3 years or less.

4.1.1.2 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 respectively (Figure 4.1). Most of the farms (85%) were in urban areas while the rest (15%) were in rural area (Figure 4.1). Besides, the largest aquaponics farm size in this study was 113,256 ft^2 while the smallest aquaponics farm was 330 ft^2 (Figure 4.1). Most of the aquaponics farms (92%) had a greenhouse to operate their aquaponics system while only one farm had both indoor and outdoor aquaponics setup with open-air cover. To date, none of the surveyed farms has obtained organic certification.

4.1.2 Types of Crop, Fish and Aquaponics System

Figure 4.2 shows the information about the type of crops, fish and aquaponics systems reported by thirteen aquaponics farms, including the pesticides and fertilizer application to their aquaponics systems.

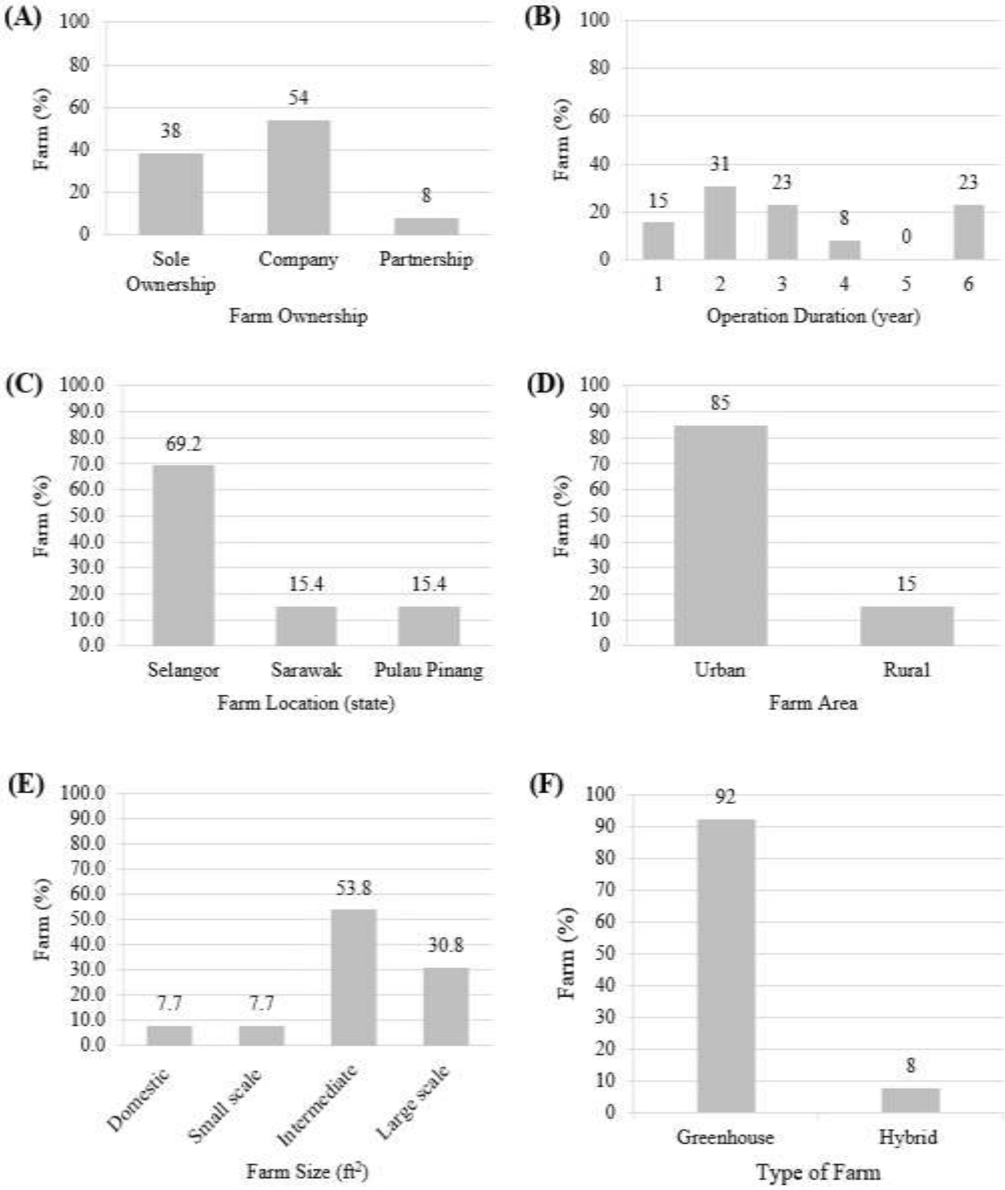


Figure 4.1: General information of aquaponics farms: (A) Farm ownership, (B) Farm operation duration (year), (C) Farm location (state), (D) Farm area, (E) Farm size (ft^2) and (F) Farm type

4.1.2.1 Crop in Aquaponics

In the Survey I, leafy vegetables were the most grown crop in the aquaponic system (100%) (Figure 4.2A). Various types of leafy vegetables were cultivated in the 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 crops in the farms surveyed. 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 utilized deep water culture (DWC) and vertical towers in their hydroponic systems (Figure 4.2B). All aquaponics farms used different types of fertilizers in their aquaponic systems. Sixty-nine percent of the farms used commercial liquid fertilizer in their aquaponic systems (Figure 4.2C). Epsom salt and chelated iron such as etheylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA) and organic certified ethylenediamine-*N*,*N*'-bis(2-hydroxyphenylacetic acid) (EDDHA) were also additional fertilizers applied by the aquaponics farmers. Based on this 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 4.2D).

4.1.2.2 Fish in Aquaponics

Figure 4.2E shows that all aquaponics farms cultured red hybrid tilapia (*Oreochromis* sp.) (100%), followed by patin (*Pangasius* spp.) (23%), Jade perch (*S. barcoo*) (23%), bighead carp (*Hypophthalmichthys nobilis*) (8%) and lemon bard (or golden belly barb, named as krai or kerai in Malay) (*Hypsibarbus* sp.) (8%). The fish stocking density used by 31% of the farms was 0.04 fish/L and varied from 0.01 to 0.27 fish/L among the 13 surveyed aquaponics farms (Figure 4.2F). Additionally, the fish:crop ratio was recorded from 8 aquaponics farms and the fish: crop ratio varied from 1 fish: 12 crops to 5 fish: 3 crops (Figure 4.2G). Five farms did not provide this information.

4.1.2.3 Production Cycle and IoT Application

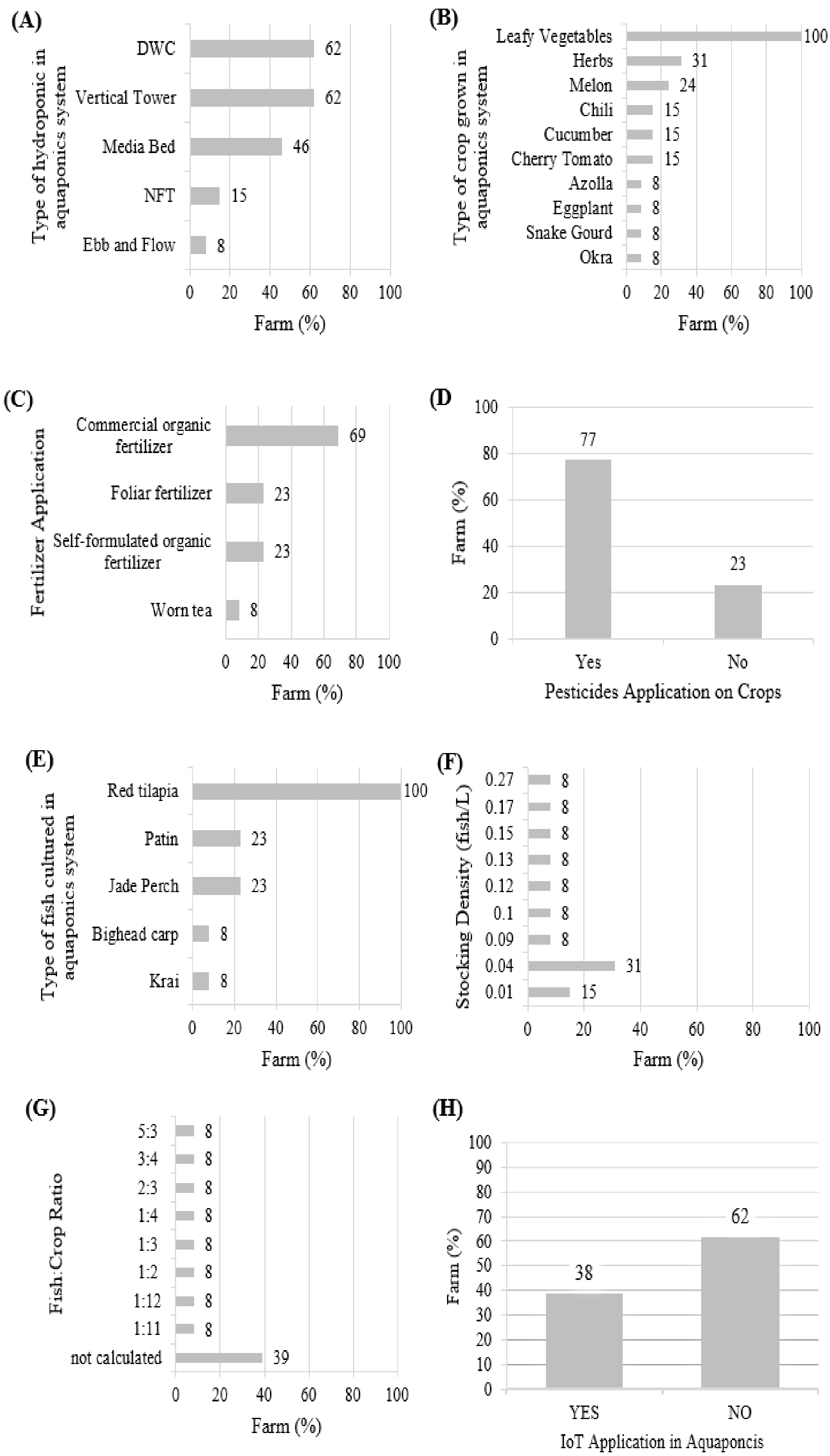
As shown in Figure 4.2I, 46% of the surveyed aquaponics farms would harvest their aquaponics fish in 6 months, while 23% of farms would harvest in 8 months. Leafy vegetables grown using aquaponics would reach marketable size in the range of 28 days to 40 days (Figure 4.2J). One farm did not sell the 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 4.2H).

4.1.3 Financial Input and Output of Aquaponics Farms

Financial input and output of the surveyed aquaponics farms are shown in Figure 4.3, including the initial capital of aquaponics farms, annual expenses of aquaponics farms, annual crop yield (RM) and annual fish yield (RM).

4.1.3.1 Initial Capital, Annual Expenses, Annual Crop and Fish Yield

As shown in Figure 4.3A, initial capitals used to set up the aquaponics farms varied among the 13 surveyed aquaponics farms, but the collected results do not


(A)
Type of hydroponic in aquaponics system
DWC 62
Vertical Tower 62
Media Bed 46
NFT 15
Ebb and Flow 8
0 20 40 60 80 100
Farm (%)
(B)
Type of crop grown in aquaponics system
Leafy Vegetables 100
Herbs 31
Melon 24
Chili 15
Cucumber 15
Cherry Tomato 15
Azolla 8
Eggplant 8
Snake Gourd 8
Okra 8
0 20 40 60 80 100
Farm (%)
(C)
Fertilizer Application
Commercial organic fertilizer 69
Foliar fertilizer 23
Self-formulated organic fertilizer 23
Worn tea 8
0 20 40 60 80 100
Farm (%)
(D
Farm (%)
100 80 60 40 20 0
77
23
Yes
No
Pesticides Application on Crops
(E)
Type of fish cultured in aquaponics system
Red tilapia 100
Patin 23
Jade Perch 23
Bighead carp 8
Krai 8
0 20 40 60 80 100
Farm (%)
(F)
Stocking Density (fish/L)
0.27 8
0.17 8
0.15 8
0.13 8
0.12 8
0.1 8
0.09 8
0.04 31
0.01 15
0 20 40 60 80 100
Farm (%)
(G)
Fish:Crop Ratio
5:3 8
3:4 8
2:3 8
1:4 8
1:3 8
1:2 8
1:12 8
1:11 8
not calculated 39
0 20 40 60 80 100
Farm (%)
(H)
Farm (%)
100 90 80 70 60 50 40 30 20 10 0
38
62
YES
NO
IoT Application in Aquaponcis

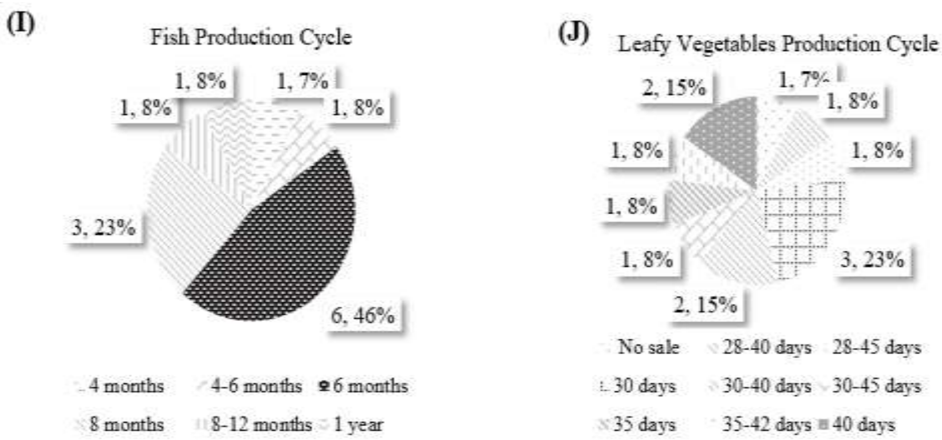


Figure 4.2: Information about the crop, fish and aquaponics system in Malaysia: (A) Type of crop grown in aquaponics, (B) Type of hydroponic applied in aquaponics, (C) Fertilizer application in aquaponics system, (D) Pesticides application on crops, (E) Type of fish grown in aquaponics, (F) Fish stocking density (fish/L), (G) Fish:crop ratio, (H) IoT application in aquaponics, (I) Fish production cycle and (J) leafy vegetables production cycle

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 Malaysia spent RM 75.44/ft^2 on the initial capital for the farm setup. Moreover, the highest annual expense of the aquaponics farm in Malaysia 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 4.3B). The largest farm (113,256 ft^2) only required RM 0.38/ft^2 for its annual expenses. On average, the average annual expense of aquaponics farms in this survey was RM 16.44/ft^2.

On the other hand, 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 yield was RM 16.00/ft^2, produced by an intermediate-sized farm (>1076 ft^2 - ≤5382 ft^2) while the lowest annual fish yield was RM 0.21/ft^2, produced by a large-scale farm (>5382 ft^2) (Figure 4.3C). Particularly, the average annual crop production value was RM 20.59/ft^2 while the annual fish production value was RM 6.76/ft^2 (Figure 4.3D).

4.1.3.2 Market Place and Farm Business Status of Aquaponics Farms

In this survey, 69% of the farms sold their aquaponics products (fish and crops) 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 crops) 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 fertilizers, as well as providing consultancy, training, and education.

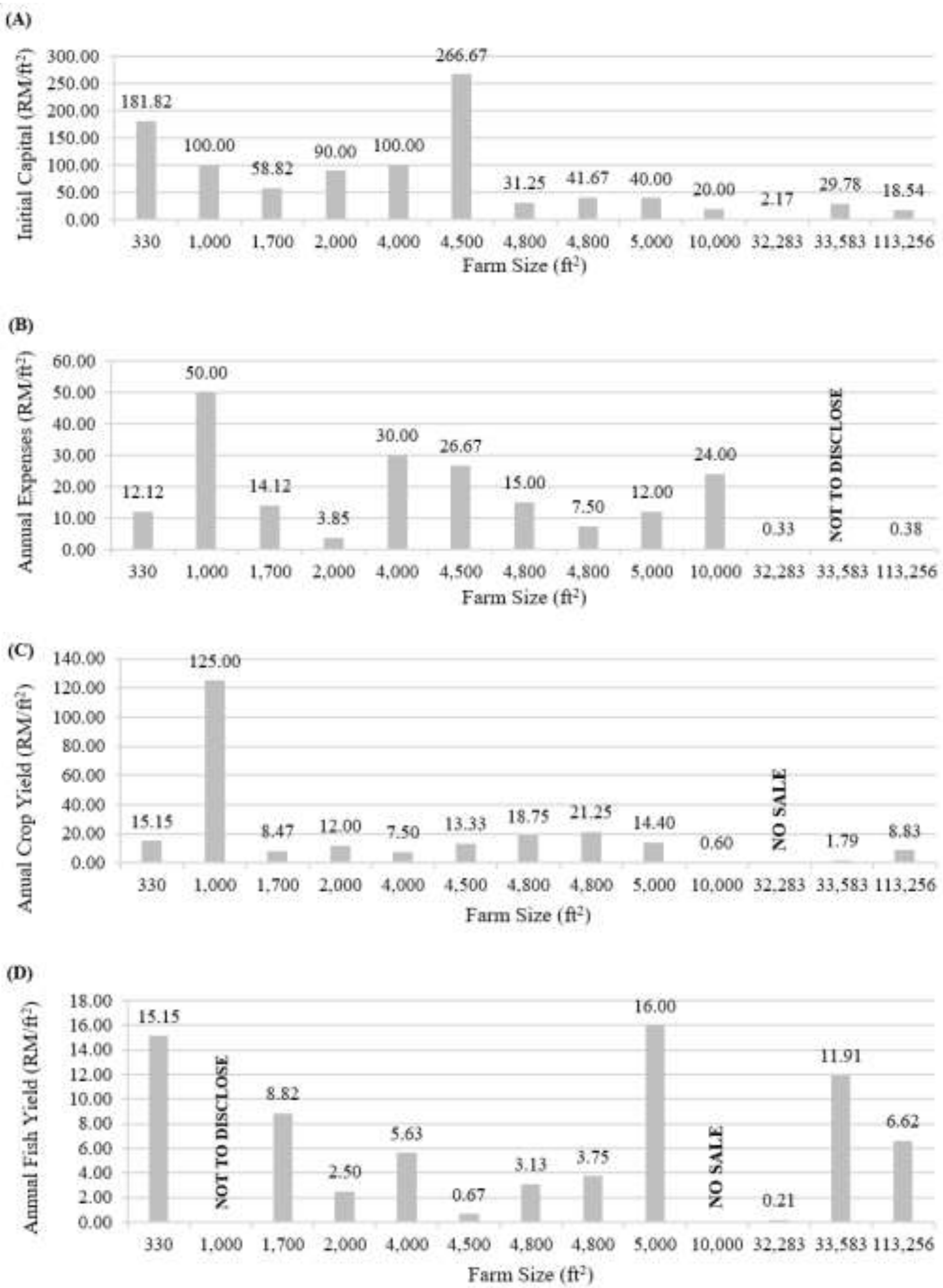


Figure 4.3: Financial input and output of aquaponics farm in Malaysia: (A) Initial capital of aquaponics farms, (B) Annual expenses of aquaponics farms, (C) Annual crop yield (RM) and (D) Annual fish yield (RM)

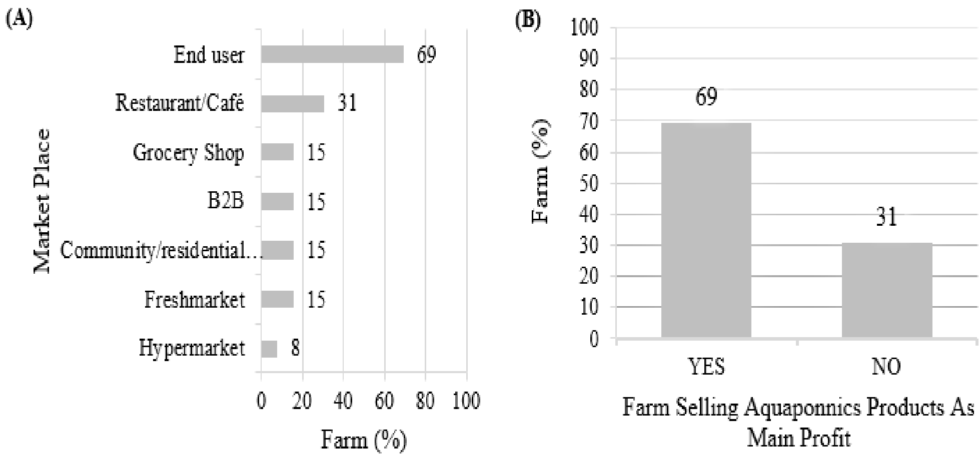


Figure 4.4: Market place and aquaponics farm business status in Malaysia: (A) Market place for aquaponics products and (B) Farms which sell aquaponics products as their main profit

4.1.4 Farm Challenges

The biggest challenge faced by the aquaponics farm based on this survey was plant pests and diseases (92%), followed by financial issues (77%), nutrient balance, pH stabilization (62%), marketing (46%), lack of skillful worker (46%), fish pests and diseases (46%) (Figure 4.5). Other challenges faced by the aquaponics farm included the lack of labor force (38%), unstable electric supply (23%), weather and climate change, technical problems of their aquaponics systems (23%), postharvest problem (15%), sourcing for good quality fish fingerlings and crop seeds (8%).

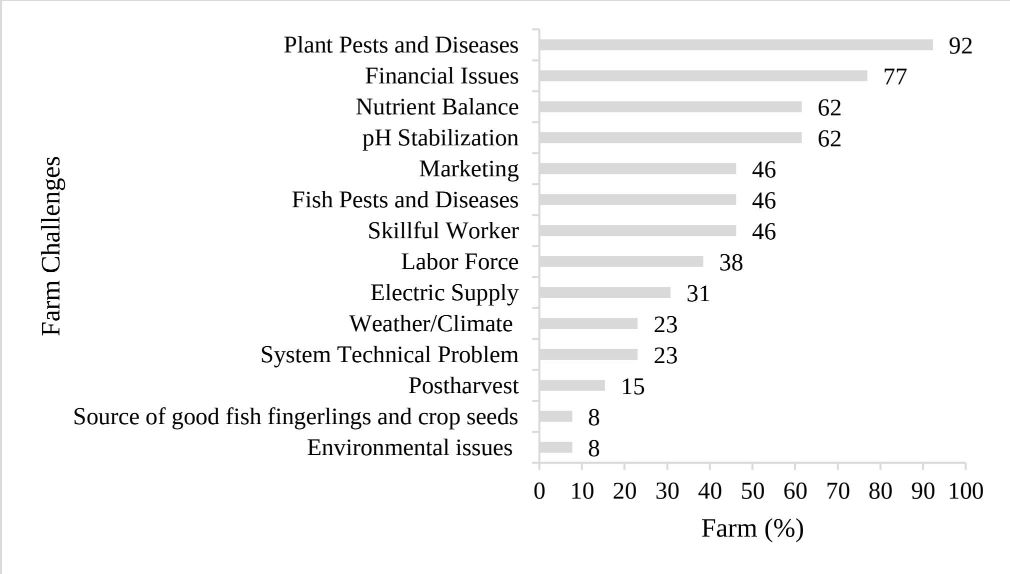


Figure 4.5: Farm challenges faced by aquaponics farms in Malaysia (%)

4.2 Survey on Consumers of Aquaponics Products (Survey II)

Survey II includes three sections: demographic information of the respondents, consumers' experience, perception and knowledge of aquaponics and its products (fish and crops), and their perspective on native fish species grown using aquaponics.

4.2.1 Demographic Information of the Respondents

A total of 385 consumers participated in this online survey. They were from the central region (34%), northern region (28%), Sarawak (17%), southern region (13%), Sabah (5%) and east coast (3%). Sixty percent of females responded to the Survey II (Table 4.1). In terms of race, 52% of respondents were Chinese, followed by 31% Malay, 10% Indian and 7% of other races. Majority of the respondents aged between 20 and 29 (74%). In terms of educational level, 66%

of the respondents obtained a bachelor's degree. Most of the respondents are students (56%), followed by having wage employment (34%), self-employed (7%), unemployed (2%) and retirees (1%). Respondents’ income level reported in this survey was not evenly distributed among the four categories where 53% of the respondents had no income, 29% were from the B40 group (<RM 4850), 16% were from the M40 group (RM 4850 – RM 10959) and only 2% were from the T20 group (>RM 10960).

4.2.2 Consumers’ Experience on Purchasing Aquaponics and Its Products (Fish and Crops)

Based on the consumers’ response on having experience in practicing aquaponics, only 16% of the respondents had practiced aquaponics. Thirty-seven percent of the respondents had experience in purchasing fish and crops grown in aquaponics systems. Fourteen percent of them claimed that there were no local aquaponics operations, while 48% were not sure whether there were any local aquaponics operations. Only 38% were aware of such operations in Malaysia. Besides, forty-five percent of the respondents stated that aquaponics products (fish and crops) are not readily available, while 30% were uncertain about the accessibility of these products in their daily lives. Only 25% of respondents reported easy access to aquaponics products in Malaysia.

Table 4.1: Summary statistics of the demographic background of participants (N=385) in this survey

Descriptions	Frequency (N=385)	Percentage (%)
Gender		
Male	154	40.00
Female	231	60.00
Ethnicity		
Malay	119	30.91
Chinese	202	52.47
Indian	37	9.61
Others	27	7.01
Age		
20-29	285	74.03
30-39	46	11.95
40-49	33	8.57
50-59	14	3.64
60-69	7	1.82
≥ 70	0	0
Educational level		
SPM and below	21	5.45
STPM/Diploma/Pre-university	59	15.32
Bachelor degree	254	65.97
Master degree and above	51	13.25
Employment status		
Student	216	56.10
Wage employment	130	33.77
Self-employed	27	7.01
Unemployed	8	2.08
Retired	4	1.04
Income level		
No income	203	52.73
B40 (< RM 4850)	112	29.09
M40 (RM 4850 – RM 10960)	61	15.84
T20 (> RM 10960)	9	2.34
Residential region		
Northern region	107	27.79
Southern region	49	12.73
Central region	131	34.03
East coast	13	3.38
Sarawak	66	17.14
Sabah	19	4.94

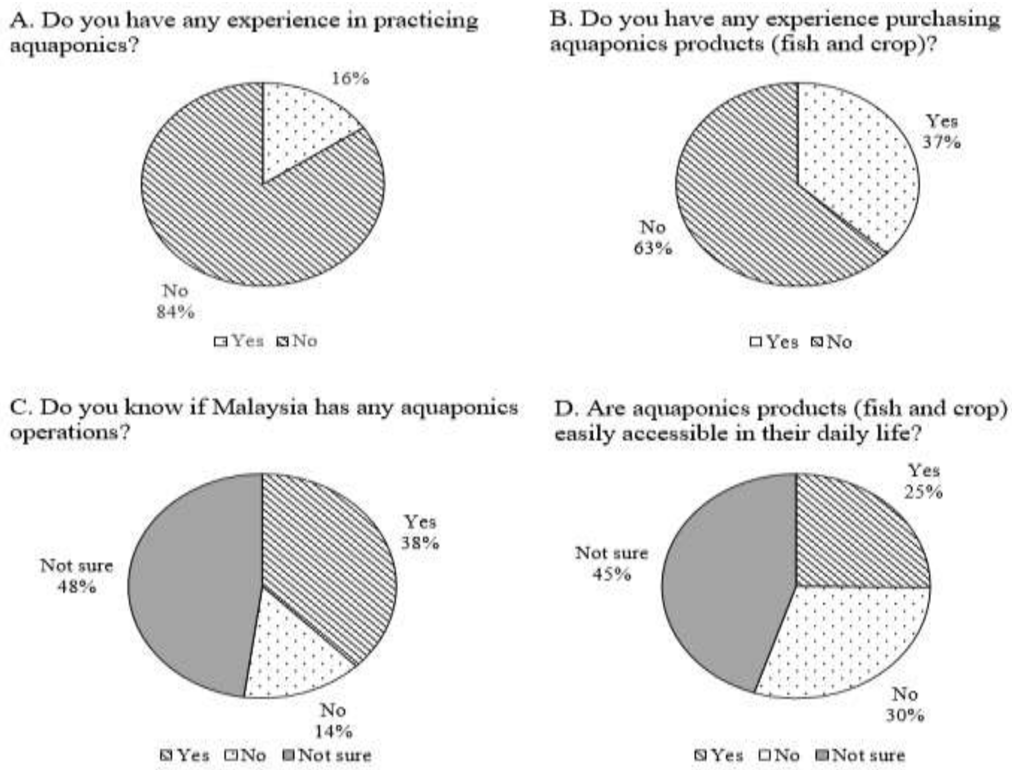


Figure 4.6: Consumer's experience on aquaponics and its products (fish and crop) among 385 respondents

4.2.3 Consumer Perception and Knowledge about Aquaponics and Its Products (Fish and Crops), and Their Perspective of Native Fish Species Cultured Using Aquaponics

Figure 4.7A shows the perception and knowledge of consumers about aquaponics and its products. Respondents agreed to statements regarding the benefits of aquaponics (items 3 to 13) but stayed neutral when asked to purchase between aquaponics products and conventional farming products (fish and crop) They were also holding a neutral attitude on whether they are willing to pay more on purchasing aquaponics products. Figure 4.7B shows the consumer perspective of native fish species cultured using aquaponics. Respondents agreed that farmers could culture native fish species, *T. tambroides* (kelah or empurau) and *L. hoevenii* (jelawat or Sultan fish) using aquaponics. Nevertheless, they neither agree nor disagree when it comes to purchasing and are willing to pay more for the native fish species grown in aquaponics instead of those harvested from aquaculture or caught in the wild.

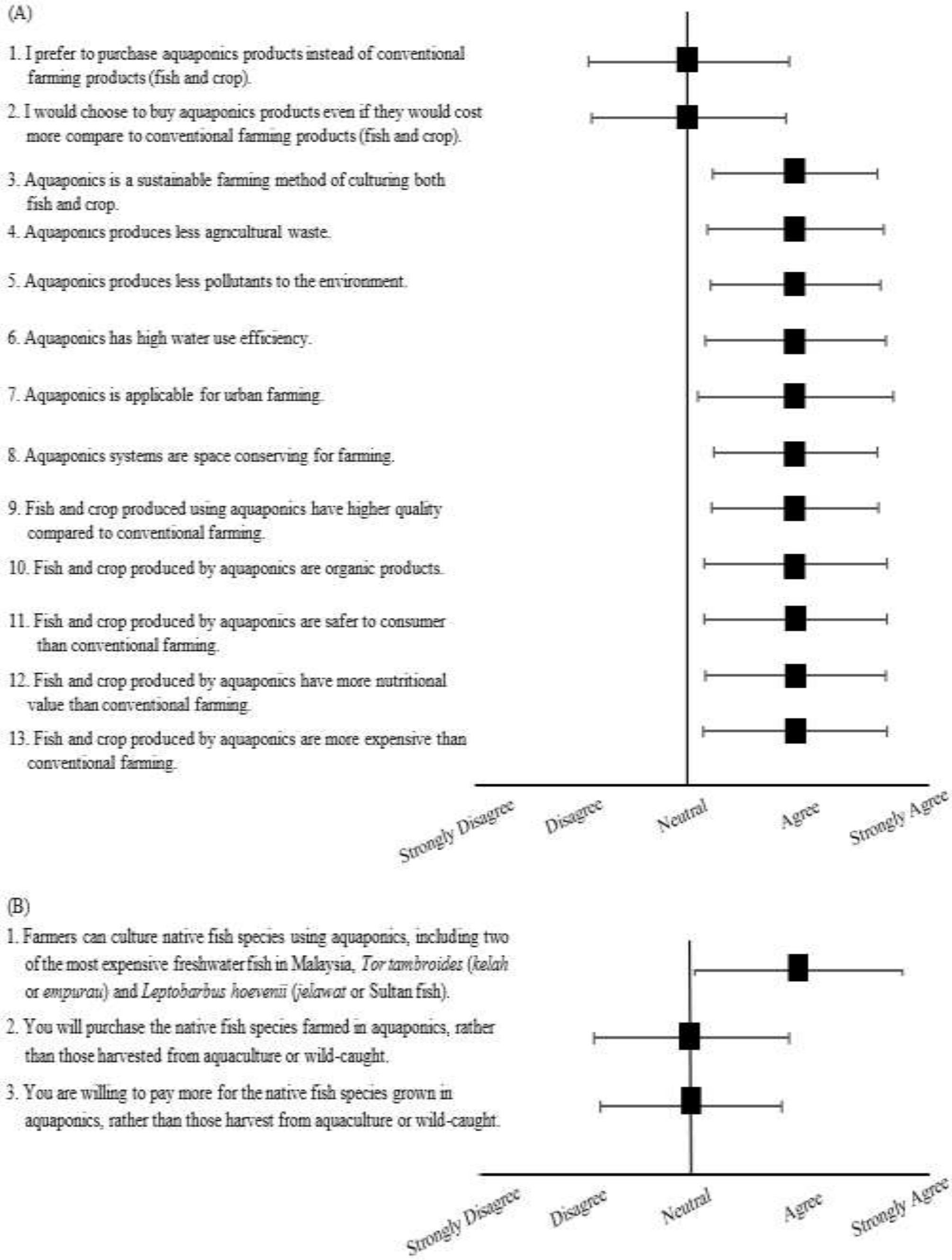


Figure 4.7: Results on the (A) consumer perception and knowledge about aquaponics and its products (fish and crop) and (B) consumer perspective of native fish species cultured using aquaponics in a Likert scale. Squares = median values, error bars = interquartile range

Price (79.2%) and food safety (67.8%) were the two major factors that affected the consumers' decision to purchase aquaponics products (fish and crop). Other factors that affect consumers' decision to purchase aquaponics produce food nutrition (52.7%), cultivation method of the aquaponics products (39.7%), food flavor (33%), accessibility (0.5%), and zoonotic diseases (0.3%) (Figure 4.8).

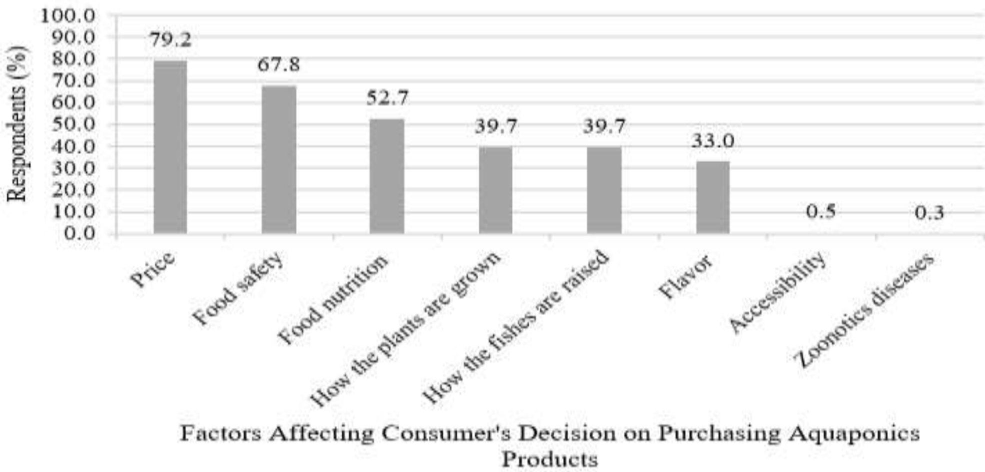


Figure 4.8: Factors affecting consumer's decision on purchasing aquaponics products (fish and crop) in percentage

4.2.4 Relationship between Consumer Age, Educational Level and Income Level with (1) Consumer Perception and Knowledge of Aquaponics and Its Products (Fish and Crop) and (2) Consumer Perspective of Native Fish Species Cultured Using Aquaponics

There was no significant correlation between age and income level with the consumer perception and knowledge of aquaponics and its products (Table 4.2). No significant correlation was also observed in the relationship between the age, educational level, and income level of the consumer and their perspective of native fish species culture using aquaponics (Table 4.3). Yet consumers' perception and knowledge of aquaponics and its products exhibited a weak negative correlation with their educational level (Rs = -.10, P-value =.04).

Table 4.2: Spearman's correlation coefficient between age, educational level and income level with the consumer perception and knowledge on aquaponics and its products (fish and crop)

N=385	**P-value**	**R-square**
Age and consumer perception and knowledge on aquaponics and its products (fish and crop)	.96	NS*
Educational level and consumer perception and knowledge on aquaponics and its products (fish and crop)	.04	-.10
Income level and consumer perception and knowledge on aquaponics and its products (fish and crop)	.48	NS*

NS*: Not significant at 0.05 level.

Table 4.3: Spearman's correlation coefficient between age, educational level and income level with consumer perspective of native fish species cultured using aquaponics

N=385	**P-value**	**R-square**
Age and consumer perspective of native fish species cultured using aquaponics	.66	NS*
Educational level and consumer perspective of native fish species cultured using aquaponics	.08	NS*
Income level and consumer perspective of native fish species cultured using aquaponics	.87	NS*

NS*: Not significant at 0.05 level.

4.3 Fish Cultivation Experiment

The growth performance, survival rate, and FCR of tilapia (control fish species), empurau, and jelawat were recorded after 70 days of cultivation in both aquaponics systems and RAS. Additionally, water quality parameters and water usage were monitored during the experimental duration.

4.3.1 Fish Growth Performance, Survival and FCR

In this fish cultivation experiment, tilapia, empurau and jelawat grew over 1900%, 390% and 1100%, respectively, in the experimental tanks (Table 4.4). Between RAS and aquaponics systems, the same fish species showed no significant difference ($P>0.05$) in their WG and SGR. Comparing the three tested fish species, tilapia showed significantly highest ($P<0.05$) WG (1925.27 – 2045.03%) and SGR (3.55 – 3.61%/day), while empurau showed significantly lowest WG (390.99%) and SGR (1.87-1.88%/day). On the other hand, fish grown in aquaponics tended to have higher survival rate than those grown in RAS despite having no significant difference observed within the same fish species. Specifically, jelawat recorded 100% of survival regardless of the culture system and empurau showed 100% survival in aquaponics. However, tilapia cultured in RAS had the lowest survival rate (66.67%). The survival rate of tilapia in aquaponics is 83.33% while empurau cultivated in RAS showed 91.67%. Fish grown in aquaponics tended to have lower FCR than those grown in RAS, although no significant difference was observed between both systems

Table 4.4: Growth performance, FCR and survival rate of the three fish species cultured in RAS and aquaponics after 70 days of experiment[1]

Fish Species	Tilapia		Empurau		Jelawat		Two-way ANOVA		
Type of System	RAS	Aquaponics	RAS	Aquaponics	RAS	Aquaponics	Type of system	Fish species	Interaction
Initial weight, (g)	2.67 ± 0.04	2.66 ± 0.05	2.62 ±0.04	2.65 ± 0.05	2.68 ± 0.05	2.68 ± 0.05	0.69	0.49	0.93
Final weight, (g)	59.78 ± 19.29 [c]	56.86 ± 15.79 [c]	12.81 ± 1.98 [a]	13.01 ± 3.14 [a]	33.02 ± 4.43 [b]	32.53 ± 4.90 [b]	0.83	<0.05	0.97
WG[2] (%)	2045.03 ± 716.80 [c]	1925.27 ± 559.95 [c]	390.99 ± 80.47 [a]	390.99 ± 115.71 [a]	1134.89 ± 195.05 [b]	1111.84 ± 162.79 [b]	0.80	<0.05	0.96
SGR[3] (%/day)	3.61 ± 0.37 [c]	3.55 ± 0.34 [c]	1.88 ± 0.20 [a]	1.87 ± 0.28 [a]	2.98 ± 0.19 [b]	2.96 ± 0.17 [b]	0.82	<0.05	0.99
Survival rate (%)	66.67 ± 38.18[a]	83.33 ± 14.43[a]	91.67 ± 14.43[a]	100.00 ± 0.00[a]	100.00 ± 0.00[a]	100.00 ± 0.00[a]	0.34	0.07	0.72
FCR[4]	1.27 ± 0.01 [a]	1.13 ± 0.07 [a]	2.62 ± 0.29 [c]	2.30 ± 0.24 [c]	1.74 ± 0.08 [b]	1.68 ± 0.12 [b]	0.11	<0.05	0.55

[1]Data are presented in mean ± standard deviation. Different superscripts in the same row indicate significant difference at P<0.05.
[2]WG = Weight Gain.
[3]SGR = Specific Growth Rate.
[4]FCR = Feed Conversion Ratio.

for the same fish species (Table 4.4). Tilapia are observed to have the lowest FCR either cultured in RAS (1.27) or aquaponics (1.13) (Table 4.4). Among the three fish species, the significantly highest FCR was recorded in empurau cultivated using either RAS (2.62) or aquaponics (2.30).

4.3.2 Water Quality Parameters and Water Usage

The water quality parameters of all the treatment tanks are presented in Table 4.5. A significant difference was observed in the temperature of initial water of the experimental tanks in which aquaponics tanks (27.65 ± 0.31°C) had higher temperature compared to RAS tanks (27.00 ± 0.13°C) (Table 4.6). On the other hand, there was no significant difference in DO across all the treatment tanks (6.82 mg/L to 7.11 mg/L). There were significant differences in the water pH between RAS (5.94 - 6.14) and aquaponics (6.44 - 6.73) systems. Aquaponics systems were observed to have constant water pH with a lower standard deviation compared to RAS (Table 4.5). Throughout the cultivation experiment, higher ammonia (0.40 - 1.17 mg/L) and nitrite (0.04 - 0.07 mg/L) were found in the RAS tanks compared to the aquaponic system. There were no significant differences in nitrate, phosphorus, calcium, magnesium and iron between aquaponics and RAS. Only K concentration in aquaponics (17.94 – 22.68) was significantly higher than RAS (10.95 – 13.87) regardless of the fish species ($P<0.05$).

Table 4.5: Average physical and chemical water parameters in experimental RAS and aquaponics tanks throughout the experiment[1]

System	Tilapia		Empurau		Jelawat		Two-way ANOVA		
Fish species	RAS	Aquaponics	RAS	Aquaponics	RAS	Aquaponics	Type of system	Fish species	Interaction
Temperature (◦C)	26.88 ± 0.77^{a}	27.35 ± 1.07^{b}	27.02 ± 0.77^{a}	27.55 ± 0.96^{bc}	26.97 ± 0.80^{a}	27.55 ± 0.93^{bc}	<0.05	0.30	0.84
pH	6.06 ± 0.31^{ab}	6.44 ± 0.09^{bcd}	5.94 ± 0.35^{a}	6.59 ± 0.07^{cd}	6.14 ± 0.34^{abc}	6.73 ± 0.15^{d}	<0.05	0.10	0.35
DO (mg/L)	6.82 ± 0.64^{a}	6.91 ± 0.49^{a}	7.11 ± 0.27^{a}	6.98 ± 0.34^{a}	6.97 ± 0.36^{a}	7.05 ± 0.26^{a}	0.47	0.29	0.09
NH_3-N (mg/L)	1.17 ± 1.47^{c}	0.08 ± 0.39^{a}	0.40 ± 0.41^{ab}	0.02 ± 0.10^{a}	0.53 ± 1.03^{b}	0.00 ± 0.00^{a}	<0.05	<0.05	<0.05
NO_2^- (mg/L)	0.07 ± 0.07^{b}	0.02 ± 0.03^{ab}	0.05 ± 0.07^{b}	0.01 ± 0.03^{ab}	0.04 ± 0.05^{b}	0.00 ± 0.01^{a}	<0.05	0.27	0.81
NO_3^- (mg/L)	65.92 ± 48.05^{a}	71.08 ± 58.59^{a}	71.31 ± 46.48^{a}	72.98 ± 55.10^{a}	67.57 ± 44.92^{a}	68.77 ± 47.70^{a}	0.76	0.92	0.98
P (mg/L)	2.77 ± 2.35^{a}	2.97 ± 1.97^{a}	2.53 ± 1.36^{a}	2.05 ± 0.83^{a}	2.80 ± 1.82^{a}	2.16 ± 1.10^{a}	0.40	0.41	0.60
K (mg/L)	13.87 ± 4.47^{a}	22.68 ±6.78^{c}	10.95 ± 3.26^{a}	17.94 ± 6.51^{b}	12.62 ± 3.11^{a}	18.88 ± 5.68^{bc}	<0.05	0.05	0.70
Ca (mg/L)	45.80 ± 29.11^{a}	70.13 ± 34.95^{a}	62.13 ± 40.23^{a}	65.87 ± 32.51^{a}	74.20 ± 36.41^{a}	63.00 ± 35.19^{a}	0.46	0.52	0.17
Mg (mg/L)	6.21 ± 3.28^{a}	7.14 ± 5.26^{a}	3.36 ± 3.58^{a}	6.00 ± 4.93^{a}	6.86 ± 4.16^{a}	6.86 ± 7.80^{a}	0.30	0.23	0.63
Fe (mg/L)	0.07 ± 0.03^{a}	0.11 ± 0.18^{a}	0.04 ± 0.01^{a}	0.05 ± 0.03^{a}	0.14 ± 0.22^{a}	0.06 ± 0.03^{a}	0.78	0.17	0.16

[1]Data are presented in mean ± standard deviation. Different superscripts in the same row indicate significant difference at P<0.05.

Table 4.6: Initial water quality of RAS and aquaponics before the commencement of fish cultivation[1]

System	RAS	Aquaponics
Temperature (◦C)	27.00 ± 0.13[a]	27.65 ± 0.31[b]
pH	6.78 ± 0.13[a]	6.92 ± 0.14[a]
DO (mg/L)	7.03 ± 0.33[a]	6.83 ± 0.31[a]
NH_3-N (mg/L)	0.00[a]	0.00[a]
NO_2^- (mg/L)	0.00[a]	0.00[a]
NO_3^- (mg/L)	12.45 ± 3.97[a]	12.41 ± 5.10[a]
P (mg/L)	0.56 ± 0.09[a]	0.75 ± 0.34[a]
K (mg/L)	9.89 ± 0.88[a]	12.33 ± 0.99[a]
Ca (mg/L)	8.11 ± 4.17[a]	8.67 ± 2.75[a]
Mg (mg/L)	3.67 ± 1.33[a]	4.50 ± 1.83[a]
Fe (mg/L)	0.04 ± 0.02[a]	0.05 ± 0.01[a]

[1]T-test was used to analyze the difference between the initial water quality of RAS and aquaponics systems. Data are presented in mean ± standard deviation. Different superscripts in the same row indicate significant difference at $P<0.05$.

There was no significant difference in the total supplementation in aquaponics across the three fish species (Table 4.7). The total fresh crop yield and relative growth rate of bak choy in aquaponics were also not significantly different among the fish species (Table 4.7). However, the crop yields varied greatly in each batch of the harvested crops among the fish species.

Weekly and total water usage in RAS were significantly higher compared to the aquaponics system for the three fish species (Table 4.8). Particularly, weekly water change was performed on the RAS tanks to lower the ammonia concentration. Significantly highest water usage was observed in RAS culturing tilapia (292.80 L), followed by RAS culturing jelawat (230.40 L) and RAS culturing empurau (194.40 L) For aquaponics tanks, only a range of 34.96 L to 37.96 L of water was added to the tanks for all the three fish species throughout the cultivation period, to compensate the water loss during evapotranspiration.

Table 4.7: Nutrient supplement, crop yield and relative growth rate (%) of bak choy harvested from the experimental aquaponics system[1]

Fish Species	Tilapia	Empurau	Jelawat	P value
Nutrient supplement (mL)	169.81 ± 4.33[a]	173.32 ± 9.31[a]	171.26 ± 3.32[a]	0.86
First batch crop yield (g)	112.15 ± 10.06[a]	105.75 ± 46.30[a]	107.59 ± 13.61[a]	0.76
Second batch crop yield (g)	69.18 ± 28.79[a]	102.23 ± 22.74[a]	99.57 ± 39.13[a]	0.69
Total crop yield (g)	181.33 ± 12.38[a]	207.96 ± 11.78[a]	207.16 ± 12.76[a]	0.71
Average crop yield (g)	88.39 ± 29.12[a]	93.20 ± 47.77[a]	94.39 ± 31.81[a]	0.96
Relative growth rate (%)	6.04 ± 1.12[a]	5.85 ± 2.00[a]	6.25 ± 2.38[a]	0.91

[1]Data are presented in mean ± standard deviation. Different superscripts in the same row indicate significant difference at $P<0.05$.

Table 4.8: Weekly and total water usage (L) of RAS and aquaponics throughout 70 days of experimental cultivation[1]

System	RAS			Aquaponics			Two-way ANOVA		
Fish Species	Tilapia	Empurau	Jelawat	Tilapia	Empurau	Jelawat	Type of system	Fish species	Interaction
Weekly water usage (L)	32.53 ± 10.56 [c]	21.60 ± 0.00 [b]	25.60 ± 5.31 [b]	4.14 ± 0.11 [a]	3.88 ± 0.09 [a]	4.22 ± 0.04 [a]	<0.05	<0.05	<0.05
Total water usage (L)	292.80 ± 34.45 [c]	194.40 ± 0.00 [b]	230.40 ± 21.20 [b]	36.23 ± 2.85 [a]	34.96 ± 2.95 [a]	37.96 ± 2.78 [a]	<0.05	<0.05	<0.05

[1]Data are presented in mean ± standard deviation. Different superscripts in the same row indicate significant difference at $P<0.05$.

CHAPTER 5

DISCUSSION

5.1 Survey on Aquaponics Operation (Survey I)

In survey I, the number of farms practicing aquaponics 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).

5.1.1 Aquaponics Farms in Malaysia

Based on Survey I, two aquaponics farms (small-scale and large-scale) were no longer operating as both farmers claimed that their harvested products were not profitable. 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 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 installment, although indoor aquaponics could provide a more controlled culturing environment (Niu and 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 optimize 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, emphasizing the importance of adaptability, innovation, and strategic planning for sustained success and growth.

All aquaponics farms in this study did not have organic certification from any agencies (see Figure 4.1G). However, all farmers in this study declare that their aquaponics products are pesticide-free and provide more health benefits compared to other fish and crops 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 fertilizers (100%) in their aquaponics system. This raises concerns about mislabelling aquaponics products as organic produce.

In fact, aquaponics farms in Malaysia may face difficulties in qualifying for organic certification (myOrganic) because the organic certification recognized by the government is only applicable to 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 non-soil farming methods (Kledal, König and 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 fertilizers application in their systems to achieve the standard of producing organic products.

5.1.2 Types of Crops Grown in Aquaponics

The most grown crop in the aquaponics system was leafy vegetables that were grown by all surveyed aquaponics farms. This finding is 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 highest value crop among the crop species grown in an aquaponics system in Malaysia, yet most of the aquaponics farms grow 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).

Herbs were the second most grown crop due to their high market value and demand, according to the aquaponics farmers in Survey I. 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 that making both crop species the main choices grown in the aquaponics system in Malaysia. Other recommendation 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 hydroponics on the aquaponics system of the surveyed farms, constituting 62% (see Figure 4.2). Compared to other methods, DWC is more space-saving and less construction work when it comes to a large-scale commercial aquaponics farm (Gosh and 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 that used vertical towers were built by the same aquaponics company that sells their aquaponics system. Hence, the design and setup for the vertical tower were well-modified to suit the aquaponics system on the farm. Similar to DWC, the vertical tower is a space-efficient system, but it may have clogging problems and rely on the water pump (Pattillo, 2017).

All aquaponics farms in Malaysia applied fertilizer to their crops as aquaponics could lead to nutrient deficiency for plant crops (Yep and Zheng, 2019). As fish require minimal amounts of potassium and metal ions (iron and magnesium), these nutrients are kept at low levels in fish feed, consequently reducing their presence in aquaculture effluent. Consequently, this decreases their availability for plant uptake, leading to nutrient deficiencies in aquaponics (Yep and Zheng, 2019). The addition of synthetic and organic fertilizers, such as foliar spray and organic liquid fertilizer in the aquaponics system would meet the nutrient requirements of plant crops 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 crop growth, for example, leafy vegetables and herbs. Plant nutrients that are insufficient in aquaponics include phosphorus, potassium, calcium, magnesium and iron (Yep and Zheng, 2019). Hence, fertilizer application fulfills the growth requirement of plant crops which is an important routine in aquaponics farms.

It is unsurprising that aquaponics farmers would apply pesticides on their planted crops 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 (Love, et al., 2015; Yep and Zhang, 2019; Tůmová, Klímová and Kalousa, 2020; Pattillo, et al., 2022). 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. Previous studies have reported the presence of aphids (Wilson, 2005) and spider mites (Goddek, et al., 2015) in aquaponics systems, along with plant diseases caused by bacteria, fungi, and viruses that affect plant health (Goddek, et al., 2015). 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 and Zheng, 2019). Plant pests and diseases are still a major challenge in aquaponic systems (Goddek, et al., 2015; Okomoda, et al., 2022). Further research is needed to ensure that pesticide-free crops are produced with healthy fish and crops from aquaponics.

5.1.3 Types of Fishes Cultured 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 Survey I. Similar results were also found in previous studies (Love, et al., 2015; Villarroel, et al., 2016; Bosma, et al., 2017; Mchunu, et al., 2018; Tůmová, Klímová and Kalousa, et al., 2020; Pattillo, et al., 2022). Tilapia fish was also the most cultured fish species in the whole aquaculture sector in Malaysia, with a production of 37,609.45 tonnes and RM 574,788.64 in 2021 (DOF, 2022). Tilapia is selected as the main fish choice to be grown in aquaponics as it has a high growth rate, high tolerance to a wide range of water quality, and is able to adapt to high stocking density (Pinho, et al., 2021). Nonetheless, a 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 in the country. 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 within the nation. *T. nilotica* was a reported species that colonized 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, improving the fish production value, and diversifying the aquaponics products 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 maximize crop production. In Survey I, 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 ranging 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 Survey I, 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 optimizes the production of both fish and crops to achieve their optimal growth performance in the system. Besides fish-to-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 and Ferrarezi, 2017). Calculation on the fish and crop ratio is important in countries with limited area and resources to maximize the fish and crop production in aquaponics (Somerville, et al., 2014; Shete, et al., 2015).

5.1.4 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).

5.1.5 Initial Capital, Annual Expenses, Annual Crop and Fish Yield

Referring to Figure 4.3, it appears that there is no relationship between farm expenses and yield. This suggests that high expenses do not necessarily lead to high yields. 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 labor 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, fertilizers, 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 and 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 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 (*L. hoevenii*) (DOF, 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.

Besides, ornamental fishes can also be considered to be cultured using aquaponics system which are not used by any farmers in Survey I. 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 (DOF, 2022).

5.1.6 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 aquaponically grown fish and crops to the restaurant or café could gain higher prices as the products are prepared as a dish 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 crop, 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.

5.1.7 Challenges Faced by Aquaponics Farm

Major challenges faced by the surveyed aquaponics farms in Survey I 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 cause great losses in the production of crops. 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).

When aquaponics continue to develop and commercialize, it faces challenges in marketing, farm management and economic viability (Hao, et al., 2020; Pattillo, et al., 2022). When considering the financial issues and marketing challenges of aquaponics, entrepreneurs must conduct a thorough financial analysis prior to embarking on this business venture. This analysis should encompass the capital for establishing an aquaponics farm as well as the annual farm expenses. Successful commercialization of aquaponics products requires a good marketing strategy aimed at identifying targeted consumer markets both locally and internationally.

Furthermore, the selection of fish species and the turnover rate of the fish production cycle in aquaponics play pivotal roles in determining the economic viability of such operations (Bosma, et al., 2017). It is imperative for entrepreneurs to carefully assess market acceptance before choosing valuable fish species for cultivation in their farms. Aquaponics farm may also consider to enhance their economic viability by exploring alternative sources of income, such as selling aquaponics compost or high-value ornamental fish, organizing agritourism activities, and offering educational opportunities with institutes (Pattillo, et al., 2022). This diversification can also address labor shortages and the problem of constant power supply, as increased profitability allows for competitive wages to attract skilled workers and improve the infrastructure of aquaponics operations.

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 fertilizers 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 and 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.

Additionally, overcoming challenges such as fish pests and diseases, technical issues within the system, postharvest processes for products, sourcing quality fingerlings and crop seeds, addressing environmental concerns on aquaponics farms and adapting to weather or climate change all require scientific knowledge to solve the problems encountered at various stages of aquaponic implementation (Pattillo, et al., 2022). Study conducted by Pattillo, et al. (2022) also reflected that knowledge and educational resources are the challenges faced by practitioners with less than five years of experience in aquaponics due to the lack of shared and correct information related to aquaponics knowledge. With more scientific knowledge, aquaponics growers would have the ability to diagnose fish pests and diseases and treat the diseases with the correct methods. It is also related to sourcing good quality of fish fingerlings and crop seeds in order to grow healthy fish and crop in their aquaponics. Aquaponics farmers would also have the knowledge in proper postharvest processes to produce high quality aquaponics products, proper disposal of farm solid and water wastes, and overcoming climate change problems with modern technologies such as IoT application and indoor farming. Therefore, fostering collaboration between researchers and aquaponics operators of diverse backgrounds and experience levels is essential for dispelling myths and enhancing the success of aquaponics development in the nation (Hao, et al., 2020; Pattillo, et al., 2022).

5.2 Survey on Consumers of Aquaponics Products (Survey II)

The results obtained in Survey 2 reveal that Malaysian consumers had less experience in practising aquaponics and purchasing aquaponics products (see Figure 4.6).

5.2.1 Consumers' Experience, Perception and Knowledge of Aquaponics and Its Products

The limited proportion of regular consumers of aquaponics products, suggesting that the awareness and availability of aquaponics and its products are relatively low among Malaysian consumers. The lack of familiarity with aquaponics products indicates the need for increased promotion and education within local markets. To enhance awareness of aquaponics, there is a requirement for more extensive promotion, focusing on educating consumers about the environmental conservation and sustainability benefits associated with aquaponics (Greenfeld, et al., 2020; Suárez-Cáceres, et al., 2021). Suárez-Cáceres, et al. (2021) suggested that increasing consumer knowledge about aquaponics production is necessary to improve their willingness to purchase aquaponics products. Particularly, exposure to the knowledge of practising aquaponics can be done by the stakeholders, including the aquaponics producers, governments and educational institutes in the nation, in which they are playing a crucial role in promoting this sustainable farming method (Xu, et al., 2018).

Moreover, consumers revealed a positive attitude towards aquaponics and its products as they mostly agreed to the benefits and advantages of aquaponics when compared to conventional farming (see Figure 4.7A, items 3 to 8). This determines that the respondents had the knowledge of aquaponics and its products. Respondents also believed that native fish species (empurau and jelawat) can be grown using aquaponics. Similar findings occurred in the previous studies in different countries of Europe (Miličić, et al., 2017), Spain and Latin America (Suárez-Cáceres, et al., 2021), in which a great majority of the survey respondents had a positive attitude towards aquaponics generally. However, positive attitude towards aquaponics and its products does not necessarily imply a higher willingness from the consumers to pay a higher price for aquaponics products (Suárez-Cáceres, et al., 2021), in which the results obtained in the Survey II also revealed that the consumers were holding a neutral attitude on spending more for aquaponics products, together with the native fish species grown using aquaponics (Figure 4.7). Consumers' knowledge towards aquaponics can be a key factor that affects their decision on purchasing its products. Previous studies conducted by Miličić, et al. (2017) and Specht, et al. (2016) were showing a low willingness among the consumers to pay more for aquaponics products, only 17% in Europe and 27% in Berlin. Conversely, Suárez-Cáceres, et al. (2021) revealed a high proportion of respondents (60.5%) are willing to pay more for an aquaponics product in Spain and Latin America, which might because of the higher proportion of respondents (nearly 60%) who had the knowledge about aquaponics. This knowledge drives the consumers to value aquaponics products as a more sustainable production and higher organoleptic quality (Suárez-Cáceres, et al., 2021).

Although the consumers in the present study agreed with the benefits of aquaponics, there are some controversies on certain relatable topics, such as labelling aquaponics products as high-quality food with high nutritional value and organic produce (Kledal, König and Matulić, 2019). Aquaponics products seem to be associated with organic labelling and higher quality standards, in which turning into a marketing strategy to sell aquaponics products at a higher price (Greenfeld, et al., 2020; Suárez-Cáceres, et al., 2021). However, aquaponics is still far behind the crossline of organic certification (Kledal, König and Matulić, 2019), even in Malaysia, none of the aquaponics products have the organic certification (see Figure 4.1G). Moreover, a considerable number of aquaponics farms (77% in Survey I) reported using pesticides on their crops grown through aquaponics. This raises health concerns, particularly regarding the potential presence of chemical residues in aquaponics products when consumed. Despite the absence of organic certification and the possibility of lower food quality in aquaponics products, Malaysian consumers seem to have confidence in their quality.

A previous study has shown that Malaysian consumers had positive intention on purchasing aquaponics products (Tamin, et al., 2015). These results are different with the results shown in the Survey II as the consumers had a neutral attitude on purchasing and paying more for aquaponics products as well as native fish species cultured using aquaponics system. These differences might be due to the locality of the consumers who were mainly from urban and rural areas in Kuala Lumpur, Johor and Sabah in Tamin, et al. (2015) while respondents in the Survey II were more widely distributed from the six regions in Malaysia (northern, central, southern, east coast, Sarawak and Sabah). Consumer's willingness to buy aquaponics products may decline when the sample population is expanded to encompass various regions across the nation. This observation is intriguing because consumer purchasing preferences for aquaponics products could potentially be influenced by diverse regional cultures. Exploring this aspect could be a promising direction for future research in understanding the dynamics of the aquaponics market among Malaysian consumers.

5.2.2 Relationship between Consumer Age, Educational Level and Income Level with (1) Consumer Perception and Knowledge on Aquaponics and Its Products (Fish and Crops) and (2) Consumer Perspective of Native Fish Species Cultured Using Aquaponics

There was a very weak correlation (Rs = -.10, P-value =.04) between consumers' educational level with consumer perception and knowledge on aquaponics and its products (fish and crops) (see Table 4.2). A coefficient value range of 0.10-0.36 is considered a "low" correlation, while a coefficient value lower than 0.10 can be negligible (Schober, Boer and Schwarte, 2018). This suggests a weak correlation between consumers' educational levels and their perception and knowledge of aquaponics and its products (both fish and crops), which can be considered negligible. In other words, there is no association between consumer age, educational level and income level with their perception and knowledge on aquaponics and its products, as well as their perspective on native fish species grown in aquaponics. Despite aquaponics being an emerging farming method, there is no resistance to its acceptance among older consumers or those with lower educational levels or income. Interestingly, they exhibit a neutral attitude on purchasing and paying a higher price to purchase aquaponics products. Despite the findings from Suárez-Cáceres, et al. (2021) suggesting that consumers in Spain and Latin America with a higher educational background tend to possess more knowledge about aquaponics, the results differ in Malaysia, where consumers' knowledge about aquaponics is not influenced by their academic level. However, consumers' general scepticism regarding novel sustainable food technologies is remaining a significant challenge to achieve sustainability in food production, including aquaponics (Davide and Jaeger, 2023). Hence, identifying the barrier to improve consumer's knowledge with a positive attitude on aquaponics as a novel sustainable food technology should be a priority in the future research. Combined with the findings that respondents acknowledge the benefits and advantages of aquaponics, this shows a potential local market for aquaponics products in Malaysia, regardless of consumers' age, educational backgrounds, and income levels.

Promoting awareness and acceptance of aquaponics products in Malaysia can be achieved through various strategies. Firstly, education is the key to raise awareness on entrepreneurs and consumers on the benefits of aquaponics, its sustainability and its potential contribution to food security, through public awareness campaigns, educational workshops and seminars, coupled with the collaboration of schools, colleges and universities (Greenfeld, et al., 2020; Suárez-Cáceres, et al., 2021). Moreover, developing aquaponics certification is also vital to ensure the quality and safety of farm products so that consumer trust can be enhanced through certification that verifies adherence to sustainable farming standards. It needs the involvement of many agencies, such as governments, industry partners, local influencers, and educators to advocate for aquaponics and garner support from the community (Okomoda, et al., 2018). This can include establishing distribution channels, organizing farmers' markets, and facilitating partnerships with retailers and restaurants. Incentives and funds are also the facilitator to promote aquaponics and its products in encouraging more farmers to venture into aquaponics. Investing in research and development is also a key to improve aquaponics and increase its productivity to address any existing challenges (Okomoda, et al., 2018). By implementing these strategies, awareness and acceptance of aquaponics products can be promoted effectively in Malaysia, leading to broader adoption and recognition of this sustainable farming method.

5.3 Fish Cultivation Experiment

In the fish cultivation experiment, the same fish species showed no significant difference ($P>0.05$) on their WG and SGR between aquaponics and RAS, indicating that fish yield produced by aquaponics is comparable to that of RAS.

5.3.1 Fish Growth Performance, Survival and FCR

Among the cultured fish species, tilapia showed the significantly highest ($P<0.05$) WG and SGR, while empurau showed the significantly lowest WG and SGR in both aquaponics and RAS. In a previous study, empurau cultivated for 14 weeks was reported to have a low SGR ranged between 0.31 to 0.51%/day (Misieng et al. 2011), which was profoundly lower than other tropical freshwater fish species such as tilapia and common carp (Kaushik 1998). However, the SGR of empurau cultured in either RAS (1.88%/day) or aquaponics (1.87%/day) in this fish experiment was higher than those reported previously (Misieng et al. 2011; Sulaiman et al. 2022). Likewise, the SGR of jelawat cultured in RAS (2.98%/day) and aquaponics (2.96%/day) was higher than that of jelawat (0.59-0.72%) cultured in a polyethylene tank without filtration (Farahiyah, et al. 2017). Increased SGR of jelawat and empurau in the present study suggested the beneficial effect of using RAS and aquaponics systems in improving the growth performance of these two native species.

On the other hand, fish grown in aquaponics tended to have higher survival rate compared to those grown in RAS despite no significant difference was observed within the same fish species. These results agree with Fischer et al. (2021) and Wang et al. (2022) where fish survival rate was relatively higher in aquaponics compared to RAS although no difference was recorded on fish growth performance. Cultivation of empurau and jelawat with aquaponics also showed 100% survival which may be attributed to the better water qualities (stable water pH, and lower ammonia and nitrite concentrations) in the aquaponic systems. In RAS, a higher survival rate was recorded in empurau compared to tilapia, which may be attributed by significantly higher ammonia and nitrite concentrations in RAS tanks (Table 4.4). These results indicate that aquaponics can reduce the ammonia and nitrite concentrations with its good biofiltration, which contributes to better water quality and ultimately higher fish survival rate (Wang, et al., 2021). Besides, frequent cannibalism that was observed in the tilapia tanks might be another contributing factor to its inferior survival rate (Duk, et al., 2017). This also implies the advantages of culturing empurau and jelawat.

Fish grown in aquaponics tended to have lower FCR than those grown in RAS, although no significant difference was recorded between the systems for the same fish species (Table 4.4). Similar findings were reported by Effendi, et al. (2017), Oladimeji, et al. (2020) and Fischer, et al. (2021). This may be attributed to the higher ammonia concentration in RAS that induces fish stress response which is energy demanding (Paust, et al., 2011). Fish grown in RAS might consume more feeds which were utilized for stress responses triggered by poor water quality rather than weight gain, resulting in higher FCR as compared to those cultured in aquaponics. Moreover, tilapia showed the lowest

FCR either cultured in RAS (1.27) or aquaponics (1.13) among the three fish species (see Table 4.4), which was lower than that reported in previous studies where a FCR of 2.02 shown in RAS and a range of 1.60-1.70 in aquaponics (Effendi et al., 2017), while a FCR ranged 1.14-1.27 has also been reported for tilapia cultured in aquaponics by Tawaha, et al., (2021).

The highest FCR among the three fish species was significantly recorded in empurau tanks, whether in RAS (2.62) or aquaponics (2.30), falling within the range of 2.13-3.26 reported in previous studies (Ng et al. 2008; Misieng et al. 2011; Sulaiman et al. 2022). Besides, FCR of jelawat cultured in aquaponics (1.68) was better than those grown in a polyethylene tank without a RAS or an aquaponics system (1.70 to 2.18) (Farahiyah, et al. 2017). Comparing empurau and jelawat to other Cyprinidaes, common carp (*Cyprinus carpio*) and grass carp (*Ctenopharyngodon idella*) cultured in RAS had a specific growth rate (SGR) of 1.28 – 2.19%/day while the feed conversion ratio (FCR) ranged between 1.06-1.70 (Enache, et al. 2011; Kristan, et al., 2018; Shao, et al., 2020). In the present study, SGR and FCR of empurau in both RAS and aquaponics are higher than common carp and grass carp, while SGR and FCR of jelawat fall within the range of that of the common carp and grass carp. Fish cultivation using aquaponics results in enhanced fish FCR and increased survival rates, leading to reduced fish feed costs and improved fish yield. This is essential for sustaining food security amid the growing human population. In other words, aquaponics has the potential to significantly improve the FCR of fish, with more pronounced benefits observed over extended cultivation periods.

5.3.2 Water Quality Parameters and Water Usage

A significant difference was observed in the temperature of initial water in which aquaponics tanks had higher temperature than RAS tanks (see Table 4.6). Higher temperature recorded in the aquaponics tanks may cause by the usage of LED lamps in the aquaponics and the lower positioning of the RAS tanks which had lesser heat exposure from the atmosphere. Yet, throughout the cultivation experiment, the difference in water temperature had no impact on the growth of fishes and crops as the temperature was within the range reported in other studies (Ogah, et al., 2020; Junaid, et al., 2023). On the other hand, the neutral and stable water pH in aquaponics tanks could be attributed to the existence of crops which act as a buffer by exchanging the ions of hydrogen and hydroxide in their roots during nitrate absorption (Makhdom, et al., 2017). There is a shortage of studies examining how various crops affect water pH in aquaponics, making it an interesting area for research.

The reduced ammonia concentration in aquaponics tanks showcases its capacity to effectively eliminate ammonia, thereby enhancing water quality for optimal fish growth. High ammonia concentration causes the reverse diffusion of ammonia molecules from the culture water into the blood that inhibits the excretion of ammonia from the fish body (Hargreaves and Kucuk, 2001). This induces stress responses in the fish which are energy demanding, competing with the energy consumption that is normally used for fish growth, ingestion and digestion (Paust, et al., 2011). Rahmati, et al. (2022) also reported that increased ammonia concentration has significantly increased fish cortisol and glucose levels which can cause death in tilapia. Furthermore, there was no mortality in jelawat regardless of cultivation system, despite the ammonia concentration was significantly higher in RAS (0.53 mg/L) than in aquaponics (0.00 mg/L). This suggests that jelawat has a higher tolerance to ammonia compared to tilapia. Previous study also reported that jelawat could grow in water containing up to 2 ppm ammonia with a 99.52% survival rate in pond culture (Kamarudin, et al., 2013). Although the nitrite concentration in RAS tanks (0.04 – 0.07 mg/L) was noticeably higher than in aquaponics tanks (0.00 – 0.02 mg/L), yet it was still below the lethal level (20 mg/L) that can cause adverse effects to the fish's haematological properties, antioxidant defenses and stress responses (Kim, et al., 2022).

In the present study, K concentration in aquaponics was significantly higher than RAS regardless of the fish species. Despite the addition of nutrients to aquaponics tanks, there was no significant effect on the concentration of NO_3^-, P, Ca, Mg and Fe between RAS and aquaponics (see Table 4.5). K, Ca, Mg and Fe are the limiting nutrients in aquaponics, which are essential for plant growth (Yep and Zheng, 2019; Yang and Kim, 2020). As a result, nutrient supplementation in aquaponics can greatly increase the K content which could also help plants absorb other nutrients (Yep and Zheng, 2019). This may explain why the P, Ca, Mg, and Fe concentrations in aquaponics were not significantly different with RAS (see Table 4.5). Besides, there was a big variation in each batch of crop yields (Table 4.7) as some crops were infected by insect pests (caterpillars and leaf miners). As no pesticides were used in this experiment, these pests were removed manually on a daily basis. Nevertheless, this manual method necessitates a great amount of effort, which might be a serious issue if a large aquaponics farm is in operation.

The total water usage in RAS was significantly higher compared to aquaponics systems (Table 4.8). In this experiment, total water usage in aquaponics are only 12.37% (tilapia), 17.09% (empurau) and 16.48% (jelawat) of the total water usage in RAS. Yep and Zheng (2019) reported that aquaponics had a higher water use efficiency than RAS because it only needed 0.3 to 0.5% of total system water per day which is lower than the total water usage recorded in Table 4.8. This variation may be attributed to different rates of evapotranspiration loss occurring within distinct experimental environments. Aquaponics enhances water use efficiency in fish farming through sustainable means (Suárez-Cáceres, et al., 2021). This practice effectively mitigates the environmental consequences of aquaculture wastewater discharge, while also promoting the recycling of water for both fish and crop cultivation in an eco-friendly way.

Several limitations were encountered during the course of this study. Firstly, in Survey I, collecting a sufficient number of aquaponics farms in Malaysia proved challenging due to the absence of a comprehensive list of such operations nationwide. Additionally, certain farms were reluctant to disclose their information as they hold confidentiality concerns. To address this issue, future research should strive to engage more aquaponics farms to expand the sample size and gather more detailed data on pest and disease management, thereby better addressing the challenges faced by aquaponics in the country.

In the fish experiment, obtaining similar initial fish weight across three different species posed a significant challenge. Besides, empurau fish fries is also difficult to purchase from the local suppliers, due to the comparatively higher cost of empurau fish fries compared to tilapia and jelawat. Nonetheless, forthcoming studies could investigate more varieties of fish species suitable for aquaponics cultivation, thereby fostering greater diversity in fish production in this farming system.

CHAPTER 6

CONCLUSION

Survey I deliberates the development status of aquaponics in Malaysia. It is obvious that aquaponics is not the main choice of crop and fish cultivation for Malaysian farmers due to various farm challenges. Most crop and fish species grown in aquaponics in Malaysia were similar to the findings reported in other regions such as the United States of America, Europe, South Africa, Czechia and Philippines. Differences were recorded in regard to 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. In terms of aquaponics production, average crop yield (RM 20.59/ft^2) was higher than the fish yield (RM 6.76/ft^2). None of the aquaponics farms in Malaysia possess organic certification due to the inapplicability of organic certification standards to aquaponics farming in the country. It is imperative to explore the possibility of making aquaponics eligible for organic certification in Malaysia, a move that could prove advantageous for both farmers and consumers. Farmers may consider obtaining Malaysian Good Agricultural Practice (MyGAP) certification to enhance their production value in the consumer markets. Future research endeavors should encompass economic feasibility and propose solutions to address the challenges encountered by aquaponics farms in Malaysia.

Findings from the Survey II indicated that aquaponics and its products had limited visibility and accessibility in the local market. Additionally, local consumers demonstrated limited experience in both practicing aquaponics and purchasing its products. Consumers agreed to the benefits and advantages in aquaponics and its products, which shows a positive attitude towards aquaponics, as well as using the aquaponics system to grow Malaysian high value native fish species (empurau and jelawat). Yet they still hold a neutral attitude towards purchasing aquaponics products and native fish species grown in aquaponics, which is more expensive than conventional farming. Promotions on aquaponics should take place to educate consumers and foster the knowledge of this sustainable farming method. Aquaponics is still an emerging farming practice in Malaysia and has a great potential market for commercialization.

The growth performance of tilapia, empurau, and jelawat reared in aquaponics were comparable to RAS. While fish FCR was generally improved in the aquaponics system, survival rates for tilapia and empurau were higher in the aquaponics compared to RAS. The advantages of aquaponics for fish cultivation extend to improved water quality, consistent pH level, and efficient water consumption when compared with RAS. Notably, although tilapia exhibited superior growth rates and lower FCR, the application of aquaponics remains viable for cultivating Malaysian indigenous fish species like empurau and jelawat. This approach holds the promise of promoting diversity and sustainably increasing fish production. In light of the above, advocating for aquaponics as a viable approach to cultivate high value indigenous fish species in Malaysia is justifiable. Given the potential consumer market, widespread adoption of aquaponics is essential to align with Malaysia's efforts toward achieving the SDGs.

References

Abdullah, F.A., Saidi, S.F.S., Abu Bakar, T.H.S.T. and Young, L.J., 2022. The level of buying behavior towards organic food among Malay consumers. *IOP Conference Series: Earth and Environmental Science*, 1102, p. 012051.

Acquacoltura Italia, 2016. *Aquaponics History and Benefits*. [pdf] Available at: <https://acquacolturaitalia.com/wpcontent/uploads/2016/10/aquaponics_history_and_benefits.pdf> [Accessed 1 December 2023].

Ahmad, A.K., Nur-Hazwani, M.N.R., Omar, S.A.S., Aweng, E.R. and Taweel, A., 2020. Preliminary study on invasive fish species diffusion in selected Malaysian freshwater ecosystems. *Pakistan Journal of Biological Sciences*, 23, pp. 1374-1379.

Ahmad, M.H., 2014. *Ikan Kelah Biru di Taman negara Endau Rompin Malaysia*. [online] Available at: <https://www.ikankelah.com/ikan-kelah-biru/> [Accessed 4 November 2023].

Alarcón-Silvas, S.G., León-Cañedo, J.A., Fierro-Sañudo, J.F., Ramírez-Rochín, J., Fregoso-López, M.G., Frías-Espericueta, M.G., Osuna-Martínez, C.C. and 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 basilisum*. *Aquaculture*, 543, 737023.

Alias, S.L.F.W., Munir, M.B., Asdari, R., Yao, L.E. and Ying, C.S., 2022. Selection of suitable aquaponics system for empurau (*Tor tambroides*) fries nursery in polyculture method. *Aquaculture International*, 30, pp. 1799-1816.

Alselek, M., Alcaraz-Calero, J.M., Segura-Garcia, J. and Wang, Q., 2022. Water IoT monitoring system for aquaponics health and fishery applications. *Sensors*, 22(19), 7679.

Amirrudin, B.A. and Zakaria-Ismail, M., 2014. Additional native fish fauna of rivers and streams flowing into Temengor reservoir, Perak, Malaysia. *Malayan Nature Journal*, 66(4), pp. 407-419.

Ariffin, F.D., Halim, A.A., Hanafiah, M.M., Awang, N., Othman, M.S., Azman, S.A.A. and Bakri, N.S.M., 2020. The effects of African catfish, *Clarias gariepinus* pond farm's effluent on water quality of Kesang river in Malacca, Malaysia. *Applied Ecology and Environmental Research*, 17(2), pp. 1531-1545.

Atique, F., Lindholm-Lehto, P. and 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*, 14, p. 1447.

Azra., M.N., Kasan, N.A., Othman, R., Noor, G.A.G.R., Mazelan, S., Jamari, Z.B., Sarà, G. and Ikhwanuddin, M., 2021. Impact of COVID-19 on aquaculture sector in Malaysia: Findings from the first national survey. *Aquaculture Reports*, 19, 100568.

Badiola, M., Mendiola, D. and Bostock, J., 2012. Recirculating Aquaculture Systems (RAS) analysis: Main issues on management and future challenges. *Aquacultural Engineering*, 51, pp. 26-35.

Bailey, D.S. and Ferrarezi, R.S., 2017. Valuation of vegetable crops produced in the UVI commercial aquaponic system. *Aquaculture Reports*, 7, pp. 77-82.

Biun, H., Sade, A., Robert, R. and Rodrigues, K.F., 2021. Phylogeographic structure of freshwater *Tor* sp. in river basins of Sabah, Malaysia. *Fishes*, 6(4), p. 44.

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

CheckMarket, 2022. *Sample Size Calculator*. [online] Available at: < https://www.checkmarket.com/sample-size-calculator/> [Accessed 10 March 2022].

Cheok, T.N. and Soo, C.L., 2021. A desktop study on fish assemblages in Malaysia lotic habitats. *Journal of Physics: Conference Series*, 2314, p. 012005.

Chong, A.J., 2023. *Aquaculture Industry in Malaysia: Challenges and Issues*. [online] Available at: <https://maritimefairtrade.org/aquaculture-industry-malaysia-5-challenges-issues/> [Accessed 7 November 2023].

Colt, J. 2006. Water quality requirements for reuse systems. *Aquaculture Engineering*, 34, pp. 143-156.

Dawa, M., Lausa, S.M. and Tibom, M.R., 2022. Internet of Things (IoT) based aquaponics management system adaptive to climate change. *AIP Conference Proceedings*, 2502, p. 050004.

Dediu, L., Cristea, V., Docan, A. and Vasilean, I., 2011. Evaluation of condition and technological performance of hybrid bester reared in standard and aquaponic system. AACL *Bioflux*, 4(4), pp. 490-498.

Department of Fisheries (DOF), 2021. *Aquaculture FAQ*. [online] Available at: <https://www.dof.gov.my/en/frequently-asked-questions/aquaculture-faq/#:~:text=In%20this%20RAS%20system%2C%20marine,and%20finally%20this%20water%20will> [Accessed 9 April 2024].

Department of Fisheries (DOF), 2023. Annual Fisheries Statistics 2022. [pdf] Malaysia: Department of Fisheries. Available at: <https://www.dof.gov.my/en/resources/fisheries-statistics-i/> [Accessed 1 November 2023].

Dosdat, A., Ruyet, J.P., Coves, D., Dutto, G., Gasset, E., Roux, A.L. and Lemarie, G., 2003. Effect of chronic exposure to ammonia on growth, food utilization and metabolism of the European sea bass (*Dicentrarchus labrax*). *Aquatic Living Resources*, 16, pp. 509-520.

Duarte, A.J., Malheiro, B., Ribeiro, C., Silva, M.F., Ferreira, P. and Guedes, P., 2015. Developing an aquaponics system to learn sustainability and social compromise skills. *Journal of Technology and Science Education*, 5(4), pp. 235-254.

Duk, K., Pajdak, J., Terech-Majewska, E. and Szarek, J., 2017. Intracohort cannibalism and methods for its mitigation in cultured freshwater fish. *Reviews in Fish Biology and Fisheries*, 27, pp. 193-208.

Effendi, H., Wahyuningsih, S. and 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*, 7, pp. 3055-3063.

Enache, I., Cristea, V., Ionescu, T. and Ion, S., 2011. The influence of stocking density on the growth of common carp, *Cyprinus carpio*, in a recirculating aquaculture system. *AACL Bioflux*, 4(2), pp. 146-153.

Estim, A., Shapawi, R., Shaleh, S.R.M., Saufie, S. and Mastafa, S., 2023. Decarbonizing aquatic food production through circular bioeconomy of aquaponic systems. *Aquaculture Studies* 23(4), p. AQUAST963.

Farahiyah, I.J., Abidin, Z., Ahmad, A.R. and Wong, H.K., 2017. Optimum protein requirement for the growth of *Jelawat* fish (*Leptobarbus hoevenii*). *Malaysian Journal of Animal Science*, 20, pp. 39-46.

Farooq, A., Verma, A.K., Hittinahalli, C.M., Varghese, T. and Pathak, M.S., 2023. Iron supplementation in aquaculture wastewater and its impact on osmoregulatory, haematological, blood biochemical, and stress responses of pangasius with spinach in nutrient film technique based aquaponics. *Aquaculture*, 567, p. 739250.

Fischer, H., Romano, N., Jones, J., Howe, J., Renukdas, N. and Sinha, A.K., 2021. Comparing water quality/bacterial composition and productivity of largemouth bass *Micropterus salmoides* juveniles in a recirculating aquaculture system versus aquaponics as well as plant growth/mineral composition with or without media. *Aquaculture*, 538, p. 736554.

Folorunso, E.A., Bohatá, A., Kavkova, M., Gebauer, R. and Mraz, J., 2022. Potential use of entomopathogenic and mycoparasitic fungi against powdery mildew in aquaponics. *Frontiers of Marine Science*, 9(7), 992715.

Food and Agriculture Organization (FAO), 2016. *The State of World Fisheries and Aquaculture 2016. Contributing to Food Security and Nutrition for All.* Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization (FAO), 2017. *The Future of Food and Agriculture - Trends and Challenges*. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization (FAO), 2020. *The State of World Fisheries and Aquaculture 2020: Sustainability in action*. Rome: Food and Agriculture Organization.

Food and Agriculture Organization (FAO), 2021. *Aquastat*. [online] Available at: < https://data.apps.fao.org/aquastat/?lang=en> [Accessed 7 November 2023].

Foss, A. Imsland, A.K., Roth, B., Schram, E. and Stefansson, S.O., 2009. Effects of chronic and periodic exposure to ammonia on growth and blood physiology in juvenile turbot. *Aquaculture*, 296, pp. 45-50.

Fruscella, L., Kotzen, B. and Milliken, S., 2021. Organic aquaponics in the European Union: towards sustainable farming practices in the framework of the new EU regulation. *Reviews in Aquaculture*, 13(3), pp. 1661-1682.

Gephart J.A., Troell M., Henriksson P.J.G., Beveridge M.C.M., Verdegem M., Metian M., Mateos L.D. and Deutsch L., 2017. The ‘seafood gap’ in the food-water nexus literature—issues surrounding freshwater use in seafood production chains. *Advances in Water Resources*, 110, pp. 505-514.

Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K., Jijakli, H. and Thorarinsdottir, R., 2015. Challenges of sustainable and commercial aquaponics. *Sustainability*, 7, pp. 4199-4224.

Goddek, S., Espinal, C.A., Delaide, B., Jijakli, M.H., Schmautz, Z, Wuertz, S. and Keesman, K.J., 2016. Navigating towards decoupled aquaponics systems: A system dynamics design approach. *Water*, 8(7), p. 303.

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

Granada, L., Sousa, N., Lopes, S. and Lemos, M.F.L., 2015. Challenges of sustainable and commercial aquaponics. *Sustainability*, 7, pp. 4199-4224.

Greenfeld, A., Becker, N., Bornman, J.F., Dos Santos, M.J. and Angel, D., 2020. Consumer preferences for aquaponics: a comparative analysis of Australia and Israel. *Journal of Environmental Management*, 257, 109979.

Hao, Y., Ding, K., Xu, Y., Tang. Y. Liu, D. and Li, G., 2020. States, trends, and future of aquaponics research. *Sustainability*, 12 (18), p. 7783.

Hargreaves, J.A. and Kucuk, S., 2001. Effects of diel un-ionized ammonia fluctuation on juvenile hybrid striped bass, channel catfish, and blue tilapia. *Aquaculture*, 195, pp. 163-181.

Isa, S.H., Ramlee, M.N.A., Lola, M.S., Ikhwanuddin, M., Azra, M.N., Abdullah, M.T., Zakaria, S. and Ibrahim, Y., 2020. A system dynamics model for analysing the eco-aquaculture system of integrated aquaculture park in Malaysia with policy recommendations. *Environment, Development and Sustainability*, 23, pp. 511-533.

Jaafar, F., Na-Nakorn, U., Srisapoome, P., Amornsakun, T., Duong, T.Y., Gonzales-Plasus, M.M., Hoang, D.H. and Parhar, I.S., 2021. A current update on the distribution, morphological features, and genetic identity of the Southeast Asian mahseers, *Tor* species. *Biology*, 10, p. 286.

Jones, S., 2002. Evolution of aquaponics. *Aquaponics Journal*, 4(1), pp. 14-17.
Junaid, A.A., Kamarudin, M.S., Junaid, Q.O., Edaroyati, W.P., Isyaka, M.S., Dauda, A.B., Umar, D.M., Igoli, J.O. and Amin, S.M.N., 2023. Nutrient uptake and recovery potentials of *Ocimum basilicum* and *Corchorus olitorius* in a polyculture aquaponic system. *Scientific African*, 20, p. e01645.

Junge, R., König, B., Villarroel, M., Komives, T. and Jijakli, M.H., 2017. Strategic points in aquaponics. *Water*, 9(3), 182.

Kamarudin, M.K.A., Idris, M. and Toriman, M.E., 2013. Analysis of *Leptobarbus hoevenii* in control environment at natural lakes. *American Journal of Agricultural and Biological Sciences*, 8(2), pp. 142-148.

Kaushik, S.J. 1998. Nutritional bioenergetics and estimation of waste production in non-salmonids. *Aquatic Living Resources*, 11, pp. 211-217.

Khai, N.X., Kusairi, M.N., Ahmad, S., Syahaneem, M.Z. and Fatimah, M.A., 2014. Market potential analysis for *tengas* (*Neolissochilus* sp.) in the Malaysian market. *International Food Research Journal*, 22(4), pp. 1429-1432.

Khaoula, T., Abdelouahid, R.A., Ezzahoui, I. and Marzak, A., 2021. Architecture design of monitoring and controlling of IoT-based aquaponics system powered by solar energy. *Procedia Computer Science*, 191, pp. 493-498.

Kim, J.H., Kang, Y.J. and Lee, K.M., 2022. Effects of nitrite exposure on the haematological properties, antioxidant and stress responses of juvenile hybrid groupers, *Epinephelus lanceolatus*♂ × *Epinephelus fuscoguttatus*♀. *Antiodidants (Basel)*, 11(3), pp. 545.

Kledal, P.R., König, B. and Matulić, D., 2019. *Aquaponics: The ugly duckling in organic regulation*. Denmark: Springer.

KÖnig, B., Junge, R., Bittsansky, A., Villarroel, M. and Komives, T., 2016. On the sustainability of aquaponics. *Ecocycles*, 2(1), pp. 26-32.

Kristan, J., Blecha, M. and Policar, T., 2018. Survival and growth rates of juvenile grass carp *Ctenopharyngodon idella* overwintered in ponds and recirculating aquaculture systems including a comparison of production economics, *Turkish Journal of Fisheries and Aquatic Science*, 19(3), pp. 261-266.

Kroupova, H., Machova, J. and Svobodova, Z., 2005. Nitrite influence on fish: on review. *Veterinární Medicína*, 50(11), pp. 461-471.

Kurniawan, S.B., Ahmad, A., Rahim, N.F.M., Said, N.S.M., Alnawajha, M.M., Imron, M.F., Abdullah, S.R.S., Othman, A.R., Ismail, N.I. and Hasan, H.A., 2021. Aquaculture in Malaysia: Water-related environmental challenges and opportunities for cleaner production. *Environmental Technology & Innovation*, 24, p. 101913.

Lau, M.M.L., Lim, L.W.K., Chung, H.H. and Gan, H.M., 2023. The first draft genome assembly and data analysis of the Malaysian mahseer (*Tor tambroides*). *Aquaculture and Fisheries*, 8, pp. 481-491.

Lennard, W. and Goddek, S., 2019. *Aquaponics: The Basics*. Cham: Springer.

Lennard, W.A., and Leonard, B.V., 2006. A comparison of three different hydroponic sub-systems (gravel bed, floating and nutrient film technique) in an aquaponic test system. *Aquaculture International*, 14(6), pp. 539-550.

Lin, W.L., Wang, S.C., Chen, L.S., Lin, T.L. and Lee, J.L., 2022. Green care achievement based on aquaponics combined with human-computer interaction. *Applied Sciences*, 12(19), p. 9809.

Love, D.C., Fry, J.P., Genello, L., Hill, E.S., Frederick, J.A., Li,X. and Semmens, K., 2015. An international survey of aquaponics practitioners. *PLoSONE*, 9(7), p. e102662.

Madsen, H., Thien, P.C., Nga, H.T.N., Clausen, J.H., Dalsgaard, A. and Murrell, K.D., 2015. Two-year intervention trial to control of fish-borne zoonotic trematodes in giant gourami (*Osphronemus goramy*) and striped catfish (*Pangasianodon hypophthalmus*) in nursery ponds in the Mekong Delta, Vietnam. *Acta Tropica*, 152, pp. 201-207.

Mapenzi, L.L., Shimba, M.J., Moto, E.A., Maghembe, R.S. and Mmochi, A.J., 2020. Heavy metals bio-accumulation in tilapia and catfish species in Lake Rukwa ecosystem Tanzania. *Journal of Geochemical Exploration*, 208, p. 106413.

Makhdom, S., Shekarabi, S.P.H. and Shamsaie Mehrgan, M., 2017. Biological nutrient recovery from culturing of pearl gourami (*Trichogaster leerii*) by cherry tomato (*Solanum lycopersicum*) in aquaponic system. *Environmental Science and Pollution Research*, 24, pp. 20634-20640.

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

Meena, L.L., Verma, A.K., Krishnani, K.K., Hittinahalli, C.M., Haridas, H. & John, V.C. 2023. Combined foliar application effect of iron and potassium on growth of okra and striped catfish using media bed based aquaponics. *Aquaculture* 569: 739398.

Miličić, V., Thorarinsdottir, R., Dos-Santos, M., Turnˇsek-Hančič, M., Dos Santos, M. and Hančič, M.T., 2017. Commercial aquaponics approaching the European market: to consumers' perceptions of aquaponics products in Europe. *Water*, 9, pp. 1-22.

Misieng, J.D., Kamarudin, M.S. and Musa, M., 2011. Optimum dietary protein requirement of Malaysian mahseer (*Tor tambroides*). *Pakistan Journal of Biological Sciences*, 14, pp. 232-235.

Mohamad, S., Liew, H.J., Zainuddin, R.A., Rahmah, S., Waiho, K., Ghaffar, M.A., Nhan, H.T., Loh, J.Y., Lim, L.S., Chang, Y.M., Liang, L. and De Boeck, G., 2021. High environmental temperature and low pH stress alter the gill phenotypic plasticity of Hoven's carp *Leptobarbus hoevenii*. *Journal of Fish Biology*, 99(1), pp. 206-218.

Mohamand, A.B.M., Siti, N.A., Mohd, I.Z. and Shahreza Md, S., 2022. Aquascape ornamental industry in Malaysia: A perspective review. *IOP Conference Series: Earth and Environmental Science*, 860(1), 012044.

Monsees, H., Kloas, W. and Wuertz, S., 2017. Decoupled systems on trial: eliminating bottlenecks to improve aquaponics processes. *Plos One*, 12(9), p. e0183056.

Narvios, W.M., Cesa, C.K.N., Batayola, F.F., Bolo, K., Verdida, S.M. and Nguyen, Y.Q., 2022. Smart aquaponics system for a small-scale farmer for highly urbanized settlers. *AIP Conference Proceeding*, 2502, 05001.

Ng, W.K., Abdullah, N. and De Silva, S.S. 2008. The dietary protein requirement of the Malaysian mahseer, *Tor tambroides* (Bleeker), and the lack of protein-sparing action by dietary protein. *Aquaculture,* 284, pp. 201-206.

Niu, G. and Masabni, J., 2018. Plant production in controlled environments. *Horticulturae*, 4(4), p. 28.

Ogah, S.I., Kamarudin, M.S., Nurul Amin, S. and Puteri Edaroyati, M.W., 2020.Biological filtration properties of selected herbs in an aquaponic system. *Aquaculture Research*, 51, pp. 1771-1779.

Okomoda, V.T., Oladimeji, S.A., Solomon, S.G., Olufeagba, S.O., Ogah, S.I. and Ikhwanuddin, M., 2022. Aquaponics production system: A review of historical perspective, opportunities, and challenges of its adoption. *Food Science & Nutrition*, 11(3), pp. 1157-1165.

Oladimeji, S.A., Okomoda, V.T., Olufeagba, S.O., Solomon, S.G., Abol-Munafi, A.B., Alabi, K.I., Lkhwanuddin, M., Martins, C.O., Umaru, J. and

Hassan, A., 2020. Aquaponics production of catfish and pumpkin: Comparison with conventional production systems. *Food Science & Nutrition*, 8, pp. 2307-2315.

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

Pattillo, D.A., Hager, J.V., Cline, D.J., Roy, L.A. and Hanson, T.R., 2022. System design and production practices of aquaponics stakeholders. *PLoS ONE*, 17(4), p. e0266475.

Pattillo, D.A., Cline, D.J., Hager, J.V., Roy, L.A. and Hanson, T.R., 2022. Challenges experienced by aquaponic hobbyists, producers, and educators. *Journal of Extension*, 60(4), p. 13.

Paust, L.O., Foss, A.K. and Imsland, A.K., 2011. Effects of chronic and periodic exposure to ammonia on growth, food conversion efficiency and blood physiology in juvenile Atlantic halibut (*Hippoglossus hippoglossus* L.). *Aquaculture*, 315(3-4), pp. 400-406.

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

Pinho, S.M., David, L.H., Garcia, F., Keesman, K.J., Portella, M.C. and Goddek, S., 2021. South American fish species suitable for aquaponics: a review. *Aquaculture International*, 29, pp. 1427-1449.

Pinho, S.M., Flores, R.M.V., David, L.H., Emerenciano, M.G.C., Quagrainie, K.K. and Portella, M.C., 2022. Economic comparison between conventional aquaponics and FLOCponics systems. *Aquaculture*, 552, p. 737987.

Quagrainie, K.K., Flores, R.M.V.F., Kim, H. and McClain, V., 2017. Economic analysis of aquaponics and hydroponics production in the U.S. Midwest. *Journal of Applied Aquaculture*, 30(1), pp. 1-14.

Rahim, K.A.A., Esa, Y. and Arshad, A., 2013. The influence of alien fish species on native fish community structure in Malaysian waters. *Kuroshio Science*, 7(1), pp. 81-93.

Rahmat, S.R., Khan, H.H., Badaruddin, R.F.R., Mohamad, M.F. and Samsurijan, M.S., 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*, 27(3), pp. 329-338.

Rahmati, M., Hassan, M. and Abdi, R., 2022. Histomorphometric analysis of skin and stress indices of Nile tilapia (*Oreochromis niloticus*) exposed to different concentrations of ammonia. *Iranian Journal of Veterinary Medicine*, 16(3), pp. 288-297.

Rakocy, J.E., Shultz, R.C., Bailey, D.S. and Thoman, E.S., 2004. Aquaponic production of tilapia and basil: Comparing a batch and staggered cropping system. *Acta Horticulturae*, 648, pp. 63-69.

Rizal, A., Dhahiyat, Y., Zahidah, Andriani, Y., Handaka, A.A. and 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*, 137, p. 012098.

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

Santanumurti, M.B., Sidik, J., Putri, B. and Hudaidah, S., 2022. Effects of *Moina* sp. [Straus, 1820] adding of snail flour to increase the larvae performance of jelawat fish (*Leptobarbus hoevenii* [Bleeker, 1851]. *IOP Conference Series: Earth and Environmental Science,* 1036, p. 012116.

Saufie, S., Estim, A., Shaleh, S.R.M. and 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*, 18(3), e0611.

Savidov, N. and Brooks, A., 2004. *Evaluation and Development of Aquaponics Production and Product Market Capabilities in Alberta*. Crop Diversification Centre South: Alberta.

Schober, P., Boer, C. and Schwarte, L.A., 2018. Correlation coefficients: appropriate use and interpretation. *Anesthesia & Analgesia*, 126(5), pp. 1763-1768.

Setiadi, E., Widyastuti, Y.R. and Prihadi, T.H., 2018. Water quality, survival, and growth of red tilapia, *Oreochromis niloticus* cultured in aquaponics system. *E3S Web of Conferences*, 47, 02006.

Shao, X., Wu, P., Jiang, W., Liu, Y., Kuang, S., Tang, L. and Zhou, X., 2020. Growth performance, digestive and absorptive capacity of on-growing grass carp (*Ctenopharyngodon idella*) fed with graded level of dietary fiber from soybean hulls. *Aquaculture Nutrition*, 27(1), pp. 198-216

Shete, A.P., Verma, A.K., Chadha, N.K., Prakash, C. and Chandrakant, M.H., 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*, 29(2), pp. 323-329.

Short, G., Yue, C., Anderson, N., Russell, C. and Phelps, N., 2017. Consumer perceptions of aquaponic systems. *HortTechnology*, 27, pp. 358-366.

Solaymani, S. and Kari, F., 2014. Poverty evaluation in Malaysian fishery community. *Ocean & Coastal Management*, 95, pp. 165-175.

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

Specht, K., Weith, T., Swoboda, K. and Siebert, R., 2016. Socially acceptable urban agriculture businesses. Agronomy for Sustainable Development, 36, pp. 1-14

Suárez-Cáceres, G.P., Fernández-Cabanás, V.M., Lobillo-Eguíbar, J. and Perez-Urrestarazu, L., 2021. Consumers' knowledge attitudes and willingness to pay for aquaponic products in Spain and Latin America. *International Journal of Gastronomy and Food Science*, 24, 100350.

Sulaiman, M.A., Yusoff, F.M., Kamarudin, M.S., Nurul Amin, S.M. and Kawata, Y., 2022. Fruit wastes improved the growth and health of hybrid red tilapia *Oreochromis* sp. and Malaysian mahseer, *Tor tambroides* (Bleeker, 1854). *Aquaculture Reports*, 24, p. 101177.

Tamin, M., Haruun, A., Estim, A., Saufie, S. and Obong, S., 2015. Consumer acceptance towards aquaponics products. *IOSR Journal of Business and Management*. 17(8), pp. 49-64.

Tawaha, A.R., Wahab, P.E.M., Jaafar, H., Zuan, A.T.K. and Hassan, M.Z., 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*, 22(1), pp. 8-19.

Tokunaga, K., Tamaru, C., Ako, H. and Leung, P., 2015. Economics of small-scale commercial aquaponics in Hawaii. *Journal of the World Aquaculture Society*, 46(1), pp. 20-31.

Troell, M., Costa-Pierce, B., Stead, S., Cottrell, R.S., Brugere, C., Farmery, A.K., Little, D.C., Strand, A., Pullin, R., Soto, D., Beveridge, M., Salie, K., Dresdner, J., Moraes-Valenti, P., Blanchard, J., James, P., Yossa, R., Allison, E., Devaney, C. and Barg, U., 2023. Perspectives on aquaculture's contribution to the Sustainable Development Goals for improved human and planetary health. *Journal of the World Aquaculture Society*, 54, pp. 251-342.

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

Villarroel, M., Junge, R., Komives, T., K¨onig, B., Plaza, I., Bittsanszky, A. and Joly, A., 2016. Survey of aquaponics in Europe. *Water*, 8(10), 468.

Villarroel, M., Lama, G.C.M., Escobar-Álvarez, R. and Moratiel, R., 2022. Fish welfare in urban aquaponics: effects of fertilizer for lettuce (*Lactuca sativa* L.) on some physiological stress indicators in Nile tilapia (*Oreochromis niloticus* L.). *Water*, 14, p. 935.

Waiho, K., Fazhan, H., Ishak, S.D., Kasan, N.A., Liew, H.J., Norainy, M.H. and Ikhwanuddin, M., 2020. Potential impacts of COVID-19 on the aquaculture sector of Malaysia and its coping strategies. *Aquaculture Reports*, 18, 100450.

Walton, S. E., Gan, H. M., Raghavan, R., Pinder, A. C. and Ahmad, A., 2016. Disentangling the taxonomy of the Mahseers (*Tor* spp.) of Malaysia: An integrated approach using morphology, genetics and historical records. *Reviews in Fisheries Science & Aquaculture*, 25(3), pp. 171-183.

Wang, S.X., Zhang, J.Y., Du, X.K., Liu, D.J., Liu, L.X. and Shen, X.H., 2022. Comparative analysis of the intestinal microbiota in goldfish and crucian carps between different aquaponics and traditional farming. *Aquaculture Reports*, 25, p. 101240.

Wang, X.J., Zhang, X.M. and Huang, G.Q., 2006. Compensatory growth of rockfish (*Sebastes schlegelii*) following low temperature stress. *Journal of Fishery Sciences of China*, 13, pp. 566-572.

Xu, S., Chu, C., Zhang, Y., Ye, D., Wang, Y. and Ju, M., 2018. Entangled stakeholder roles and perceptions of sustainable consumption: An evaluation of sustainable consumption practices in Tianjin, China. *Journal of Environmental Management*, 223, pp. 841-848.

Yang, T. and Kim, H.J., 2020. Characterizing nutrient composition and accumulation in tomato-, basil-, and lettuce-based aquaponic and hydroponic systems. *Water*, 12(5), p. 1259.

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

Yildiz, Y.H., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D. and Parisi, G., 2017. Fish welfare in aquaponic systems: its relation to water quality with an emphasis on feed and faeces – a review. *Water*, 13, p. 9.

Young, N., Brattland, C., Digiovanni, C., Hersoug, B., Johnsen, J.P., Karlsen, K.M., Kvalvik, I., Olofsson, E., Simonsen, K., Solås, A. and Thorarensen, H., 2019. Limitations to growth: Social-ecological challenges to aquaculture development in five wealthy nations. *Marine Policy*, 104, pp. 216-224.

Zhong, L., Song, C., Chen, X., Deng, W., Xiao, Y., Wang, M., Qin, Q., Luan, S., Kong, J. and Bian, W., 2016. Channel catfish in China: historical aspects, current status, and problems. *Aquaculture*, 465, pp. 367-373.

Zugravu, A., Rahoveanu, M., Adrian, T.R., Khalel, M.S. and Ibrahim, M.A.R., 2016. The perception of aquaponics products in Romania. *Proceedings of the International Conference "Risk in Contemporary Economy"*. ISSN-L (pp. 2067-0532).

Appendices

Appendix A

Section 1: Demographic information on farm owner

Gender
Jantina
性别

- Male, Lelaki, 男
- Female, Perempuan, 女

Age
Umur
年龄

≤ 19
20-29
30-39
40-49
50-59
60- 69
≥70

Educational Level
Tahap Pendidikan
受教育程度

- No formal education, tidak menerima pendidikan formal, 没有受过正规教育
- UPSR, 小六鉴定考试
- PMR, 中三评估
- SPM, 马来西亚教育证书
- STPM, or the equivalent qualification, atau kelayakan yang setaraf, 马来西亚高等教育证书，或同等资格
- Diploma, 文凭
- Pre-university or foundation, 大学预科或基础班
- Bachelor Degree, 学士
- Master Degree, 硕士
- Doctor of Philosophy, 博士
- Others, lain-lain, 其他 ____________________

State
Negeri
州

- Perlis，玻璃市
- Kedah，吉打
- Penang，槟城
- Perak，霹雳
- Kelantan，吉兰丹
- Terengganu，登嘉楼
- Pahang，彭亨
- Selangor，雪兰莪
- Negeri Sembilan，森美兰
- Melaka，马六甲
- Johor，柔佛
- Sarawak，砂拉越
- Sabah，沙巴

<u>Section 2: General information about the farm</u>

Farm Ownership, Pemilikan Ladang, 农场拥有权

Sole ownership, pemilikan tunggal, 个人拥有权

Family, keluarga, 家族

Community, komuniti, 社区

Corporation or company, syarikat, 公司

Others, lain-lain, 其他 ____________________

Start date (year) of the aquaponics farm operation
Tarikh mula (tahun) ladang akuaponik operasi
鱼菜共生农场开始营业的日期（年份）

Does the farm have any organic certification?
Adakah ladang tersebut memiliki sijil organik?
请问农场是否持有任何有机认证？

Farm Size (ha)
Saiz Ladang (ha)
农场的面积 （公顷）

Farm Location (Urban area or non-urban area) (Indoor, greenhouse or rooftop)
Lokasi ladang (Kawasan bandar atau bukan bandar) (dalaman, rumah tanaman atau atas bumbung)
农场的所在地 （市区或非市区）（室内、温室或屋顶）

Section 3: Financial input and output of the farm

Initial aquaponics farm capital, RM
Pelaburan modal permulaan di ladang akuaponik (RM)
农场的初始资本投入 （零吉）

Annual expenses since the last five years (RM), including electricity and water, storage and packaging, transportation, labor cost, fertilizers and fish feeds – 2017, 2018, 2019, 2020, 2021
Perbelanjaan tahunan ladang akuaponik sejak lima tahun lepas (RM), termasuk elektrik dan air, penyimpanan dan pembungkusan, pengangkutan, gaji pekerja, baja dan makanan ikan
农场的年开销自过去五年以来（零吉），包括水电费，收纳与包装，运输，员工费，肥料及鱼料

2019:	
2020:	
2021:	

Annual crop yield since the last five years (RM, kg) – 2017, 2018, 2019, 2020, 2021
Jumlah pengeluaran tumbuhan tahunan sejak lima tahun yang lepas (RM)
自过去五年以来农作物的年产量 （零吉）

2017:	
2018:	
2019:	
2020:	
2021:	

Annual fish yield since the last five years (RM, kg) – 2017, 2018, 2019, 2020, 2021
Jumlah pengeluaran ikan tahunan sejak lima tahun yang lepas (- <RM100k

2017:	
2018:	
2019:	
2020:	
2021:	

Selling markets of aquaponics' products (e.g. nearby wet market, supermarket, franchise store)
Pasaran jualan bagi produk akuaponik (cth. pasar basah berdekatan, pasar raya, kedai francais)
鱼菜共生农产品的销售市场 （例：附近的湿货市场，超级市场，连锁店）

Section 4: Crop, fish and aquaponics system

Type of crop species planted in the aquaponics system, their amount and the reason why they are chosen
Spesies tanaman yang ditanam pada system akuaponik, jumlahnya dan sebab pilihan tumbuhan spesies tersebut
种植于鱼菜共生系统中的农作物种类，数量以及其中的原因

Crop species	Amount	Reason

Species tanaman 农作物种类	Jumlah 数量	Sebab 原因

Type of hydroponic that applied on the aquaponics system, and the reason (e.g. media bed, deep water culture, nutrient film technique, vertical tower, wicking bed, dutch bucket or others)
Jenis hidroponik yang yang digunakan pada sistem akuaponik, dan sebabnya
应用于鱼菜共生系统的水耕法，以及其中的原因

Type of hydroponic system Jeniis hidroponik system 水耕法的类别	Reason Sebab 原因

Fertilizer that applied to the aquaponics system
Baja yang digunakan pada sistem akuaponik
应用于鱼菜共生系统的肥料

Cultured fish species in the aquaponics system, their amount and the reason why they are chosen
Spesies ikan yang diternak dalam sistem akuaponik, jumlahnya dan sebab pilihan ikan spesies tersebut
饲养于鱼菜共生系统的鱼种， 数量以及其中的原因

Fish species Species ikan 鱼的种类	Amount Jumlah 数量	Reason Sebab 原因

Fish stocking density in the aquaponics system (fish m^{-3})
Kepadatan stok ikan pada system akuaponik (seekor m^{-3})
鱼菜共生系统里，鱼的放养密度 （尾 米$^{-3}$）

Fish feed type and feeding amount in a day (g day^{-1}), e.g. pellet, live feed or aquatic plants
Jenis makanan ikan dan jumlahnya dalam satu hari (g $hari^{-1}$)
鱼饲料的种类及一天的喂食量 （克 日$^{-1}$）

Fish feed Jenis makanan ikan 鱼饲料的种类	Daily feeding amount Jumlah makanan sehari 一天的喂食量

Fish and plant ratio, e.g. 10 fish: 1 lettuce.
Nisbah ikan dan tanaman, cth. 10 ikan: 1 bak choy.
鱼与菜的比例, 列：10 鱼：1 白菜

Type of combination between fish species and crop/plant (e.g. tilapia with lettuce)
Jenis gabungan antara spesies ikan dan tanaman (cth. tilapia dengan selada)
鱼类与农作物的组合类型 （例：罗非鱼与生菜）

Section 5: Challenges
Challenges facing during farm operation
Cabaran yang dihadapi semasa ladang operasi
农场经营过程中所面对的挑战

- Financial risks, risiko kewangan, 财务风险
- Marketing, pemasaran, 市场营销
- Nutrient balance, keseimbangan nutrien, 营养平衡
- pH stabilization, kestabilan pH, pH 稳定性
- Plant pests and diseases, perosak dan penyakit tumbuhan, 植物疾病及虫害
- Fish pests and diseases, perosak dan penyakit ikan, 鱼类疾病及虫害
- Others, lain lain, 其他

Appendix B

<u>Demographic Information, Maklumat demografi, 人口统计</u>

Gender, Jantina, 性别

- Male, Lelaki, 男
- Female, Perempuan, 女

Ethnicity, bangsa, 种族

- Malay
- Chinese
- Indian
- Others, lain-lain, 其他 ____________________

Age, Umur, 年龄

- ≤ 19
- 20-29
- 30-39
- 40-49
- 50-59
- 60- 69
- ≥70

Education level, tahap pendidikan, 受教育水平

- No formal education, tidak menerima pendidikan formal, 没有受过正规教育
- UPSR, 小六鉴定考试
- PMR, 中三评估
- SPM, 马来西亚教育证书
- STPM, or the equivalent qualification, atau kelayakan yang setaraf, 马来西亚高等教育证书，或同等资格
- Diploma, 文凭
- Pre-university or foundation, 大学预科或基础班
- Bachelor Degree, 学士
- Master Degree, 硕士
- Doctor of Philosophy, 博士
- Others, lain-lain, 其他 ______________________

Employment Status, status pekerjaan, 就业状况

Student, pelajar, 学生

Employed with wage, bekerja dengan gaji, 有薪工作

Self-employed, bekerja sendiri, 自雇工作
Unemployed, tidak bekerja, 无工作
Retired, bersara, 退休
Others, lain-lain, 其他 ____________________

Income status, Status pendapatan, 收入状况
<RM 4849 (B40)
RM 4850 – RM 10959 (M40)
>RM 10960 (T20)

Which state are you from? Negeri, 州属
Perlis，玻璃市
Kedah，吉打
Penang，槟城
Perak，霹雳
Kelantan，吉兰丹
Terengganu，登嘉楼
Pahang，彭亨
Selangor，雪兰莪
Negeri Sembilan，森美兰
Melaka，马六甲
Johor，柔佛
Sarawak，砂拉越
Sabah，沙巴

Aquaponics is an agricultural system that integrates aquaculture with hydroponic. It grows aquatic organisms together with plant crops in a farming system, creating a symbiotic environment.
Akuaponik ialah sistem pertanian yang mengintegrasikan akuakultur dengan pertanian hidroponik. Organisma akuatik dan tanaman akan diternak bersama dalam sistem ini dan mewujudkan persekitaran simbiotik.
鱼菜共生是一个结合水产养殖与水耕种植的农业系统。这套系统将水生生物与农作物一起养殖，从而创造出一个共生的环境。

Consumer’s experience and perception on aquaponics and its products
Pengalaman dan persepsi pengguna terhadap akuaponik dan produknya
消费者对鱼菜共生及其产品的体验和认知

Do you have any experience on practising aquaponics?
Adakah anda mempunyai pengalaman mengoperasi sistem akuaponik?
您有经营鱼菜共生系统的经验吗?
- Yes
- No

Do you think that the crops and fishes produced by aquaponics are organic products?

Adakah anda berpendapat bahawa tanaman dan ikan yang dihasilkan dengan akuaponik ialah produk organik?
您认为鱼菜共生所生产的鱼和农作物是有机产品吗？

- Yes
- No

Do you think that aquaponics will produce higher product's (crops and fishes) quality than the conventional/soil-based farming?
Adakah anda berpendapat bahawa akuaponik akan menghasilkan produk (tanaman dan ikan) yang lebih berkualiti daripada pertanian konvensional/tanah?
您认为鱼菜共生可生产比传统/土耕农业更高质量的农产品（农作物和鱼）吗？

- Yes
- No

Do you have any experience purchasing aquaponics' products (crops and fishes)?
Pernahkah anda membeli produk akuaponik (tanaman dan ikan)?
您曾经购买鱼菜共生所生产的农产品（农作物和鱼）吗？

- Yes
- No

Are aquaponics produce (crops and fishes) easily accessible near your place?
Adakah anda boleh membeli produk akuaponik (tanaman dan ikan) dengan mudah di pasaran sekitar anda?
您是否可以轻松的在您附近的市场购买到鱼菜共生所生产的农产品（农作物和鱼）？

- Yes
- No

Do you prefer to purchase aquaponics products instead of conventional farm's products (crops and fishes)?
Adakah anda lebih suka membeli produk akuaponik berbanding dengan produk ladang konvensional (tanaman dan ikan)?
您是否更倾向于购买鱼菜共生的农产品而不是传统农业所生产的农产品（农作物和鱼）？

- Yes
- No

Are you willing to pay more for aquaponics products, rather than the conventional farm's products (crops and fishes)?
Adakah anda sanggup membayar lebih untuk produk akuaponik daripada produk ladang konvensional (tanaman dan ikan)?
您是否愿意为鱼菜共生的农产品支付比传统农产品（农作物和鱼）更多的费用？

- Yes
- NO

1. Native freshwater fish – Freshwater fish species that are locally found in Malaysia, such as Malaysian Masheer (named as Empurau in Sarawak, *Tor* sp..), Sultan Fish (*Jelawat*, *Leptobarbus hoevenii*), Silver catfish (*Ikan Patin*, *Pangasius* sp..), Crossbanded Barb (*Tengalan*, *Puntioplites bulu*), Hampala Barb (*Hampala macrolepidota*) and Marble Goby (*Oxyeleotris marmorata*).

Ikan asli air tawar – Species ikan air tawar yang terdapat secara tempatan di Malaysia, seperti Keleh (dinamakan sebagai empurau di Sarawak), ikan Sultan (ikan jelawat), patin, tengalan, sebarau dan ketutu.

原生淡水鱼种 – 马来西亚本地原有的淡水鱼种, 例如吉罗鱼 (砂拉越称为"忘不了") 、 苏丹鱼、巴丁鱼、 "丁加兰" 、 "水马骝" 和顺壳鱼。

2. Invasive freshwater fish – Freshwater fish species that are introduced into Malaysia, such as tilapia (*Oreochromis* spp.), grass carp, jade perch and barramundi.

Ikan invasif air tawar – Spesies ikan air tawar yang diperkenalkan ke Malaysia dari luar negara, seperti tilapia, ikan karp rumput, jade perch dan siakap air tawar.

外来入侵的淡水鱼种 – 国外引入马来西亚的淡水鱼种，例如罗非鱼、草鱼, 宝石鲈和金目鲈。

<u>Consumer's perspective of native species cultured using aquaponics system</u>
<u>Perspektif pengguna terhadap spesies asli yang dikultur menggunakan sistem akuaponik</u>
<u>消费者对使用鱼菜共生系统培养原生鱼种的看法</u>

Do you think farmers can culture native fish species using aquaponics system, including two of the most expensive freshwater fish in Malaysia, *Tor tambroides* (kelah or empurau) and *Leptobarbus hoevenii* (jelawat or Sultan fish)?
Pada pendapat anda, bolehkah penternak menternak spesies ikan asli menggunakan sistem akuaponik, termasuk dua daripada ikan air tawar yang paling mahal di Malaysia, *Tor tambroides* (kelah atau empurau) dan *Leptobarbus hoevenii* (jelawat atau ikan Sultan)?
您认为农民可以在马来西亚使用鱼菜系统养殖本地原生鱼种, 包括最昂贵的两种淡水鱼，吉罗鱼 ("忘不了") 和苏丹鱼吗?

- Yes
- No
- Not sure

Would you purchase the native fish species farmed in aquaponics, rather than those harvested from aquaculture or wild-caught?
Adakah anda akan membeli spesies ikan asli yang diternak dalam akuaponik, bukannya yang dihasil daripada akuakultur atau tangkapan liar?
您会购买鱼菜共生系统中养殖的原生鱼种，而不是水产养殖或在野外捕获的原生鱼种吗?

- Yes
- No

Are you willing to pay more for the native fish species grown in aquaponics, rather than those harvest from aquaculture or wild-caught?
Adakah anda sanggup membayar lebih untuk spesies ikan asli yang dikultur dalam akuaponik, bukanya yang dihasil daripada akuakultur atau tangkapan liar?
您是否愿意支付更多的费用来购买鱼菜共是生系统中养殖的原生鱼种，而不是水产养殖或在野外捕获的原生鱼种吗?

- Yes
- No