DESIGN AND INSTALLATION OF A MINI AQUAPONIC SYSTEM

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A MINI AQUAPONIC SYSTEM

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering

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DECLARATION

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

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DESIGN AND INSTALLATION OF A MINI AQUAPONIC SYSTEM"** was prepared by **CHOONG ZI YEW** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Chemical Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Aquaponics is one sort of urban agriculture that integrates the separated aquaculture and hydroponic system into one whole system. As the population increases every year, aquaponics can help to generate various edible foods to prevent food scarcity. However, implementing an aquaponic system can be complicated because it involves integrated design concepts and knowledge related to aquatic life and crops. The system also necessitates well maintenance, including the water quality parameters, fish, and plant care. Hence, the knowledge and experience in handling an aquaponic system will define the successfulness of the system. The study aimed to develop a complete operation of a mini aquaponic system with appropriate design and monitoring. This study reviewed the design and operational aspects such as the types of aquaponics, fish aspects, plant aspects, and water quality parameters. A mini aquaponic system with Deep Water Culture concept were successfully set up at the school laboratory. Two Oranda goldfish and four parsleys were introduced to the mini aquaponic system. System monitoring and operation were conducted for four weeks. The water quality parameters, such as water temperature, pH value, dissolved oxygen, ammonia level, nitrite level, nitrate level, general hardness, and carbonate hardness, were recorded at least twice a week during the 4 weeks. The results indicated that the water quality was maintained at a suitable range for the goldfish and parsleys, except for the low water hardness. Besides, the parsleys had assimilated some nutrients for the root's development. However, the nutrient deficiency symptoms on parsleys during the late stage of system operation indicates the system is lack of phosphorus and potassium nutrients. Overall, the performance of the aquaponic system was moderate as nutrients supplement and water hardness adjustment are required.

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$Ca(OH)_2$	calcium hydroxide
H_3PO_4	phosphoric acid
KOH	potassium hydroxide
KH	Carbonate Hardness
DWC	Deep Water Culture
DO	Dissolved Oxygen
GH	General Hardness
NFT	Nutrient Film Technique
ppm	parts per million
RAS	Recirculating Aquaculture System
TAN	Total Ammonia Nitrogen

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Malaysia can be considered as a country that is highly involved in urban development and has significant population growth. The Department of Statistics Malaysia Official Portal (2020) stated that the estimated population of Malaysia in 2020 is 32.7 million. Comparing to the reported population in 2010 which is around 28.6 million, it showed a notable growth of population in the 10 years. It is expected that the urban population will reach 60 - 85 % in 2025 (Islam and Siwar, 2012). With the continuous annual growth of population and urbanization, food security especially in urban areas become one of the crucial issues that should be emphasized by the government (Paul, 2013). Thus, the introduction of urban agriculture in Malaysia can be one of the solutions to resolve the possible problems raised by urbanization, population growth, and food insecurity.

The movement and development of urban agriculture are widespread across the globe including Malaysia. Although the implementation of urban agriculture in Malaysia is low compared to other countries, Malaysian Government considered this activity a significant movement towards a successful nature urban habitant (Othman et al., 2018). Urban agriculture is defined as a combination of cultivating, processing, and food distributing in urban areas (Bailkey and Nasr, 2000). The application of urban agriculture can be implemented in every corner of the metropolitan area in various ways. Figure 1.1 shows the common types of urban agriculture such as rooftop farming, vertical farming, and community farming. Each farming designs applies similar practices and purposes but with different characteristics on the space organization (Norul Hafizah, Ramzi, and Tukiman, 2017).

Community Farming Rooftop Farming Vertical Farming

Figure 1.1: Types of Urban Agriculture (Norul Hafizah, Ramzi, and Tukiman, 2017).

Urban agriculture potentially benefits the community in terms of four main categories which are health and nutrient, environmental, social improvement, and economic (Norul Hafizah, Ramzi, and Tukiman, 2017). The practice of urban agriculture increases the accessibility to food sources such as meat, vegetable, and fruits. The practice of urban agriculture is essential as it helps to prevent food scarcity in the world. Besides, the growth of the population directly increases the demand for job opportunities in society. In this case, large scale commercial urban agriculture can generate more job opportunities for the citizens as it requires more labour forces (Rezai et al., 2014). With more exploration in urban agriculture, society will have more opportunities to involve in green education which helps to improve environmental stewardship.

An aquaponic system is one sort of urban agriculture that integrates the separated aquaculture and hydroponic system into one whole system. The main objective of an aquaponic system is to use nutrients rich water which consists of fish feeds and excretion to grow the crops. The crops absorb the nutrients in the water and act as a filter to clean up the water for the fish (Junge and Antenen, 2020). The aquaculture system constantly requires removing the nutrients rich water in the fish tank and replaced it with clean water to ensure the fishes grow in a healthy environment. On the other hand, the hydroponics system requires expensive nutrients to grow the crops leading to additional expenses. Implementing an aquaponic system can eliminate the negative aspects of both individual systems and retains the positive elements, which provide an efficient way for the production of fish and crops (Backyard Aquaponics, 2011).

However, an aquaponic system requires regular maintenance and a well-designed plan in order to ensure proper operation. Many researchers studied various factors that are critical to the aquaponic system including water quality parameters, pest control, and nutrients balance. The application of aquaponic system involves many specific system measurements and technologies which requires in-depth theoretical studies (Goddek et al., 2015). Poor management on each aspect may lead to the failure of the operation of aquaponic. Thus, the knowledge of an aquaponics system's design parameters and operation aspects are essential to operate a productive aquaponic system.

1.2 Importance of the Study

The present study may provide some significant impact on the application of an aquaponic system. The study included information about the important aspects and parameters for conducting a successful aquaponic system. Besides, the study illustrated the methodology of design and installation for a mini aquaponic system which can supply some guidelines for the start-up of a mini aquaponic system. It can encourage more people to acknowledge and develop an aquaponic system as it is an environmentally friendly practice.

1.3 Problem Statement

As the population increases every year, people are required to explore more sustainable pathways to produce various edible foods. The development of urban agriculture in Malaysia is relatively slow compared to other countries due to the lack of adequate land for urban agriculture activities (Jalil, 2017). An aquaponic system not only provides an efficient way to produce large amounts of food sources, but it also requires small space for operation compared to conventional agriculture (Toal, Clagget, and Goh, 2017).

However, an aquaponic system can be very complex because it involves integrative design concepts and knowledge related to aquatic life and crops. Also, the system requires careful maintenance in terms of various operation parameters, especially the water quality control parameters. Design flaws and inadequate care of the aquaponic system highly affect the growth of the fish and crops. Thus, the complexity of operation for an aquaponic system becomes a barrier to introduce aquaponics to society.

1.4 Aim and Objectives

This study aims to develop a complete operation of a mini aquaponic system with appropriate design and monitoring. The specific objectives to accomplish the aim are as shown:

i. To review the design parameters and operational aspects of an aquaponic system.
ii. To design a mini aquaponic system for goldfish and parsley.
iii. To evaluate the performance of the designed aquaponic system.

1.5 Scope and Limitation of the Study

1.5.1 Scope of the Study

The scope of this study is focusing on the implementation of an aquaponic system. The study is applicable to supply a basic understanding of aquaponics and the important operation aspects. The information for aquaponics setup is mainly collected from secondary data such as e-books and articles throughout the research. The study provides a demonstration of the operation of mini aquaponics for four weeks.

1.5.2 Limitation of Study

The study is restricted to a mini-sized aquaponics with a 50-gallon aquarium tank. The aquaponics design is created by using some budget materials and equipment to overcome the limitation on cost. The equipment for larger aquaponics design such as mechanical pump, high performance filter, and sensor were not implemented in this study due to the space and cost limitation. Thus, the performance of the mini aquaponic system could be affected.

1.6 Contribution of the Study

The study focused on the operation of a mini aquaponic system. The information provided in the study can contribute essential knowledge about aquaponics to society. Further improvement and modification can be provided in future according to the study outcomes.

1.7 Outline of the Report

Chapter 1 provides a general introduction to aquaponics in urban agriculture. It includes the importance of the study, problem statement, aim and objectives, scope and limitation of the study and the contribution of the study. In Chapter 2, a further detailed introduction to aquaponics is provided. The important design and operational aspects such as types of aquaponics, fish aspect, plant aspect, and water quality parameters are reviewed. Chapter 3 demonstrates the methodology and work plan of the mini aquaponic system, and Chapter 4 presents the results and outcomes of the study. Lastly, the conclusion and recommendations for future work are included in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Aquaponics

Aquaponics is described as a method for growing fish and crops in a well-constructed ecosystem that involves microorganisms to convert fish excretion and waste to plant nutrients (Bernstein, 2011). An aquaponic system integrates aquaculture and hydroponics into one closed-loop system that can solve some problems that generated by the individual technologies.

2.1.1 Aquaculture

The term aquaculture appertains to the growing of fish and other marine creatures in a controlled aquatic habitat that is suitable to the species. Aquaculture is one of the world’s most rapidly expanding food production methods, and it is performed for multi-purposes, including recreational, public, and commercial purposes (Martinez et al., 2019). The implementation of aquaculture can be varied in the different regions depending on the environment and climatic conditions. According to Figure 2.1, the world capture fishery production in the past decade is relatively static and has no significant increment leading to concern in protein sources production. However, with the aquaculture production almost tallying with the capture production in 2012, aquaculture plays an important role in the supply of fish for human meals (FAO, 2018). Besides, it has been more vital in recent decades due to overfishing and consequent reduction of the wild fish population. It may become much more critical in the future as the pressure from climate change will directly affect the wild fish stocks (Gibbens, 2019).

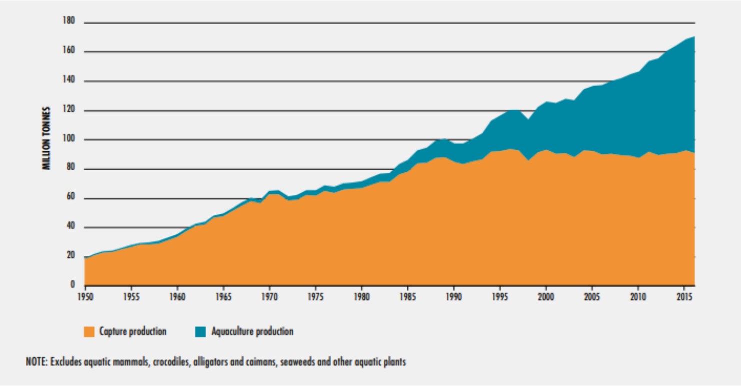

Figure 2.1: World Capture Fishery and Aquaculture Production (FAO, 2018).

The four main categories of aquaculture that are often implemented around the globe are recirculating aquaculture system (RAS), inland pond culture, open water system, and flow-through raceway. An aquaponic system can be known as a similar form or an extension of RAS. In a RAS, the water from the fish tank will constantly undergo the cleaning and filtering process for the fish reuse purpose (Somerville et al., 2014). Other open aquaculture systems such as flow-through and net-enclosures systems will discharge a large amount of nutrient-rich wastewater into the environment, potentially leading to eutrophication. RAS provides a more environmentally friendly and water-saving technique compared to other aquaculture systems as it requires a meagre amount of water usage and produces fewer wastewater flows. However, RAS has some drawbacks, including the potential risk of failure-prone technology and high operating expenses. The fish species are also limited to carnivores which call for a higher market price than herbivores species (Junge and Antenen, 2020). Figure 2.2 illustrates the operation of RAS.

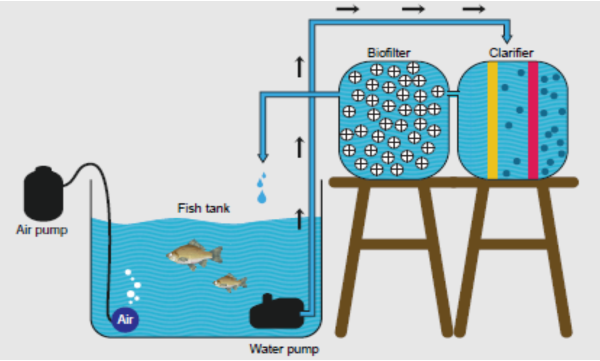

Figure 2.2: Operation of Recirculating Aquaculture System (Somerville et al., 2014).

2.1.2 Hydroponics

The terms hydroponics is the combination of two Greek words, ‘hydro’ and ‘ponos’, which means water and labour, respectively. In early 1930, Professor William Gericke coined hydroponics to describe the growing of plants with the roots submerged in the rich nutrients water (Sharma et al., 2018). Hydroponics is one term of soil-less culture that cultivates crops directly in an aqueous medium or soil-less medium, including leca, perlite, and gravel (Somerville et al., 2014). The nutritional solution is delivered to the crop’s roots through an active or passive method. An active method involves pumps to aerate the nutrient solution and transfer it to the crops, while the passive method does not require any pumps, mainly depending on gravity and flooding (Trees.com, 2021).

Hydroponics has successfully produced various edible vegetables and fruits, including tomato, lettuce, and cucumber (Cifuentes-Torres et al., 2021). In a hydroponic system, the crop’s roots constantly submerge in the medium with rich nutrients. The sufficient nutrients prevent the crops from consuming immense energy on the growth of extensive roots system and more focus on the up growth. Consequently, the crops cultivated in the hydroponics can mature up to 25 % faster than the same crops grown in soil. Besides, hydroponic systems utilise lesser water than typical soil systems despite the fact that hydroponic systems mainly rely on water to grow crops. In soil plantation, a large amount of water evaporates when passing through the soil, and only minor potion of water reaches the roots. In contrast, the crops in hydroponics readily absorb the water with less evaporation (Trees.com, 2021). The water in hydroponics is also constantly filtered and supplied back to the crops, ensuring a water recirculation rather than squandered (Vertical Roots, 2020). Thus, the hydroponic system uses 80%-90% less water than traditional soil cultivation (Trees.com, 2021).

Furthermore, the contactless between crops and soil can prevent soil-borne diseases. These diseases mainly result from pathogens that inoculate the crops through the soil medium (UC Davis Global Soil Health Portal, 2018). The substrates commonly used in hydroponics can be reused for another batch of crops by conducting some sterilization to eliminate the pathogen. Thus, the reuse of substrate matches the demands of intensive production (Somerville et al., 2014). In fact, hydroponics serves as a more productive and sustainable technique compared to ordinary agriculture due to its high production yield, low presence of soil-borne diseases, better water efficiency, and less fertiliser usage (Barbosa et al., 2015). However, there are also several limitations of hydroponics. The primary issue is that the system requires a high initial build-up cost and constantly relies on electricity for the operation, leading to high expenses. Hydroponics also involves complicated management, which requires knowledge of the proportion of nutrients and lighting, pest control, and nutritional difficulties. These issues also become the major restriction to aquaponics (Lee and Lee, 2015). Figure 2.3 demonstrates a simple hydroponic system.

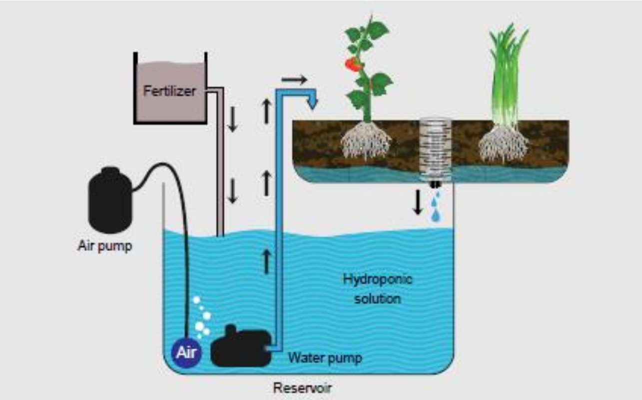

Figure 2.3: Simple Hydroponic System (Somerville et al., 2014).

2.1.3 Aquaponics

As mentioned in Section 1.1, aquaponics integrates both aquaculture and hydroponics into one system. The main goal is to eliminate some unsustainable factors of both individual technologies and reuse the nutrient-rich water that contains fish feed and excretion to grow crops. The wastes produced by the fish supply are vital nutrients for the plants, while the plants absorb the nutrients to enhance the water quality for the fish (Arroyo and Ines, 2018). In an aquaponic system, the water is cycled between the fish tank and the plant’s bed with filters and pumps. The mechanical filter acts as a separation media to remove the waste deposits before transferring to the plant’s bed in order to prevent the clogging effect in pumps. Biofilter offers a place for nitrifying bacteria to turn the ammonia excreted by the fish into nitrate, a more suitable form for plant intake. The process is known as nitrification (Somerville et al., 2014). Nevertheless, some small scale aquaponic systems may not have external biofilters. In this case, the bacteria will deposit on the available surface like the inert media or hydroponic compartment walls (Eck, Körner, and Jijakli, 2019).

The nitrification process is essential for aquaponics where the microorganism will convert the nitrogen sources into a usable source. Rafiee and Saad (2005) stated that the fish only uses up to 30 % of the nitrogen in the fish feed for metabolism and assimilation. The remainder is excreted from the fish grills in the form of ammonia and ammonium. 0.02 to 0.07 mg/L of ammonia-nitrogen concentration are sufficient to cause negative impacts on the fishes. Nitrification is separated into two steps in which ammonia and ammonium from fish excretion will be converted first to nitrite and subsequently to nitrate by aerobic chemosynthetic autotrophic bacteria. Bacteria will consume a high level of dissolved oxygen during the nitrification process (Eck, Körner, and Jijakli, 2019). If the system is correctly balanced, the nitrification process enables the fish, plants, and bacteria to burgeon symbiotically by working together for a healthy growth habitat (Somerville et al., 2014). Figure 2.4 illustrates the nitrogen flow in aquaponics.

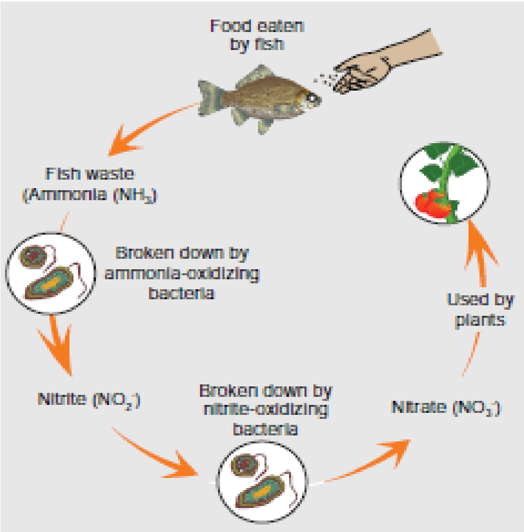

Figure 2.4: Nitrogen Flow in Aquaponics (Somerville et al., 2014).

One of the major benefits derived from aquaponics is it does not release the waste effluent to the environment like the aquaculture technique while at the same time it fulfils the high nutrients required by the plants. Consequently, inorganic fertilizers and related fertilization management expenditures are no longer necessary. Other advantages include low water consumption due to the close recirculating system and high yields production as it produces two types of agriculture products (fish and crops) using one nitrogen source. However, aquaponics involves a high start-up cost compared to conventional agriculture and requires knowledge of the complicated management, including the fish, plant and bacteria aspects, daily management, etc. (Somerville et al., 2014; Masabni and Sink, n.d.).

2.1.4 Brief History of Aquaponics

Although the implementation of modern aquaponics started a few decades ago, the concept of the combination of fish and plant cultivation has an ancient history (Hambrey, 2013). The earliest track of aquaponics goes back to the lowland Maya and Aztecs Indian generation, who grew crops on rafts on the surface of a lake. The Aztecs had formulated a system known as chinampas for their agricultural activities. Some consider this system as the first form of aquaponics (Bradley, 2014). As shown in Figure 2.5, Chinampas is a technique that relies on a network canal and stationary floating land to cultivate crops by using the nutrient-rich water that flows from the canals (Carrasco, 2001). The nutrient-rich water mainly came from the lakeside that contained uncountable freshwater fish. Famers in Asia countries such as China and Thailand also raised fish in paddy fields flooded with water. This traditional technique is still practised today due to the significant annual fish and rice production (Bradley, 2014).

Figure 2.5: Traditional Chinampas (Holloway, 2019).

In 1969, William McLarney, John Todd, and Nancy Jack Todd founded the New Alchemy Institute in Massachusetts, the United States, which conducts research and investigation on agriculture design, including aquaculture, bioshelter, and organic agriculture (Gordan, 2018). A prototype of a bio-shelter known as “Ark” is created to supply the basic needs of humans as a whole unit, including shelter, fish, and vegetables, to a family with four members. The design of the Ark included the concept of being solar-powered and self-sufficient that using the sun as power for the operation of an indoor ecosystem (Regenerative Design Group, 2021).

During the 1970s, researchers started to perform some studies on the possibility of using crops as a natural filter for fish-raising systems. Professor Doug Sanders and a student from North Carolina University, Mark McMurry, had developed the first closed-loop aquaponic system in the mid-1980s. The system is invented to grow vegetables with the effluent of fish water acting as the nutrient source. The sand used for the crops’ growing media acts as the biofilter of the system, and the water that passes through the sand media is recirculated back to the fish tank. The early invention of this system by Professor Doug Sanders and Mark McMurry underpinned the development of modern aquaponics (Southern and King, 2017).

2.2 Types of Aquaponics

There are several sorts of aquaponic system designs that can be found around the globe. The three primary aquaponic system designs are Nutrient Film Technique (NFT), Media Bed, and Deep Water Culture (DWC) (Goering, 2019). Although many other designs can be found, the majority of the aquaponic designs are iterations or combinations of the three fundamental aquaponics setups. The designs do not differ in the aquaculture part but in the method of cultivating crops (Martinez et al., 2019).

2.2.1 Nutrient Film Technique (NFT)

Nutrient Film Technique (NFT) as shown in Figure 2.6 is an irrigation technology based on hydroponics. The primary purpose of NFT is to supply a constant water film to the crops; hence it is named as ‘nutrient film’ (Martinez et al., 2019). In NFT, an extremely shallow stream of nutrient-rich water from the fish tank is passed through a horizontal PVC channel. These PVC pipes channel has unique holes for the crops to sit on it, and the roots hang in the flowing water. Thus, the roots are partially submerged into the water film to ensure the accessibility of nutrients and oxygen from the atmosphere (Junge and Antenen, 2020).

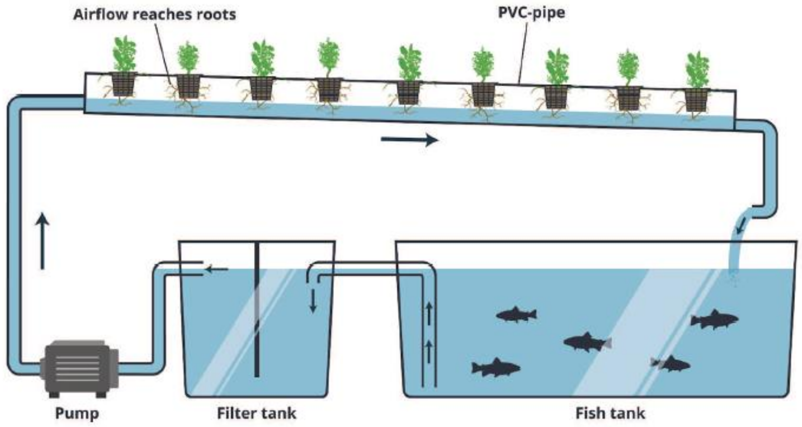

Figure 2.6: Nutrient Film Technique (Martinez et al., 2019).

Due to its space efficiency and low labour cost, the NFT system is widely implemented in the commercial market (Goering, 2019). The NFT approach with the low water volume in the pipe channel is reliable and easier to be monitored compared to other systems that utilise a high amount of water. The grow beds of NFT are also light and ideal for vertical aquaponic setups, making them suitable for compact areas (Walsworth, 2016). However, the NFT system is more suitable for specific crops, typically leafy green vegetables with small and easily growing water roots, such as lettuces and watercress (Walsworth, 2016). Larger crops with extensive roots systems, including potatoes, may block the channel, and the weight may not be supported in NFT design (Backyard Aquaponics, 2012a). Additionally, the NFT system requires biofilters and particle filters as it does not use any growing media (Walsworth, 2016). Table 2.1 summarises the advantages and disadvantages of NFT.

Table 2.1: Advantages and Disadvantages of NFT (Goering, 2019; Junge and Antenen, 2020).

Advantages	Disadvantages
▪ Space efficient ▪ Utilize less water ▪ Small sump tank required ▪ Constant supply of nutrients, water, and oxygen ▪ Easy for maintenance and cleaning	▪ Only suitable for crops with a small roots system ▪ Fluctuation of water temperature may occur ▪ Root's clogging susceptibility

2.2.2 Media Bed

Media bed technique as illustrated in Figure 2.7 is the simplest form of aquaponics that uses a container with rock medium or expanded clay to provide mechanical supports to the crops. The media also functions as a biofilter and mechanical filter to break down and trap wastes (Goering, 2019). Hence, no additional filter compartment is needed. In the media bed technique, the plant bed is constantly undergoing the flooding and draining process. The nutrient-rich water is pumped into the beds up to a certain level and is drained back to the fish tank by a bell siphon (Brooke, 2021a).

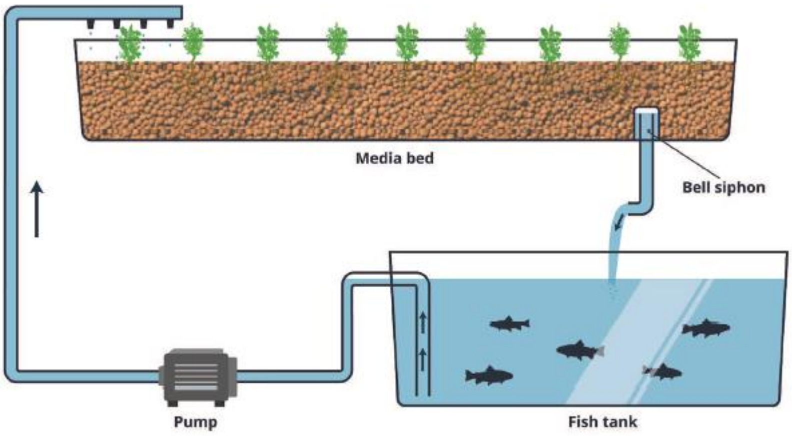

Figure 2.7: Media Bed Technique (Martinez et al., 2019).

A bell siphon is a simple and efficient mechanism used to manage the water flow in aquaponics without any human intervention (Castelo, 2021).

When the bell siphon is draining the water back to the fish tank, the pump will continue to transfer nutrient-rich water to the grow beds just that the water is removed faster than the pumping rate. Therefore, it is recommended to place the plant grow beds above the fish tank to increase the draining efficiency using gravity and siphon (Brooke, 2021a).

The media bed system is a famous design for a small scale aquaponic system since the system is comparatively inexpensive and appropriate for beginners due to its simple design (El-Essawy, Nasr, and Hani, 2019). Furthermore, the growing media provides support like the soil, allowing the system to grow crops with extensive roots, including tomato and cucumber (Goering, 2019). However, the system may not be space efficient with the horizontal arrangement and not be applicable for large scale as the media is costly and heavy (Martinez et al., 2019). Table 2.2 shows the advantages and disadvantages of the media bed technique

Table 2.2: Advantages and Disadvantages of the Media Bed Technique (Goering, 2019; Junge and Antenen, 2020).

Advantages	**Disadvantages**
▪ The media act as both mechanical and biofiltration ▪ Able to grow crops with extensive roots ▪ Simple and inexpensive design ▪ Suitable for small scale aquaponics	▪ High water evaporation due to larger exposure surfaces ▪ Large sump required ▪ Complex maintenance and cleaning ▪ Expensive and ineligible for large scale production

2.2.3 Deep Water Culture (DWC)

Deep Water Culture (DWC) can be known as floating raft system, is an idea of floating a styrofoam raft with crops on an approximately 30 cm depth of water. The raft contains special holes for the crop’s net pots, and the roots are suspended in nutrient-rich water (Junge and Antenen, 2020). The raft can be placed on top of the fish tank or in another compartment depending on the available space. More often, the raft is placed in another tank as the fish may consume the roots if the raft is placed on top of the fish tank (Korniichuk, 2021; Nelson and Pade, 2021). Filtration systems must be implemented into the system since it does not use any growing media. Figure 2.8 shows the Deep Water Culture.

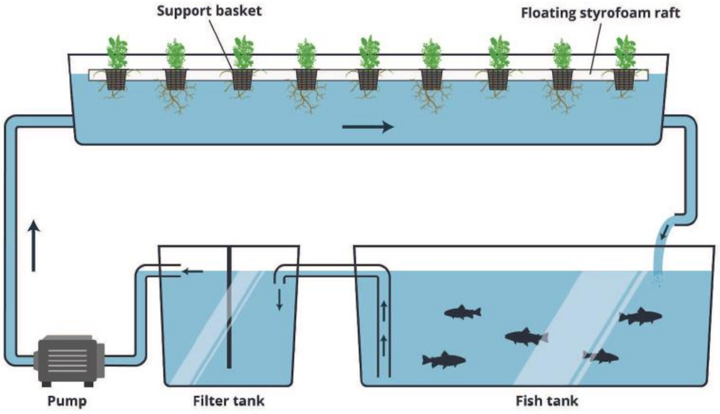

Figure 2.8: Deep Water Culture (Martinez et al., 2019).

The DWC is commonly used for the large commercial production of crops like basil and lettuce. It generates greater profits and allows larger margin error than the other two systems (Goering, 2019). The large volume of water in the raft compartment supplies a buffer for fish, decreasing stress and any water quality issues (Nelson and Pade, 2021). DWC is well suited in warmer countries due to its ability to withstand temperature swings. Therefore, temperature fluctuation in the system may be eliminated (Goering, 2019). The aeration system provided in the raft tank can enhance the water absorption by roots leading to better cell growth within the crops (Grant, 2020). However, the crop root fully immersed in water may suffer oxygen depletion when electricity outages as the aquaponic system highly depends on the aeration and pump devices for oxygen supplemental (Epic Gardening, 2021). Table 2.3 and depicts the advantages and disadvantages of DWC.

Table 2.3: Advantages and Disadvantages of Deep Water Culture (Goering, 2019; Junge and Antenen, 2020).

Advantages	Disadvantages
▪ Resist to temperature fluctuation ▪ Easy to clean and low maintenance needed ▪ High yield for commercial production ▪ Cost-effective	▪ Large space area required ▪ Addition of filtration and roots aeration system ▪ High usage of water

2.3 Fish Aspect

Fish are the heart and powerhouse of an aquaponic system. They supply essential nutrients for the plants and act as a protein source for us if it is an edible fish. Growing fish may seem intimidating to people without experience as it may involve complicated management. However, growing fish from fingerling size to edible size in an aquaponic system is straightforward compared to keeping fish in an aquarium if the basic principles are followed (Backyard Aquaponics, 2012b). In this section, several fish aspects are discussed, including the selection of fish, essential nutrients, and fish health and behaviour in aquaponics.

2.3.1 Fish Species

Many fish species have shown exceptional growth rates in the aquaponic systems (Somerville et al., 2014). The selection of fish in an aquaponic system highly depends on the surrounding climate and the available supplies. For instance, people living in cooler climates are looking forward to growing trout, while a tilapia is popular fish species for warmer areas (Backyard Aquaponics, 2012b). As there are cold and hot water fish species, it is important to consider the local climate and the willingness to cover the water temperature when choosing the fish for the aquaponic system (BTL Liners, 2019). Some of the most popular fish species for aquaponics are discussed in the following section.

2.3.1.1 Edible Species

Trout is a carnivorous cold water species under the salmon family. They are famous for aquaponic systems because of their excellent growth rates and food conversion ratios. Besides, trout have a high tolerance to water salinity and are suitable to be bred in freshwater. All trout species can be grown in the water temperature range of 10 – 18 °C. To be specific, trout grow best in 15 °C water temperature and above 21 °C are vulnerable to trout species as they may not efficiently utilise the dissolved oxygen present in the water. Compared to carp and tilapia, trout demand a higher protein diet from various feed options, which means more nitrogen in the total nutritional pool per unit of the provided fish feed. This phenomenon allows larger cultivable regions for green crops, while also keeping the balance of the aquaponics. However, trout require better management in water quality than carp and tilapia, particularly with the dissolved oxygen levels and ammonia concentration (Somerville et al., 2014). Trout are famous for commercial, even small scale aquaponics due to their rich in omega-3s, making them an excellent fish species for consumption (Walsworth, 2016).

Tilapia is one of the famous fish species for aquaponics as well as traditional aquaculture. They are ideal for small-medium scale aquaponics due to a variety of reasons. The tilapia species are easy to breed and have a high tolerance to stress, diseases, and water quality (Somerville et al., 2014). They are well-known for their strong survivability and do not require high levels dissolve oxygen; they are thus easy to be grown. Although tilapia can withstand a broad range of water conditions, the ideal water temperature range for optimum growth is 27 – 30 °C. They may perish when the water temperature falls below 10 °C (Brooke, 2021b). Therefore, tilapia is an excellent species to be grown in Malaysia due to the warm climate. Besides, tilapia have a high conversion rate with a diverse variety of suitable fish feeds. Certain fish require to be fed with high-protein diets that are costly to maintain a consistent development rate. As an omnivore species, Tilapia is suitable to be provided with fish feed that is partially replaced by plants or grains, resulting in a significant reduction in feed expenses compared to other species (BTL Liners, 2019). In an ideal condition, the tilapia can reach edible size (approximately 700g) in 6 – 9 months, which is the biggest reason for their popularity in commercial systems. However, tilapia may consume smaller fish, even their own young, during breeding. Separating the tilapia according to their size is essential to prevent this problem (Bernstein, 2011; Somerville et al., 2014).

Catfish is a robust type of fish that can easily adapt to the environment and withstand large changes in water temperature, pH value, and dissolved oxygen level. They also have high immunity to a wide range of fish diseases as well as parasites. Catfish may be stocked at larger densities due to the excellent physiology that provides high tolerance to rich ammonia and low dissolved oxygen concentration in water. Therefore, catfish are one of the easiest fish for novices to raise in aquaponics (Vergeer, 2019a). Similar to tilapia, catfish are warm-water fish species that grow best in warmer conditions. The preferred temperature range for catfish is 24 – 30 ℃. A temperature lower than 22 ℃ may affect their appetite and health, even causing fatality (Brooke, 2021b). In terms of waste management, catfish's solid excretion is less voluminous and easy to dissolve, providing better mineralization than tilapia species.

Consequently, the crops in aquaponics can obtain higher minerals from the fish tank water. Catfish are benthic species, which means they like to live at the bottom of the water body. As they are not spread widely across the tank, they may injure each other with their sharp spines because their bodies do not have scales for protection. It is suggested to breed catfish in a horizontal arrangement to increase the spreading rate along the bottom of the water body (Somerville et al., 2014).

2.3.1.2 Ornamental Species

If one does not interest in edible fish species as discussed, there are some ornamental fish for aquaponic gardening, including goldfish and koi. Both goldfish and koi are categorised under the carp family. Goldfish is an excellent decorative fish option as they are tough and easy to take care (Backyard Aquaponics, 2012b). They can live in a highly polluted water body and develop to astonishing size with little pellet feeds. Although the size of goldfish is small, they are experts at generating significant volumes of excrement, providing an excellent nutrient supplement to the aquaponics crops (BTL Liners, 2019; Farming Aquaponics, 2020a). Goldfish can survive in water temperatures ranging from 18 – 25 °C with a wide pH range of 6 – 8, making their characteristic as hardy as tilapia. It is important to note that there are single-tailed and twin-tailed goldfish. Since single-tailed goldfish are more aggressive than twin-tailed goldfish, it is not suitable to breed both sorts in a single tank as they may harm each other (Brooke, 2021b).

Koi is a common ornamental fish within the Asian region. They can be grown together with edible species if there is sufficient space and nutrients. Koi are bigger and hardier than their goldfish cousin, that possibly lives up to 30 years. One of the major benefits of breeding koi in an aquaponics system is they can tolerate to wide temperature range. They can grow in a water temperature range of 2 – 30 °C, ideally 15 – 25 °C (Brooke, 2021b). Thus, no additional heating or cooling equipment is required for growing koi. Besides, as a not picky eaters, Koi can consume natural substances such as algae and plant debris, requiring relatively low fish food. Their large intestines can finish many foods and generate more vital nutrients for the crops. This situation can reduce the feeding cost and boost the growth of crops. However, koi are not the cheapest fish species in terms of their buying cost. People usually invest in young koi and sell them to collectors when they are matured to generate greater profits (Ward, 2021).

2.3.2 Fish Nutrition

Appropriate fish nutrition is critical in aquaponics since the fish feed supplies vital nutrition to both fish and plants. Similar to humans, fish require a balanced and healthy diet to support their development. Without sufficient nourishment, fish will grow slower and even more susceptible to diseases that may affect their health (Vergeer, 2020). In the beginning stage of small scale aquaponics, commercially produced feeds are most recommended as they supply all essential nutrients for fish. A complete fish diet supplies five primary nutrients: protein, fats, carbohydrates, minerals as well as vitamins (Somerville et al., 2014). The nutritional portion of the fish feed varies depending on the fish species and life stages. It is important to provide a balanced dietary portion according to the condition. Fish raised in aquaponics may not forage on natural foods like aquatic plants and algae. Thus, a complete fish diet is essential for the fish (Craig, 2017).

Protein is the most critical component for the fish to build weight. Due to the protein being a pricey component in fish feed, an accurate determination of protein requirement for the grown species at their life stage is critical to cost management. For instance, tilapia, catfish, and trout require average protein levels up to 40 %, 32 %, and 45 %, respectively, in their grow-out stage. Carnivorous fish species like trout normally demand higher protein levels compared to omnivorous and herbivorous fish species to achieve optimum growth. Protein requirements by fish usually decrease with their age as younger fish require more protein for their body development and enzyme synthesis. Generally, protein is made up of a chain of amino acids. Fish bodies can synthesize some amino acids, but the ten essential amino acids can only be obtained from foods. Methionine and lysine are commonly the limiting essential amino acid and require to be supplemented with vegetable-based feeds. (Craig, 2017; Somerville et al., 2014).

Fats are a high-energy source to support the fish’s daily activities. Fish oil is a popular ingredient in commercial fish diets. It has nearly double the energy amount compared to protein and carbohydrate, and fats usually occupy 7 – 15 % of daily fish diets. The addition of fish oil in fish feed supplies the necessary omega-3 and omega-6 to the fish. These components can improve human cardiovascular health when consumed (Craig, 2017; Somerville et al., 2014).

Carbohydrates are the cheapest energy ingredient in fish diets. Starch is the most prevalent form of carbohydrate in fish feeds. The starch and sugar contents help to bind the feeds in a pellet form for easier consumption. Generally, the amount of carbohydrates is low in fish feeds as fish find it difficult to digest the carbohydrate substances (Junge and Antenen, 2020). For instance, normal mammals may get roughly 4 calories/gram of carbohydrate, but fish only get 1.6 calories from the same quantity (Craig, 2017). Although carbohydrates are usually low concentrated in fish feed, fish nutritionists try to include more carbs to replace the costly proteins content in fish diets. This strategy has a disadvantage that may convert a carnivorous species to be more herbivorous due to supplements of carbohydrates mainly from plants (Lazzarotto et al., 2018).

Both vitamins and minerals are important for fish health and development. Vitamins are organic compounds typically in two forms, water-soluble and fat-soluble. The fish requires vitamins A, B, C, D, E, and K. Of these, vitamin C and vitamin E are the most vital water-soluble and fat-soluble vitamins. They both serve as antioxidants to build up the fish's immunity system. A lack of vitamins for fish will increase the risk of suffering symptoms such as scoliosis. On the other hand, minerals are inorganic compounds classified into macro-minerals and micro-minerals. Macro-minerals such as sodium, calcium, magnesium, etc., help with the fish’s bone development and integrity by regulating the osmotic balance. A trace amount of micro-minerals, including iron, manganese, copper, etc., support the enzymes and hormone system. These minerals may be absorbed directly from water by fish via their gills and skin to compensate for some mineral shortages in the fish diet (Craig, 2017).

2.3.3 Fish Health and Behaviour

The primary sign of fish health is their behaviour. It is important to observe and monitor their daily behaviour and appearance to understand their health condition. The best time to notice their condition is before and after the feeding process, as well as noting their appetite. A healthy fish exhibits the following signs:

- Good appetite and consume meals quickly.
- The fish’s eyes appearance is sharp and clear.
- Swim actively and freely with a straight tail.
- The breathing rhythm at a regular pace and not constantly gulping at the water surface.
- No additional spots and scars on the fish scales.

(RSPCA, 2021)

Stress can be detrimental to fish, just like humans. Generally, fish may suffer stress when living in a less ideal environment. Many factors such as incorrect pH, temperature, and overstocking will lead to stress in fish. The fish may need to adapt and work harder to counteract these adverse conditions, potentially weakening their immune system (Somerville et al., 2014). With this, the ability to confront disease and self-healing are diminished. Despite stress will not directly dispatch the fish, long-term exposure to stress will cause health complications (Hartz, 2021). Thus, it is important to realise and resolve instantaneously if the fish is stressed. Table 2.4 summarises the cause and indication of stress in fish.

Table 2.4: Cause and Indication of Stress in Fish (Hartz, 2021; Somerville et al., 2014).

Cause of Stress	Indication of Stress
▪ Fish bullying ▪ Poor water quality ▪ Improper pH range ▪ Low dissolved oxygen ▪ Improper temperature range ▪ Overstocking and malnutrition ▪ High toxin and ammonia concentrations	▪ Injuries and scars on the body ▪ Irregular breathing pace ▪ Unusual swimming patterns ▪ Constantly gasping at the water surface ▪ Poor appetite ▪ Clamped fins ▪ Rubbing and crashing the tank or rocks

Fish diseases can result from both abiotic and biotic factors. Abiotic factors are those directly associated with water quality and toxicity. Nonetheless, these adverse water conditions can cause infections in the fish. In contrast, the biotic factors mainly are resulted from pathogens. The common pathogens that lead to fish diseases are bacteria, parasites, and fungus. The pathogens are generally present in the system by adding new fish and water, but a healthy fish’s immune system can resist the infection. Thus, it is important to monitor the water quality and conduct necessary preventions to minimize the risk of suffering fish diseases. If there are infected fish in the aquaponics, they must be isolated and provide immediate treatment to prevent infections to other fish (Somerville et al., 2014). Some of the crucial actions for preventing fish diseases in aquaponics are as follow:

- Provide a sufficient and nutritious diet.
- Conduct necessary maintenance to ensure the key parameters are in ideal condition.
- Remove unconsumed fish feed or other pollutant substances to prevent pollution.

- Do not be in contact with the water and fish without any proper hygiene procedure.
- Always assess newly added fish for diseases symptoms.
- Avoid big fluctuations in water temperature, pH, and dissolved oxygen concentration.
- Keep fish tank away from moisture and direct sun exposure place.

(Farming Aquaponics, 2020b)

2.4 Plant Aspect

Plants are as important as fish due to their role in maintaining the overall cycle of aquaponics. They serve as a natural filter to absorb nitrates and purify the water. The clean water is recirculating back to the fish tank for fish usage. In commercial aquaponics, the plants may achieve a higher profit gain than the fish. Western aquaponic units suggested that 9the plants can contribute 90 % of financial income due to the faster turnover rate compared to fish (Somerville et al., 2014). Although plants are not moving actively like fish, it requires specific practices and knowledge to succeed in the desired plant production in aquaponics (BTL Liners, 2019). This section highlights some recommended plant species for aquaponics, the essential nutrients for plant growth, and pest management to ensure plant productivity.

2.4.1 Plant Species

Different plants have different requirements and growing conditions. When deciding the plants to cultivate in an aquaponic system, it is critical to examine the following factors. Firstly, the type of aquaponic system that is going to operate. As discussed in Section 2.2, the main three types of aquaponic systems are NFT, media bed, and DWC system. One of the main considerations is the ability of roots to be supported by the aquaponic system. For instance, plants with extensive roots are more suitable for being grown in a media bed system as it provides more support with the presence of growing media. Plants with smaller roots system mainly grow well in NFT and DWC systems. Secondly, the aquaponist shall consider the plant’s requirements on the environmental condition. It is important to select the fish and plants with similar water temperature and pH requirements to ensure that the adjusted water conditions are acceptable by both fish and plants. Thirdly, the available space around the aquaponics system is important for plant selection. Some plants require larger space to grow, so they may not grow well in a compact indoor area. Therefore, it is essential to consider the space requirement of the selected plants. Lastly, evaluate the number of fish required to cultivate in the aquaponic system. It is necessary to control the fish to plant ratio in order to achieve a well-balanced system. If the system consists of high fish stocking, it may require more plants or plants with higher nutrient demand to maintain the water quality by absorbing the excess nutrients (Vergeer, 2019b).

There are many types of plants had successfully grown in small-medium and commercial-scale aquaponics. Leafy green plants like lettuces can cultivate extremely well in aquaponics due to their ability to thrive in high nitrogen and low micro-nutrient environment (Walsworth, 2016). The fast-harvesting period and low nutrients demand by leafy green plants make them a good aquaponics option. Some fruiting crops such as tomatoes and cucumbers are also commonly grown in aquaponics, but they demand higher nutrients to achieve optimal growth. Thus, they are only suitable for an aquaponics system with sufficient fish stocks. In general, the plants vary in terms of their nutrients demand. Low nutrients demand plants are typically green crops like lettuce, basil, and parsley. In contrast, high nutrients demander is typically fruit crops with extensive roots, such as tomatoes and strawberries. The cabbage family, including broccoli and kale, is the common medium nutrient demander (Junge and Antenen, 2020).

2.4.1.1 Leafy Greens

Lettuce can grow well in aquaponics by taking up a little space. This plant can survive with the nitrogen supply from fish and low nutrient levels because it does not require blossom or develop the fruit by the harvesting time (BTL Liners, 2019). The standard lettuce varieties grown in aquaponics are crisphead lettuce, butterhead lettuce, and Romaine lettuce. The seeds require 3 – 7 days to germinate and can be transplanted into the aquaponic system when it grows 2 – 3 true leaves. It is important to supply phosphorus nutrients to the seedlings for better roots growth and prevent plant stress during the transplant period. Supplement of calcium also can reduce the risk of tip burn, especially in warmer weather. The harvesting process can be done when the leaves are large enough for consumption. The shelf life is highly dependent on the harvesting method and humidity. It is recommended to harvest the plant in the morning as the leaves are moist and crisp (Junge and Antenen, 2020). The ideal growing condition and characteristics of lettuce are shown as follow:

- pH range: 6.0 – 7.0
- Temperature range: 15 – 22 ℃
- Grow spacing: 18 – 30 cm
- Nutrient's demand: Low
- Plant size: 20 – 30 cm (height); 25 – 35 cm (width)
- Harvesting period: 24 – 32 days
- Suitable types of aquaponics: NFT, media bed, DWC

Cabbage is a highly nutritious crop and easily to be raised in aquaponics. Cabbage is susceptible to typical pests, which highly reduces the work on pest management. However, their most prevalent issue is splitting, where their head cracks and separates. The plant must be grown in a consistent condition and harvested appropriately to prevent this problem (Storey, 2016). The seeds require 4 – 7 days to germinate and can be transplanted when it has 4 – 6 leaves. Cabbage is more suitable to be grown in media bed systems because they are too heavy for NFT and DWC. It is also not suited for newly installed aquaponics units as it demands high nutrients levels. Phosphorus and potassium are important supplements when the head starts to grow. Cabbage can be harvested when the head diameter is about 10 – 15 cm by cutting off the head from the stem. If the head starts to crack, the crop is over-ripe and must be harvested immediately (Junge and Antenen, 2020). The ideal growing condition and characteristics of cabbage are shown as follows:

- pH range: 6.0 – 7.2
- Temperature range: 15 – 20 ℃
- Grow spacing: 60 – 80 cm
- Nutrient's demand: High
- Plant size: 30 – 60 cm (height); 30 – 60 cm (width)
- Harvesting period: 45 – 70 days
- Suitable types of aquaponics: media bed

2.4.1.2 Herbs

Basil is a heat-loving herb that can be grown in Malaysia all year round. The high-value and fast-growing basil provides a great selection for commercial aquaponics to maximize income (Ferrarezi and Bailey, 2019). Basil is sensitive and easily affected by fungal diseases when in high moisture conditions. Therefore, it demands plenty of airflow with sufficient light up to 10 – 12 hours/day to reduce infection and stress. The light supplement may also boost the production yield. As a warm-weather crop, the basil requires a higher temperature, particularly 20 – 25 ℃, to trigger germination. The germination will hold for 6 – 7 days and can be transplanted in aquaponics once it has 4 – 5 true leaves. Basil leaves can be harvested once the plant reaches around 15 cm in height. It is best to remove the blooming tips if it exists to eliminate the bitter taste. The basil flowers can attract beneficial pollinators and insects, which improves aquaponics gardening (Junge and Antenen, 2020). The ideal growing condition and characteristics of basil are shown as follows:

- pH range: 5.5 – 6.5
- Temperature range: 18 – 30 ℃
- Grow spacing: 15 – 25 cm
- Nutrient’s demand: Low
- Plant size: 30 – 70 cm (height); 30 cm (width)
- Harvesting period: 35 – 42 days
- Suitable types of aquaponics: NFT, media bed, DWC

Parsley is an easily raised herb due to the low nutrients demand compared to other crops. It carries rich vitamins A, C, and K leading to a higher market value. The most common types of parsley for aquaponics are Italian, Japanese, and curly parsley (Ariffin, 2021). Similar to basil, parsley loves the sun and warm temperature, which can expose to sunlight for more than 8 hours/day but requires shading when the temperature exceeds 25 ℃. The seed germinates in 8 – 10 days with the presence of sufficient moisture as well as a stable temperature. Soaking in warm water for 1 – 2 days is recommended to accelerate the germination period. The seedlings can be transplanted to an aquaponic unit when the true leaves exist in 5 – 6 weeks. The harvesting process can be carried out once the plant reaches 15 cm in height. With parsley can be harvested multiple times, it is suggested to harvest the outer stem instead of the top leaves to encourage future growth (Junge and Antenen, 2020). The ideal growing condition and characteristics of parsley are shown as follows:

- pH range: 6.0 – 7.0
- Temperature range: 15 – 25 ℃
- Grow spacing: 15 – 30 cm
- Nutrient's demand: Low
- Plant size: 30 – 60 cm (height); 30 – 40 cm (width)
- Harvesting period: 20 – 30 days from seedling size
- Suitable types of aquaponics: NFT, media bed, DWC

2.4.1.3 Fruiting Crops

Tomato is a good summer fruiting crops selection for aquaponics. It can withstand hot temperatures, but it requires a roots support system and high nutrients level. Tomato requires a lot of phosphorus, potassium, and nitrogen to grow fruits. Thus, the balance between the crops and fish biomass determines the growth rate of the crops in the aquaponic system (BTL Liners, 2019). The pruning process is also essential for tomato cultivation to prevent the plant consume more energy to produce foliage rather than fruits. Without pruning, the tomato yield is decreased to 50 % (Vanderlinden, 2021). The seed is expected to germinate in 4 – 6 days with a temperature of 20 – 30 ℃ and can be transferred to the aquaponics unit when the seedling reaches 10 cm height. Plant support must be prepared to prevent roots from getting damaged during transplantation. Tomato can be harvested once it reaches firm reddish colour. Even if it is not fully ripe, the tomato fruit will continue to ripe when keeping in indoors (Junge and Antenen, 2020). The ideal growing condition and characteristics of tomato are shown as follows:

- pH range: 5.5 – 6.5
- Temperature range: 22 – 26 ℃
- Grow spacing: 40 – 60 cm
- Nutrient's demand: High
- Plant size: 60 – 180 cm (height); 60 – 80 cm (width)
- Harvesting period: 50 – 70 days
- Suitable types of aquaponics: media bed, DWC

Cucumber is a high-value summer vegetable that appears to benefit from aquaponics gardening. It can thrive in an aquaponic system due to its green leafy, and water-loving nature. Cucumber demands a high level of nutrients, especially nitrogen and potassium. Thus, the available fish biomass and nutrients level should be well evaluated before determining the quantity of plants for the aquaponic unit. As a warm climate crop, cucumber also requires a hot and humid environment with direct sunlight or artificial lights for indoor cultivation to reach its full bearing capacity. Lack of sunlight may affect the production yield (Flourishing Plants, 2021). The cucumber seed is expected to germinate in 3 – 7 days with a temperature of 20 – 30 ℃. After germination, the seedling can be transplanted to aquaponics when it grows 4 – 5 leaves. Cucumber is a fast-growing plant, so it is good to divert the nutrients to fruits growing by eliminating their apical tips. The cucumber can be harvested up to 15 times after 2 -3 weeks of transplantation. Harvest the fruits every few days to prevent overgrowth and encourage future growth (Junge and Antenen, 2020). The ideal growing condition and characteristics of cucumber are shown as follows:

- pH range: 5.5 – 6.5
- Temperature range: 22 – 28 ℃
- Grow spacing: 30 – 60 cm
- Nutrient’s demand: High
- Plant size: 20 – 200 cm (height); 20 – 80 cm (width)
- Harvesting period: 55 – 65 days
- Suitable types of aquaponics: media bed, DWC

2.4.2 Plant Nutrition

Generally, plants obtain the essential nutrients from the soil source. In aquaponics, fish feed and fish waste are the main source of nutrients for plants due to soilless cultivation. Plants require 17 essential elements to support their normal life cycle. Of these, carbon, oxygen, and hydrogen can be obtained from the atmosphere and are more than sufficient for plants intake. These elements are usually categorized as non-mineral. The remaining 14 essential elements are divided into macronutrients and micronutrients (Bittsanzky et al., 2016). Figure 2.9 illustrates the classification of essential nutrients for plants.

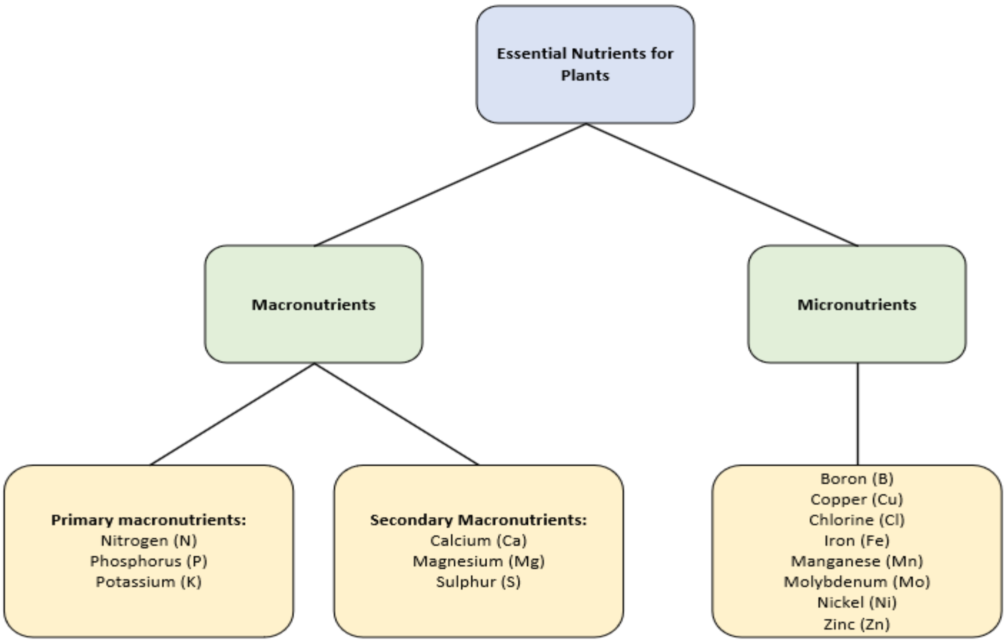

Figure 2.9: Classification of Essential Nutrients for Plants.

Macronutrients are plant nutrients that require in larger amounts which are further divided into primary and secondary macronutrients. The primary and secondary macronutrients are defined according to the amount needed but not the importance of the nutrients. In contrast, micronutrients are plant nutrients that require in trace amounts. The deficiency of both macronutrients and micronutrients is detrimental to plant growth (Wiedenhoeft, 2006). Although all the nutrient elements are present in the fish feed and solid waste, some nutrients may be in limited concentration resulting in nutrients deficiency. Thus, it is important to understand the function of each essential nutrient and identify the lacking nutrients if nutrient deficiency occurs to provide suitable adjustment. Table 2.5 summarises the function, deficiency symptoms, and effects of each nutrient.

Table 2.5: Function, Deficiency Symptoms, and Effects of Each Nutrients (Junge and Antenen, 2020; Somerville et al., 2014; Uchida, 2000; Wiedenhoeft, 2006).

Nutrients	**Function**	**Deficiency Symptoms / Effects**
Nitrogen (N)	▪ Serves as a building block of proteins ▪ Essential for chlorophyll production, photosynthesis, and metabolic process ▪ Improves dry matter in leafy plants	▪ Yellowish leaf due to chlorosis effect ▪ Flowering reduced ▪ Stunted growth may occur
Phosphorus (P)	▪ Used as the part of phospholipid layer, DNA and ATP ▪ Involves photosynthesis to convert energy from sunlight ▪ Stimulate germination and flower growth ▪ Improves the crops quality and disease resistance	▪ Leaf with dark green pigment ▪ Burnt occurs in the tips of the leaf ▪ Delay maturity and seed development in early stages
Potassium (K)	▪ Acts as a coenzyme for metabolism ▪ Uses for protein synthesis and ATP generation ▪ Regulate water movement by controlling stomata ▪ Improves the crops quality and disease resistance	▪ Leaf curling inward ▪ Yellowish leaf due to chlorosis effect ▪ Causing slow growth and weak stems

Table 2.5: (Continued).

Calcium (Ca)	▪ Major component for cell wall and cell membrane ▪ Helps to strengthen roots and stem ▪ Act as an enzyme activator	▪ Leaf and roots tip turns brown ▪ Cell walls are not rigid leading to weak stem structure
Magnesium (Mg)	▪ Electron acceptor in chlorophyll ▪ Highly involved in photosynthesis ▪ Helps to maintain ribosome structure	▪ Yellowish between leaf veins due to chlorosis effect ▪ Leaf drop prematurely
Sulphur (S)	▪ Involves amino acids and proteins synthesis ▪ Critical in electron transferring during photosynthesis	▪ Yellowish leaf due to chlorosis effect ▪ Late maturity
Boron (B)	▪ Used with Ca for cell wall structuring ▪ Improves sugar transportation and water intake ▪ Stimulate roots development and pollen germination	▪ Branches and roots swollen ▪ Leaf curling, fragile ▪ Stem, tip, and roots necrosis
Copper (Cu)	▪ Important for some enzymes in photosynthesis and reproduction ▪ Stabilise the colour pigment of the plant	▪ Leaf rolling and chlorosis ▪ New leaf is smaller than usual ▪ Necrosis
Chlorine (Cl)	▪ Involves stomata opening to regulate water concentration ▪ Generate oxygen from water during photosynthesis ▪ Resist and tolerate diseases	▪ Leaf may turn bronze colour ▪ Thickened root tips ▪ Necrosis and chlorosis

Table 2.5: (Continued).

Iron (Fe)	▪ Critical for chlorophyll synthesis ▪ Involves in heme enzyme and protein metabolism	▪ Interveinal chlorosis ▪ Leaf turns yellowish
Manganese (Mn)	▪ Function in enzyme and metabolic system ▪ Formation of DNA and RNA ▪ Converts oxygen in photosynthesis	▪ Yellow spots in dicots and greenish-grey specks in monocots ▪ Necrosis and chlorosis
Molybdenum (Mo)	▪ Nitrogen fixation ▪ Catalyse redox reaction ▪ Convert nitrate to ammonium for amino acids synthesis	▪ Leaf curling inward ▪ Yellowish leaf ▪ Necrotic spots may present
Nickel (Ni)	▪ Cofactor of urease-enzyme ▪ Function as catabolic detoxification of urea from fish waste	▪ Tip burns in leaf ▪ Chlorosis ▪ Urea toxicity
Zinc (Zn)	▪ Involves in protein and RNA synthesis ▪ Formation of hormones and enzymes ▪ Stem elongation and growth control	▪ Interveinal chlorosis ▪ Smaller leaf growth ▪ Shorten inter-nodal length

2.4.3 Pest Management

The pests can become a big issue for plant productivity in aquaponics because they may transmit diseases to plants. These pests also dig the plant to extract their fluids, resulting in potential stunted growth (Somerville et al., 2014). However, pest and plant health management in aquaponics are limited due to the complex biological system and interconnectivity. The selected pest management must be acceptable to plants, fish, and bacteria since each organism may be sensitive to different types of treatment (Southern and King, 2017). The

Integrated Pest Management (IPM) protocols are highly recommended for pest control in aquaponics. It emphasises the growth of healthy plants with careful consideration and appropriate measurement of all the possible protection strategies to achieve the least disruption to the environment and ecosystem (Félix, 2018).

The first choice of pest management should start with the physical and mechanical controls. Physical and mechanical controls mainly rely on the farmers' daily management with some physical equipment to remove the pest. The simplest physical method for small scale aquaponics is hand inspection to remove those visible pests on the plants. Farmers can also use high-pressured water spray to spray the leaves, especially the underside of leaves, to prevent pests from spreading across the plants. Besides, trapping methods by using sticky traps and nets are also effective methods for pest eradication. The sticky trap is commonly designed in both yellow and blue colours. The yellow sticky trap can capture pests like Micro-Lepidoptera and whiteflies, while the blue sticky trap is useful for trapping adult thrips. This method is highly effective in indoor areas as the pathway for pests to enter the protected area is limited (Somerville et al., 2014). For the net strategy, the main function is to prevent the pest from contacting the plants. The mesh size varies depending on the targeted pest. For instance, 0.15 mm mesh size for preventing thrips while 20 mm mesh size against birds (Junge and Antenen, 2020). Anti-pest net is commonly resistant to UV rays meaning that the net can withstand a long exposure period to sunlight. However, the netting method may induce a temperature rise under the net, causing adverse effects to plant physiology. It is necessary to include some ventilation for the plants (Simon et al., 2014).

If the pest problem still exists after physical and mechanical methods, aquaponists can implement chemical control. However, it should be considered as the last option in aquaponics. The reason is that the chemical used not only toxic to the pests, but also harmful to the fish and beneficial microorganisms. Insecticides and pesticides should never be used in aquaponics as the chemicals are toxic to fish. If possible, natural repellent is more recommended because it may not be harmful to the fish and plants. The main idea of natural repellent is to use the natural smell of herbs or plants to expel the pests. Citrus and citronella are commonly mixed with water and spread across the plant to attain the expel effect. Biological control also can be effective in pest control. The most widely accepted species for biological pest control are *Bacillus thuringiensis* and *Beauveria bassiana*. *Bacillus thuringiensis* generates proteins that are useful to harm the digestive tract of insects and kill it when consumed. At the same time, *Beauveria bassiana* can penetrate insects' skin and dispatch them through dehydration. These organisms can be spread on the plant and provide no harmful effect on the fish and plants because they only act specifically on insects (Félix, 2018; Somerville et al., 2014).

2.5 Water Quality Parameters

Water is the core of aquaponics. It is a medium that transports all the essential elements to fish and plants, including oxygen, macro- and micronutrients. In order to achieve well-balanced aquaponics, it is vital to understand the water quality parameters that highly affect the system. The five main water quality parameters for aquaponics monitoring are dissolved oxygen, pH, water temperature, nitrogen composition, and water hardness. Each parameter has its impact on the aquaponics system, and it is critical to obtain the ideal parameters range for the fish, plants, and bacteria (Thorarinsdottir et al., 2015).

2.5.1 Dissolved Oxygen

Dissolved oxygen (DO) is described as the quantity of oxygen molecule present in the water and is typically measured using milligram per litres (mg/L) or parts per million (ppm). DO is important to fish respiration, and insufficient DO will cause stress and even be fatal to fish. Every fish species demands different DO levels to achieve its optimum growth. For instance, catfish require approximately 5 mg/L of DO concentration while trout need 6.5 mg/L of DO concentration. The general requirement of DO levels for warm-water and cold-water fish are not lower than 3 mg/L and 4 mg/L, respectively. Besides, the nitrifying bacteria also consume high DO levels to convert fish waste to plant nutrients, and the plant's roots require at least 3 mg/L of DO concentration to assimilate the nutrients. The optimum DO levels for the organism in an aquaponics are 5 – 8 mg/L (Masabni and Sink, 2020; Junge and Antenen, 2020).

It is advised to measure DO levels regularly, especially in a new aquaponic setup. Even when the system is stabilised, DO levels should be checked at least once a day to prevent low DO levels that cause harmful effects on the organisms (Masabni and Sink, 2020). The most reliable method to measure DO levels is using a DO meter, as it provides an accurate DO reading. However, the DO meter can be expensive and less economically friendly for farmers or beginners. Thus, the suggested method for small scale aquaponics is to frequently monitor the fish's daily behaviour, water condition, and oxygen supply equipment. If fish are constantly gulping on the water surface, it denotes that the DO levels in the water are below the requirement (Somerville et al., 2014).

Generally, some factors such as temperature and salinity will affect the DO concentration. Warmer water can hold lesser DO concentrations, whereas colder water contains higher DO concentrations. If the salt content in the water body is high, the amount of DO will also be lesser (Bernstein, 2011). Thus, additional DO supplement equipment must be implemented in aquaponics even though atmospheric oxygen can dissolve into the water. For small scale aquaponics, the pumps and aerators are responsible for generating air bubbles in the water. The more movement in the water, the more DO will be produced (Somerville et al., 2014). If DO levels in water are low, add more air stones to boost the aeration system or use a larger pump. It is better to provide excess DO rather than insufficient DO concentration, as the surplus DO will then scatter into the atmosphere when the water is saturated (Sallenave, 2016).

2.5.2 pH

The term pH is defined as the power of hydrogen. It refers to the concentration of hydrogen ions in a solution. It is used to measure the acidity and alkalinity ranging from 0 – 14. The pH value of 7 indicates a neutral condition, while below pH of 7 is acidic and above pH of 7 is alkaline. It is important to manipulate the pH value that is suitable to the organisms in aquaponics, especially the plants and nitrifying bacteria. The availability of the plant's nutrients is typically based on water pH control. Most of the plant's nutrients are available and easy to absorb in the pH range of 5.5 – 6.5. If the pH is not maintained in the range, the plants may experience a nutrient lockout, meaning that the plant cannot access some of the nutrients, especially iron, manganese, and phosphate, even though these nutrients are present in the water body. The nitrification process is unable to take part by bacteria when the pH value is lower than 6. Consequently, the ammonia concentration in the water body will increase, which may harm the fish. As most of the fish species can tolerate the pH range of 6 – 8.5, the recommended pH range for small scale aquaponics is 6 – 7 to maintain the efficiency of nitrifying bacteria and plant's nutrients uptake rate (Junge and Antenen, 2020; Sallenave, 2016; Somerville et al., 2014).

The pH level should be checked at least once a week. If possible, daily monitoring of pH level is encouraged as it typically fluctuates in the time frame of 1 day due to the fish respiration and nitrification process (Masabni and Sink, 2020). The simplest and cheapest method to measure the pH level is using the pH strips. However, this method only provides an estimation of the pH range, and it is less accurate. A pH meter is suggested for more precise analysis as it gives a specific value to the water pH level (Junge and Antenen, 2020).

It is more often to increase rather than lower the pH level in aquaponics. The reason is that the nitric acid and carbon dioxide generated during nitrification and fish respiration mainly decrease the water pH level. Bases such as potassium hydroxide (KOH) and calcium hydroxide ($Ca(OH)_2$) can be dissolved in the water system to increase the pH level. Alternate the addition of KOH and $Ca(OH)_2$ to ensure balanced potassium and calcium supplement for plants intake. In a high pH condition, mild acids such as phosphoric acid (H_3PO_4) can be added to the water to provide acidity. Both acid and base should be added gradually and allow the water to circulate and stabilise for a few hours before taking another measurement to check whether a further adjustment is required (Masabni and Sink, 2020).

2.5.3 Water Temperature

Water temperature is crucial to every aspect of aquaponics. As discussed, fish and plant have their ideal growth temperature range. Inappropriate water temperature control increases the risk of disease infection and restricts nutrients intake. The best strategy is to select fish and plant species that can adapt to the aquaponic system's ambient temperature, as altering water temperature is energy-intensive and requires additional expenses. The compromise water temperature falls in the range of 18 – 30 °C (Junge and Antenen, 2020). Besides, the water temperature highly influences the concentration of unionised ammonia and the DO levels. Warmer water holds a lesser DO concentration and a higher ammonia concentration compared to colder water. These parameters directly affect the productivity of aquaponics and should be well maintained (Masabni and Sink, 2020).

It is encouraged to check the water temperature every day by using a digital thermometer or temperature sensor as it fluctuates easily. There are some managements that can be implemented to minimise the temperature fluctuations in small scale aquaponics. During the daytime, a shading structure should cover the water surface to prevent direct exposure to sunlight and reduce the evaporation rate. Similarly, insulation material such as polystyrene or dark-coloured material can be applied to protect the aquaponic unit thermally. The minimal temperature fluctuation highly promotes the productivity of aquaponics (Somerville et al., 2014).

2.5.4 Nitrogen Composition

Nitrogen composition is an important water parameter in aquaponics as the organism in the aquaponics requires nitrogen to thrive. Ammonia is the main form of nitrogen which the fish excrete through their gills and urine. It typically exists in two forms, the ionised (NH_4^+) and unionised (NH_3) forms. In aquaponics, the bacteria nitrify the ammonia into nitrite (NO_2^-) and nitrate (NO_3^-). Both unionised ammonia and nitrite are highly toxic to fish health and sufficient to kill the fish in high concentrations. However, these nitrogen sources are nourishing for plants. The plant can be utilised all three forms (NH_3, NO_2^-, NO_3^-) for growth, but nitrate is the most accessible. Thus, adequate biofiltration in aquaponics is vital to balance the nitrogen requirements of fish and plants. (Sallenave, 2016).

Generally, unionised ammonia is hard to quantify on its own. The sum of ionised and unionised ammonia, known as Total Ammonia Nitrogen (TAN), is the standard ammonia measurement for aquaponics (Masabni and Sink, 2020). TAN can be measured by using normal aquarium kits. Spectrometric kits are usually used on laboratory scales for more accurate TAN, nitrite, and nitrate analysis. For well-functioning aquaponics, the ammonia and nitrite concentration are typically maintained at < 1 mg/L and < 0.2 mg/L, respectively (Junge and Antenen, 2020). The recommended nitrate and nitrite assessment frequency are once a week or a month, while TAN should be monitored in weekly or more frequently depending on the setup conditions (Thorarinsdottir et al., 2015).

If the ammonia and nitrite concentrations are too high, it may indicate overfeeding problems. Reduce the fish feed amount or stop feeding for several days to adjust the ammonia concentration in the system. In contrast, the ammonia concentration is low when the fish density to water volume ratio is too low. Low ammonia concentration may starve the bacteria and plants. Thus, add more fish or decrease the fish tank's size to resolve the low ammonia issue. The excess nitrate level may imply insufficient plants to absorb the nitrates. Add more plants or harvest some of the fish to alleviate the excess of nitrates. In short, a balanced fish to plant ratio is crucial for nitrogen composition control (Sallenave, 2016).

2.5.5 Water Hardness

Water hardness can be classified into general hardness (GH) and carbonate hardness (KH). GH is represented as the portion of magnesium (Mg^{2+}), calcium (Ca^{2+}), and iron (Fe^{+}) ions present in water. In fact, GH is vital for both fish's and plants' nutrients, especially magnesium and calcium are the plant's macronutrients. A water body with sufficient calcium concentration can help fish retain the useful salts in their body, resulting in healthier growth. On the other hand, KH refers to the concentration of dissolved carbonates (CO_3^{2-}) and bicarbonates (HCO_3^{-}) in water. It also measures the calcium carbonate ($CaCO_3$) concentration in mg/L. In aquaponics, KH plays an important role in pH level control by acting as a buffering agent to provide alkalinity to the system. As the acidity of water will increase due to the nitrification and fish respiration process, the carbonate and bicarbonate in water will bind and remove the free hydrogen ions (H^{+}) from the acid content. Thus, it provides better pH stability to avoid pH swings, which may impact the aquaponics ecosystem (Somerville et al., 2014). Table 2.6 describes the water hardness level based on calcium carbonate concentration.

Table 2.6: Water Hardness Level based on Calcium Carbonate Concentration (Junge and Antenen, 2020).

Water Hardness Level	Calcium Carbonate Concentration (mg/L)
Soft	0 – 60
Moderate Hard	60 – 120
Hard	120 – 180
Very Hard	Above 180

Although water hardness is a vital water quality parameter, it does not require frequent monitoring if the water source has sufficient GH and KH concentrations. The ideal condition is to keep the water moderately hard, which is 60 – 120 mg/L. If the hardness level is too low, coral and limestone can be used to raise the water hardness (Junge and Antenen, 2020).

2.6 Summary

An aquaponic system integrates aquaculture and hydroponics into one closed-loop system which solves some problems that generated by the individual technologies. The most common aquaponic system designs are Nutrient Film Technique (NFT), Media Bed, and Deep Water Culture (DWC). Each system design has advantages and disadvantages regarding the maintenance routine, utility usage, cost, and crop selection. The fish species for aquaponics are classified into edible and ornamental species, and the selection of fish depends on the aquaponic operational purpose. Proper caring for the fish is necessary by understanding the fish's nutrition. A complete fish diet supplies five primary nutrients: protein, fats, carbohydrates, minerals as well as vitamins. Besides, fish health is directly expressed by their behaviour. Frequently observing their behaviour changes to detect stress and diseases is crucial to fish health.

Meanwhile, the typical plant species for aquaponics are leafy greens, herbs, and fruiting crops. Each plant species has its ideal growing condition and nutrient demand, which must be considered before selecting the plant for aquaponics. Plants mainly require 17 essential elements to support their normal life cycle. The essential nutrients are divided into macronutrients and micronutrients. The deficiency of both macronutrients and micronutrients are detrimental to plant growth. Moreover, pests can become a big issue for plant productivity in aquaponics because they may transmit diseases to plants. These pests also dig the plant to extract their fluids, resulting in potential stunted growth. Thus, a good understanding of the plant nutrients and pest management will encourage the plant’s growth in aquaponics.

Subsequently, water is the core of an aquaponic system. It is a medium that transports all the essential elements to fish and plants, including oxygen and nutrients. The five main water quality parameters for aquaponics monitoring are dissolved oxygen level, pH value, water temperature, nitrogen composition, and water hardness. Maintaining the water quality parameters in the ideal range is vital as each parameter impacts the aquaponics system.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Material and Equipment

This section decided the fish and plants species for the mini aquaponics. Some other necessary materials and equipment for the setup were listed and prepared.

3.1.1 Fish Selection

Goldfish were selected as the fish species for the mini aquaponics. It is a prevalent aquarium fish that can be easily found in any fish pet shop. In fact, both single-tailed and twin-tailed goldfish are suitable for aquaponics but not breeding the two species in a single tank. The reason is that single-tailed goldfish are more aggressive and may hurt the twin-tailed species. The common goldfish and fantail goldfish are the most viable options for beginners to start up a small aquaponic system due to their hardy characteristics. Some of the growing criteria and characteristics for goldfish are as follows:

- Water pH: 6.0 – 8.0
- Water Temperature: 18 – 25 °C
- Dissolved Oxygen: 4 – 10 mg/L
- Fish Feed: Floating or sinking goldfish pellets

Figure 3.1: Goldfish (Farming Aquaponics, 2020).

3.1.2 Plant Selection

As aforementioned in Section 2.4.1.2, parsley is a suitable plant species to grow in aquaponics. Many aquaponists use parsley plants for their indoor aquaponics. The parsley seeds are also affordable and can be bought from any seed supplier. Thus, parsley was selected to cultivate in the mini aquaponics. The ideal growing conditions of parsley are shown as follows:

- pH range: 6.0 – 7.0
- Temperature range: 15 – 25 ℃
- Grow spacing: 15 – 30 cm

Figure 3.2: Parsley (Somerville et al., 2014).

3.1.3 Other Materials and Equipment

Table 3.1 shows the material and equipment that required for the mini aquaponics.

Table 3.1: Material and Equipment that Required for the Mini Aquaponics.

Material / Equipment	
50-gallon Fish Tank	API Test Kit
Leca Clay Pebbles	Carbonate Hardness Test Kit
Goldfish Floating Pellets	General Hardness Test Kit
Net Pots	Goldfish
Aquarium Water Pump	Parsley Plant
Polystyrene Raft	Filter Floss
Water Conditioner	LED Plant Growth Light
Nitrifying Bacteria Solution	Automatic Fish Feeder
Top Filter	Ich Solution
Bio-media	

3.2 Design Concept

As the experiment was conducted in a limited time, it is essential to illustrate a design concept before proceeding to the setup process. It can reduce the time required and increase the efficiency of the setup process. Figure 3.3 demonstrates the design concept of the mini aquaponics. The main concept of the mini aquaponics design was growing the plants on a polystyrene raft that floats on the aquarium water. It can be known as a mini DWC system. The polystyrene raft had some cutting holes to fit in the net pots. The parsley was placed in the net pots with the roots submerging into the water. LECA clay pebbles were filled into the net pots to support the parsley and supply spaces for nitrifying bacteria to grow. The dimension of the polystyrene raft was not fully covered the water surface of the fish tank. The purpose was to provide open spaces for fish feeding and water quality testing.

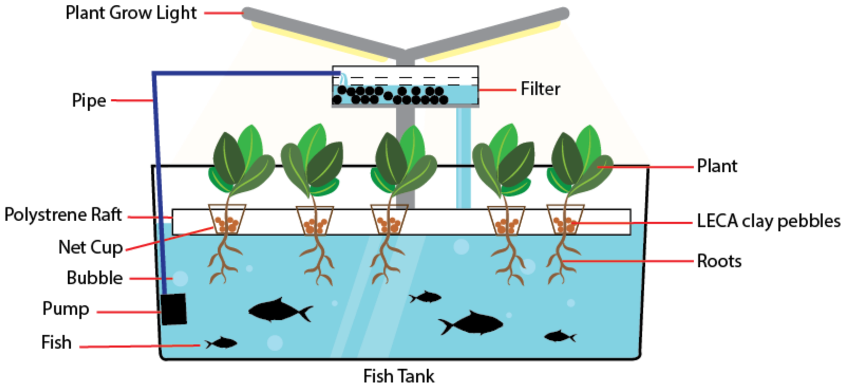

Figure 3.3: Design Concept of the Mini Aquaponics.

3.3 Design Calculation

<u>Fish Tank</u>

Figure 3.4: Fish Tank.

Dimension: 91.5 cm (Length), 47 cm (Height), 45.5 cm (Width)

Let freeboard height = 10 cm

The fish tank’s water volume can be calculated as follow:

$Volume = Length \times Height \times Width$

$Volume = 91.5\ cm \times (47 - 10)\ cm \times 45.5\ cm$

$Volume = 154040\ cm^3$

$Volume \approx 40\ gallon;\ 154\ L$

<u>Polystyrene Raft</u>

Estimated Dimension: 65 cm (Length), 5 cm (Height), 40 cm (Width)

From top view, let:

Left and right offset = 4.5 cm, Top and bottom offset = 3 cm

The raft’s area can be calculated as follow:

$Area = Length \times Width$

$Area = [65\ cm - 2(4.5\ cm)] \times [40\ cm - 2(3\ cm)]$

$Area = 1904\ cm^2$

<u>Net Pot</u>

Dimension: 13.2 cm (Diameter), 8.5 cm (Height)

The net pot’s area can be calculated as follow:

$Area = \frac{\pi \times Diameter^2}{4}$

$Area = \frac{\pi \times (13.2\ cm)^2}{4}$

$Area = 136.8\ cm^2$

By leaving a distance of 15 cm between each plant, the polystyrene raft can fit maximum 8 net pots.

<u>Feed to Plant Ratio</u>

Step 1: Calculate the number of plants that can be cultivated in the growing area.

According to Walsworth (2016), 16 – 25 leafy greens per m^2 of growing area.

The number of plants for the system can be calculated as follow:

$1\ m^2 = 10000\ cm^2$

$\frac{Number\ of\ plants}{1904\ cm^2} = \frac{16}{10000\ cm^2}$

$$Number\ of\ plants = 3.05$$

$$\frac{Number\ of\ plants}{1904\ cm^2} = \frac{25}{10000\ cm^2}$$

$$Number\ of\ plants = 4.76$$

Thus, approximately 3 – 4 plants can be cultivated in the mini aquaponics.

Step 2: Determine the fish feed required.

According to Walsworth (2016), an average of 45 g of fish feed per m^2 of leafy greens' growing area. The daily fish feed amount can be calculated as follow:

$$\frac{Fish\ feed\ amount}{1904\ cm^2} = \frac{45\ g}{10000\ cm^2}$$

$$Fish\ feed\ amount = 8.568\ g/day$$

Step 3: Compute the quantity of fish.

According to Walsworth (2016), fish consume 2 % of their body weight every day. The fish's biomass for the system can be calculated as follow:

$$fish\ biomass = \ fish\ feed\ amount \times \frac{100\ g\ fish}{2\ g\ feed/day}$$

$$fish\ biomass = \frac{8.568\ g\ feed}{day} \times \frac{100\ g\ fish}{2\ g\ feed/day}$$

$$fish\ biomass = 428.4\ g$$

The average weight of a goldfish is approximately 90g (Mohr, 2015). The number of fish can be determined as follow:

$$Number\ of\ fish = \frac{fish\ biomass}{average\ fish\ weight}$$

$$Number\ of\ fish = \frac{428.4\ g}{90\ g}$$

$$Number\ of\ fish = 4.76$$

Thus, a maximum of 4 goldfish can be bred in the mini aquaponics.

Step 4: Calculate the fish stocking density.

According to Walsworth (2016), the healthy fish stocking density is 15000 g of fish per 1000 L of water. The fish stocking density for the system can be calculated as follow:

$$\frac{Fish\ stocking\ density}{water\ volume} = \frac{15000\ g}{1000\ L}$$

$$Fish\ stocking\ density = \frac{15000\ g}{1000\ L} \times 154\ L$$

$$Fish\ stocking\ density = 2310\ g$$

$$fish\ biomass < Fish\ stocking\ density$$

The calculated fish biomass was lower than the fish stocking density. Thus, the fish biomass for the system is within a healthy range. Considering that goldfish generate a high excretion volume, it was decided to start with a lower stocking density. This provides a larger tolerance of error for a new aquaponics setup. In short, two goldfish and four parsley plants were used to start the mini aquaponics. The necessary adjustment will be made according to the water quality readings after several measurements.

3.4 Setup Process

The mini aquaponic system was set up according to the design concept as aforementioned in Section 3.2. Figure 3.5 shows the overall setup of the mini aquaponic system which implemented the DWC concept. In this section, the setup process is discussed to provide a guideline for starting a mini aquaponic system. It is divided into three sections: tank cleaning, equipment installation, and introducing fish and plants.

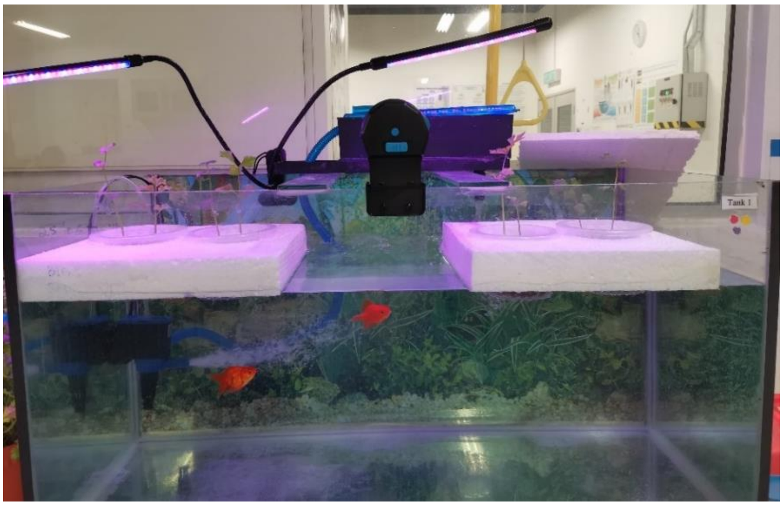

Figure 3.5: Overall Setup of the Mini Aquaponic System.

3.4.1 Tank Cleaning

The 50-gallon aquarium tank was rented from the school laboratory throughout the experiment. The initial condition of the aquarium tank consists of dust and dirt, which is necessary to be removed before adding the fish. The dirt will highly pollute the water and affect the fish’s health. The aquarium tank was filled with tap water and wiped with a sponge to remove the dirt in the tank. After cleaning it, the water in the tank was removed by an aquarium siphon. The condition of the tank before and after the cleaning is shown in Figure 3.6.


Before
After

Figure 3.6: Tank Condition Before and After Cleaning.

3.4.2 Equipment Setup

Some equipment such as filter, pump, and plant grow light are necessary to be implemented in the system to ensure the mini aquaponics performance. The filter used in the setup is a top filter that fish hobbyists are commonly practiced. The top filter is cheap and effective enough to provide clean water circulation. After cleaning the filter box, ceramic rings and bio-balls were placed into the top filter, followed by the filter floss to achieve mechanical and biological filtration. Both ceramic rings and bio-balls contain many small holes that create a porous surface for the beneficial bacteria to grow. Beneficial bacteria are essential for the nitrogen cycle in the aquarium. Figure 3.7 shows the top filter with bio-medias and filter floss.

Figure 3.7: Top Filter with Bio-medias and Filter Floss.

After setting up the filter box, a multifunction aquarium water pump was installed in the aquarium to provide water circulation. A submersible pump aims to draw and transfer the water to the top filter to generate clean water back into the aquarium. The multifunctional pump used in the mini aquaponics can circulate up to 1000 L/h of water and also supply oxygen injection to the aquarium water. As a result, it delivered a sufficient concentration of dissolved oxygen and cleaned water for the goldfish and parsley to survive.

Next, the plant growth light was installed to supply the essential light for the parsley to thrive. For optimum growth, a parsley plant requires six hours of direct sunlight (Iannotti, 2022). However, the laboratory’s mini aquaponic system had limited access to direct sunlight. Thus, plant growth light is one of the best substitutions to replace sunlight. The plant growth light comes with red and blue LED bulbs as most plants require both light waves for their growth. The phytochromes in the plant are responsible for leafy development, and they are sensitive to red light waves, whereas the cryptochromes that govern the plant light response are susceptible to blue light waves (Grant, 2022).

3.4.3 Introducing Goldfish and Parsleys

Before adding the goldfish and parsley, the water was well treated and cycled to eliminate the presence of harmful components. First, water conditioner was added to the water to remove chlorine and heavy metal in the tap water. The pump was switched on to cycle the water for 10 – 20 minutes before adding the nitrifying bacteria solution. The water was circulated for 24 hours to homogenise the water. After checking the water quality parameters, the goldfishes were introduced into the aquarium tank. The plastic pack containing the goldfish was placed into the water for water adaptation, as shown in Figure 3.8. After 10 minutes, a small portion of tank water was added to the plastic bag. This process was repeated 2 – 3 times in 5 minutes intervals, and the goldfishes were slowly released into the fish tank. This process described above is crucial to prevent the goldfish from suffering extensive stress and thermal shock. Subsequently, the polystyrene was cut into a dimension that could fit the four net pots. Each net pot was filled with LECA pebbles to support the parsley cuttings. Last, the polystyrene was floated on the water surface to allow the parsley plant to contact the water.

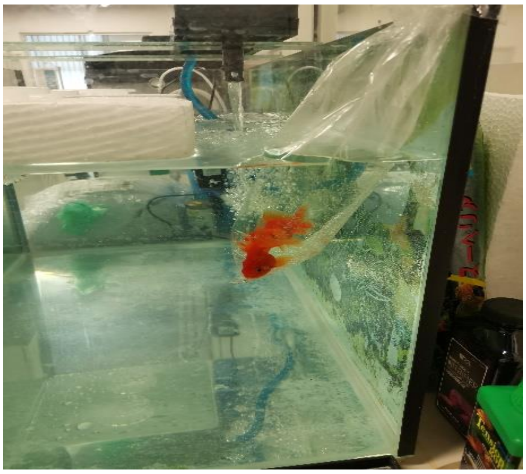

Figure 3.8: Water Adaptation Process for Goldfish.

3.5 Water Quality Control

The procedure for measuring the water quality parameter is discussed in this section. API freshwater master test kit was the primary tool for testing the water quality of the mini aquaponics. The master test kit is applicable to test ammonia, nitrite, and nitrate concentration. Similarly, the GH and KH levels were tested using their respective reagent test kits, which are not included in the API freshwater master test kit. For water temperature, pH, and dissolved oxygen, the measuring equipment is thermometer, pH meter, and dissolved oxygen meter, respectively. The water quality parameters were tested at least twice a week during the four weeks.

3.5.1 Water Temperature

The water temperature was measured by using the thermometer. The thermometer was rinsed with distilled water to remove the dirt attached to the thermometer. Next, the thermometer was dipped into the aquarium water, and the water temperature was recorded. The eye-level was parallel to the reading ruler to prevent parallax error.

3.5.2 pH Test

The pH of the system was recorded by using the pH meter at the school laboratory. The pH meter was well calibrated before conducting the pH test. First, 100 mL of water sample was filled in a beaker. The pH probe was rinsed with distilled water to remove impurities and dipped into the water sample. The pH value was recorded once the displayed value was stabilised. Lastly, the pH probe was cleaned with distilled water and wiped with a clean tissue before submerged into a potassium chloride solution.

3.5.3 Dissolved Oxygen Test

The dissolved oxygen was tested using a dissolved oxygen meter. Calibration of the DO meter was conducted before any sample testing. First, the DO meter was warmed up for 15 minutes, and the probe temperature was recorded. Next, the DO meter was adjusted to the location’s altitude and salinity value. Zero salinity was set for freshwater samples. The DO meter was toggled to mg/L unit, and the post-calibration DO reading was recorded. The corresponding DO value for the probe temperature and altitude was obtained from the calibration DO chart. The calibration process was completed once the DO meter and DO chart value had a difference of < 0.3 mg/L. After calibration, the DO test of the water sample was conducted. 100 mL of aquarium water was collected into a cup. The DO probe was rinsed with distilled water and dipped into the water sample. The DO value was measured and recorded when the value on the DO meter was stabilized.

3.5.4 Ammonia Test

The ammonia test kit measures the ammonia concentration in ppm units. It can read from 0 – 8.0 ppm of ammonia concentration. First, a test tube was rinsed with distilled water and cleaned with a dry cloth. 5 mL of aquarium water was filled into the clean test tube. The water sample was added with 8 drops of the 1st ammonia test solution. Another 8 drops of the 2nd ammonia test solution were then added to the water sample. The test tube was homogenised by shaking the test tube for 5 seconds. The solution was stilled for 5 minutes to develop the colour. Lastly, the ammonia concentration in the water sample was acquired by comparing the solution colour with the ammonia colour chart.

3.5.5 Nitrite Test

The nitrite test kit reads the nitrite concentration from 0 – 5.0 ppm. First, a test tube was rinsed with distilled water and cleaned with a dry cloth. 5 mL of aquarium water was filled into the clean test tube. 5 drops of nitrite test solution were added to the water sample. The test tube was homogenised by shaking the test tube for 5 seconds. The solution was stilled for 5 minutes to develop the colour. Lastly, the nitrite concentration in the water sample can be acquired by comparing the solution colour with the nitrite colour chart.

3.5.6 Nitrate Test

The nitrate test kit reads the nitrate concentration from 0 – 160 ppm. First, a test tube was rinsed with distilled water and cleaned with a dry cloth. 5 mL of aquarium water was filled into the clean test tube. 10 drops of 1st nitrate test solution were added to the water sample. Next, the 2nd nitrate test solution was shaken vigorously for 30 seconds. This step is important for the result accuracy. After that, 10 drops of well-shaken 2nd nitrate test solution were dripped into the water sample. The test tube was shaken vigorously for another 1 minute to ensure an accurate result. After the homogenising process, the solution was stilled for 5 minutes to develop the colour. Lastly, the nitrate concentration in the water sample was obtained by the solution colour with the nitrate colour chart.

3.5.7 General Hardness Test

The prepared vial in the test kit was washed carefully with clean water. The vial was filled with 5 mL of aquarium water. 1 scoop of 1st reagent was added to the water sample. After swirling for 10 seconds, 1 drop of 2nd reagent was added to the water sample, and the water sample turned into pink colour. The 2nd reagent was added drop by drop and swirled after each drop until the pink solution turned blue. The number of drops in this step was recorded for total hardness analysis. 1 drop of 2nd reagent is equivalent to 1 degree of German hardness.

3.5.8 Carbonate Hardness Test

The prepared vial in the test kit was washed carefully with clean water. 5 mL of aquarium water was filled into the vial. The test reagent was added drop by drop and swirled after each drop. The colour of the water changed from transparent to blue, followed by a sharp yellow. The number of drops to obtain a sharp yellow water sample was recorded for carbonate hardness analysis. 1 drop of test reagent is equivalent to 1 degree of German hardness.

3.6 Summary

The combination of goldfish and parsley plants was implemented in the mini aquaponic system due to the similar growing criteria of the two species. The aquaponic design concept was based on the DWC method by floating a polystyrene raft with parsleys on the aquarium water. The detailed calculation indicated that the system could fit four goldfish and four parsley plants. However, since goldfish generate a high excretion volume, it is decided to start with a lower stocking density. Two goldfish and four parsley plants were used to start the mini aquaponics. The mini aquaponic system was set up successfully. The procedure descriptions of tank cleaning, equipment setup, and introducing the goldfish and parsley were discussed in Section 3.4. Water quality parameter tests were conducted by following the procedure stated in Section 3.5. The measuring instruments and equipment were the API test kit, hardness test kit, thermometer, pH meter, and dissolved oxygen meter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Costing Summary

The cost of the mini aquaponic system is summarised in Table 4.1. The costing summary discussed in this section provides a rough idea of the initial budget required to set up a mini aquaponic system. The materials and equipment utilised in the project were mainly purchased from aquarium pet shop and online platforms such as Shopee. The costs for the 50-gallon tank, top filter, and bio-media were excluded as they were rented from the school laboratory.

Table 4.1: Costing Summary of the Mini Aquaponic System.

Material/Equipment	**Quantity**	**Cost Included Shipping Fee (RM)**
Leca Clay Pebbles	4	26.60
Goldfish Floating Pellets	1	16.00
10 Pcs. Net Pots	1	21.50
Multifunctional Aquarium Water Pump	1	30.00
Polystyrene Raft	1	19.10
Water Conditioner	1	28.60
Nitrifying Bacteria Solution	1	21.00
API Test Kit	1	124.49
Carbonate Hardness Test Kit	1	24.25
General Hardness Test Kit	1	24.25
Oranda Goldfish	2	16.00
Parsley Plant	2	32.00
Filter Floss	1	6.50
LED Plant Growth Light	1	41.40
Automatic Fish Feeder	1	55.00
Ich Solution	1	10.00
Total Cost		**501.19**

4.2 Water Quality Parameters Results

The monitoring and operation of the mini aquaponic system were conducted for four weeks at the school laboratory. The water quality parameters, such as water temperature, pH value, dissolved oxygen, ammonia, nitrite, nitrate, general hardness, and carbonate hardness, were recorded at least twice a week during the four weeks. The water quality parameters data are tabulated in Appendix B, Table B-1.

4.2.1 Water Temperature Data

Figure 4.1 presents the dynamics of water temperature for the mini aquaponics.

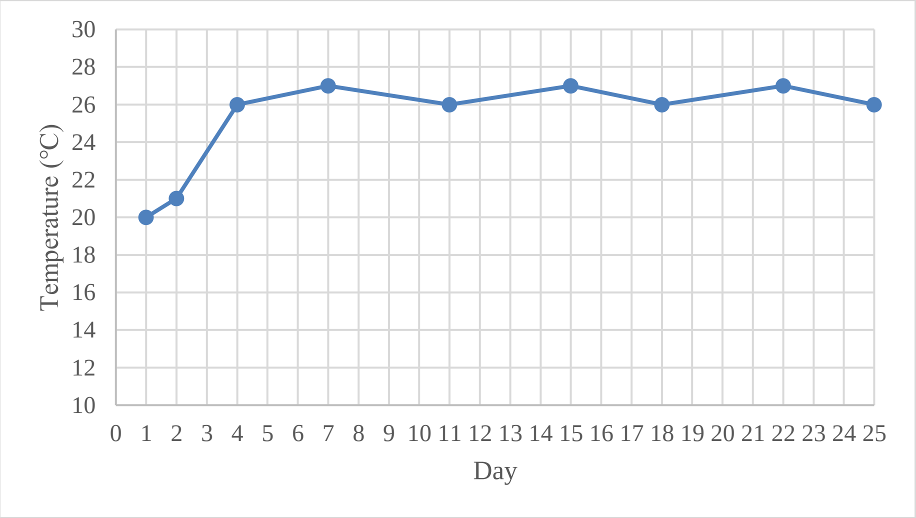

Figure 4.1: Dynamics of Water Temperature.

The overall water temperature of the mini aquaponic system was maintained at 20 – 27 °C. The water temperature recorded for day 1 and 2 was 20 and 21 °C, respectively. The relatively low water temperature was mainly influenced by the operation of the air conditioner in the laboratory. After day 4, the water temperature fluctuated between 26 – 27 °C, around the room temperature. As the optimum water temperature for the goldfish and parsley plant falls between 15 – 25 °C, the water temperature after day 4 slightly overshot the optimum temperature. However, the goldfish and parsley plant can tolerate a slight deviation from the ideal temperature since there was no immediate health impact on them. It is suggested to float a bag of ice on the water surface to lower the water temperature if necessary.

4.2.2 pH Data

Figure 4.2 depicts the dynamics of pH for the mini aquaponic system.

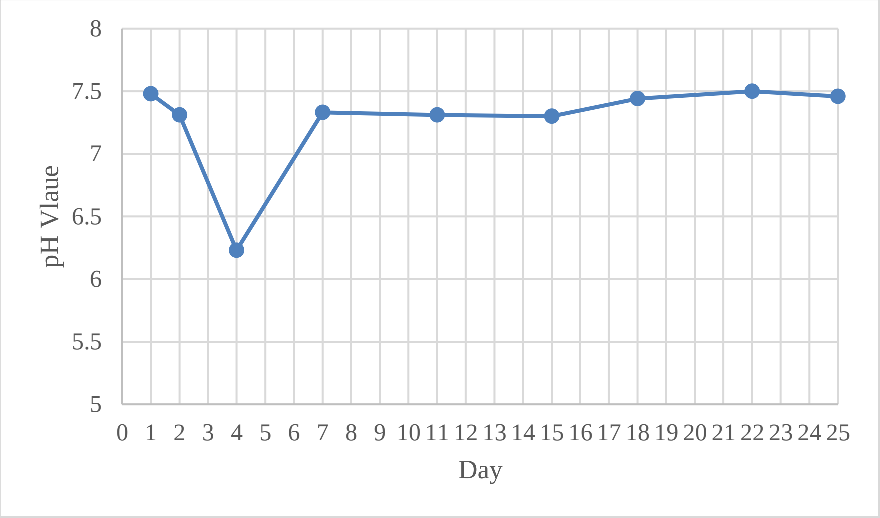

Figure 4.2: Dynamics of pH.

According to Figure 4.2, most of the recorded pH values were around 7.30 – 7.50. These pH values implied slightly alkaline water, which is suitable for the goldfish. Besides, the pH value of the system also fulfils the condition for the nitrification process with the optimum pH range of 6.5 – 8.5 (Filep et al., 2016). However, the pH values were slightly higher than the parsley plant's optimum condition, which is the pH of 6 – 7. It is recommended to provide mild acid such as phosphoric acid (H_3PO_4) to decrease the pH value to favour the parsley plant's growth. Nevertheless, the following action was not taken during the experiment as pH fluctuation will provide stress to the goldfish. On the other hand, the pH for day 4 was 6.23, which seems abnormal. Possible reasons such as the pH meter not being well rinsed or calibrated before testing, may result in a relatively low pH value.

Overall, the pH shows a decreasing trend until day 15 and reached its peak on day 21 before declining towards the end. Masabni and Sink (2020) stated that the pH tends to decrease along the time due to the nitrification process and the fish respiration. The average trend before day 15 shows the system was fulfilled with the condition. On day 15, a water change was performed to remove the organic matter. The presence of the ions in the tap water resulted in a pH rose in the following days.

4.2.3 Dissolved Oxygen Data

Figure 4.3 shows the dynamics of the dissolved oxygen throughout the experiment.

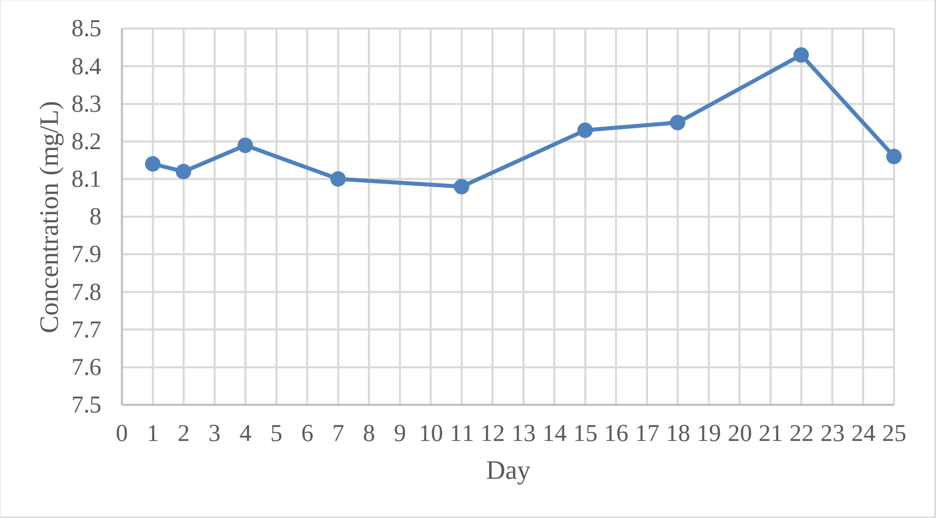

Figure 4.3: Dynamics of Dissolved Oxygen.

According to Filep et al. (2016), nitrifying bacteria require oxygen to oxidise ammonia. The recorded dissolved oxygen concentration values were relatively high, exceeding 8 mg/L. Using the saturation monogram as shown in Appendix C, Figure C-1, the saturation percentage was approximately 100 %, categorised as excellent condition. Above 85 % of water oxygen saturation highly promote the nitrification process. Besides, goldfish and parsley plants can grow well in the water with a dissolved oxygen concentration higher than 3 mg/L. Thus, the finding shows that the living organisms in the system had sufficient oxygen for their survival and development.

4.2.4 Ammonia, Nitrite, and Nitrate Data

Figure 4.4 expresses the dynamics of the ammonia, nitrite, and nitrate throughout the experiment.

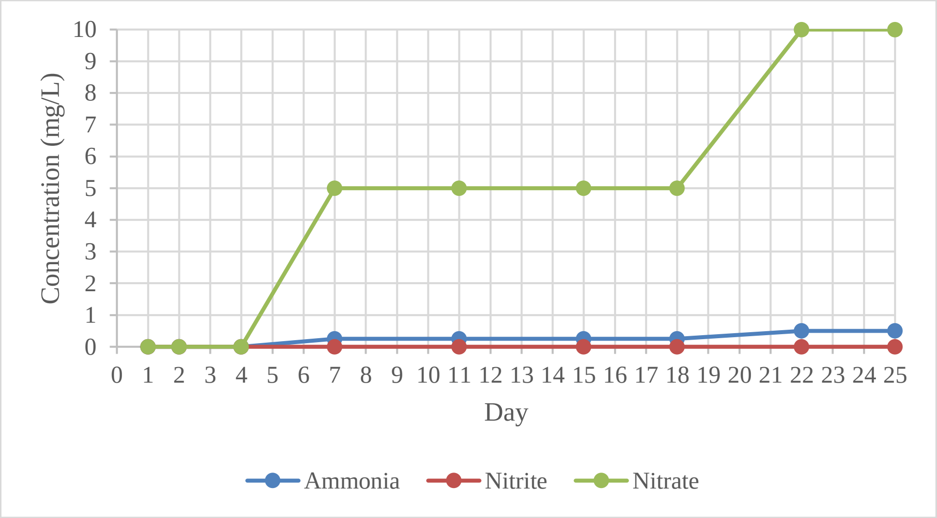

Figure 4.4: Dynamics of Ammonia, Nitrite, and Nitrate.

Regarding the nitrogen composition, the ammonia, nitrite, and nitrate values were not too high. It was noticed that the ammonia concentration gradually increased throughout the experiment. The peak value of the ammonia concentration was 0.50 mg/L, which was recorded on day 22 and day 25. The ammonia concentration increment mainly results from the fish feed and the fish excretion. On the other hand, the nitrite level was maintained at 0 mg/L throughout the four weeks. The results are significant as the goldfish can only tolerate ammonia and nitrite levels less than 1 mg/L and 0.2 mg/L, respectively. High concentrations of ammonia and nitrite are harmful to the goldfish, and long-period exposure to them can be fatal. Thus, the nitrifying bacteria in the system are vital to break down the ammonia and nitrite into nitrate, which is less toxic to the goldfish.

According to Figure 4.4, the nitrate concentration increased to 5 mg/L on day 7 before reaching 10 mg/L on day 22. The condition is acceptable as the ideal is to maintain the nitrate concentration between 5 – 10 mg/L. Although the parsley plant act as a part to remove the nitrate levels, water change is performed once every two weeks to further reduce the nitrate concentration. Besides, it can be assumed that the nitrifying bacteria started to develop between day 4 and day

7 due to the conversion from ammonia to nitrate. However, the constant increment of the ammonia concentration may imply a slow nitrification rate, indicating a low population of nitrifying bacteria present in the system. After consulting the aquarium pet shop owner, the system was added with nitrifying bacteria solution once a day to increase the growth probability of beneficial bacteria. To supply more grow space, more ceramic rings and bio-balls were added to the top filter.

4.2.5 General and Carbonate Hardness Data

Figure 4.5 illustrates the dynamics of the ammonia, nitrite, and nitrate throughout the experiment.

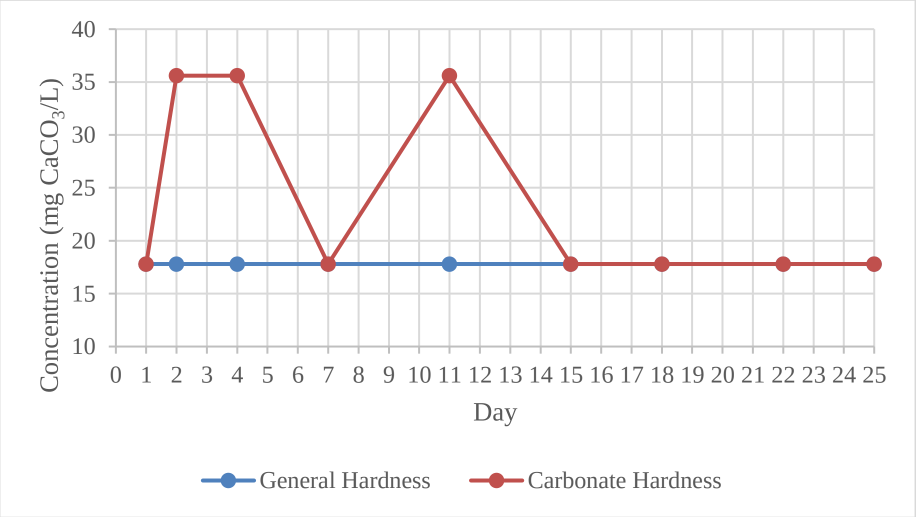

Figure 4.5: Dynamics of General and Carbonate Hardness.

General hardness is the portion of magnesium (Mg^{2+}), calcium (Ca^{2+}), and iron (Fe^{+}) ions present in water. Meanwhile, carbonate hardness refers to the concentration of dissolved carbonates (CO_3^{2-}) and bicarbonates (HCO_3^{-}) in water. The test kit utilised to determine the water hardness was measured in German degree (˚D). With 1˚D equal to 17.8 mg $CaCO_3$/L, unit conversion from German degree to calcium carbonate concentration was conducted to maintain the unit consistency for the water quality parameters. From Figure 4.5, it expresses a constant general hardness dynamic. The general hardness was held at 17.8 mg $CaCO_3$/L throughout the experiment. For carbonate hardness, 17.8 mg $CaCO_3$/L was measured on day 1 before it rose to 35.6 mg $CaCO_3$/L on day

2. The carbonate hardness fluctuated between 17.8 and 35.6 mg $CaCO_3$/L from day 5 to 15 before stabilising at 17.8 mg $CaCO_3$/L during the late stage of the experiment. The inconsistency of the carbonate hardness may be resulted from external factors as there was no additional hardness neutraliser or supplement added during the experiment. For the hardness test, it implements a colour test that lacks specificity and unclear interpretation. As mentioned in Section 3.5.8, the number of test reagent drop to obtain a sharp yellow water sample was used to determine the concentration of carbonate hardness. A sharp yellow colour is very abstract, considering that the surrounding lightning will visually affect the colour. Some samples required 2 drops of test reagent to obtain a sharp looking yellow, which provided a 35.6 mg $CaCO_3$/L reading. Thus, it resulted in the fluctuation of carbonate hardness concentration.

According to the results, the water was considered soft since both general hardness and carbonate hardness fell between 0 – 60 mg $CaCO_3$/L. Chemical additives such as alkaline buffer effectively increase the general and carbonate hardness. However, the following consideration was taken before adding the alkaline buffer. Most of the recorded pH values fall around 7.30 – 7.50, which implies slightly alkaline water. Theoretically, the harder the water, the higher the pH value. Adding alkaline buffer will further increase the pH value and penetrate the optimum pH for the fish. The high pH value will highly affect the goldfish's health. Since the goldfish tolerated well with the soft water, no additional changes to the water environment will benefit the goldfish.

4.3 Parsleys Growth

Some of the parsley cuttings started to show roots development on day 14. It indicates that the parsley accessed some of the nutrients from the water for the root's growth. According to Salvia (2021), plants require at least nitrogen, phosphorus, and potassium, the three main macronutrients, to grow successfully. The function of these nutrients was discussed in Section 2.4.2. Nitrate in the aquaponic system act as the primary source of nitrogen for the parsley plant. The parsley plant could suffer nitrogen deficiency from day 1 to day 7 as the water quality test showed no nitrate concentration in the system. After day 7, the nitrogen content for the parsley plant is abundant due to the intake rate is slower than the nitrate producing rate. It indicates a sufficient nitrogen supplement for the parsley plant after day 7. Unlike nitrogen, phosphorus and potassium cannot be found in water or produced by the goldfish. The parsley plant exhibited phosphorus and potassium deficiency symptoms such as the yellowish leaf, leaf curling, and burnt at the leaf tips during the late stage of the system operation. Aquarium plant fertiliser can be added to the system to provide some vital nutrients for the parsley. Figure 4.6 shows the roots growth and nutrient deficiency observed in parsley at the end of week 4.

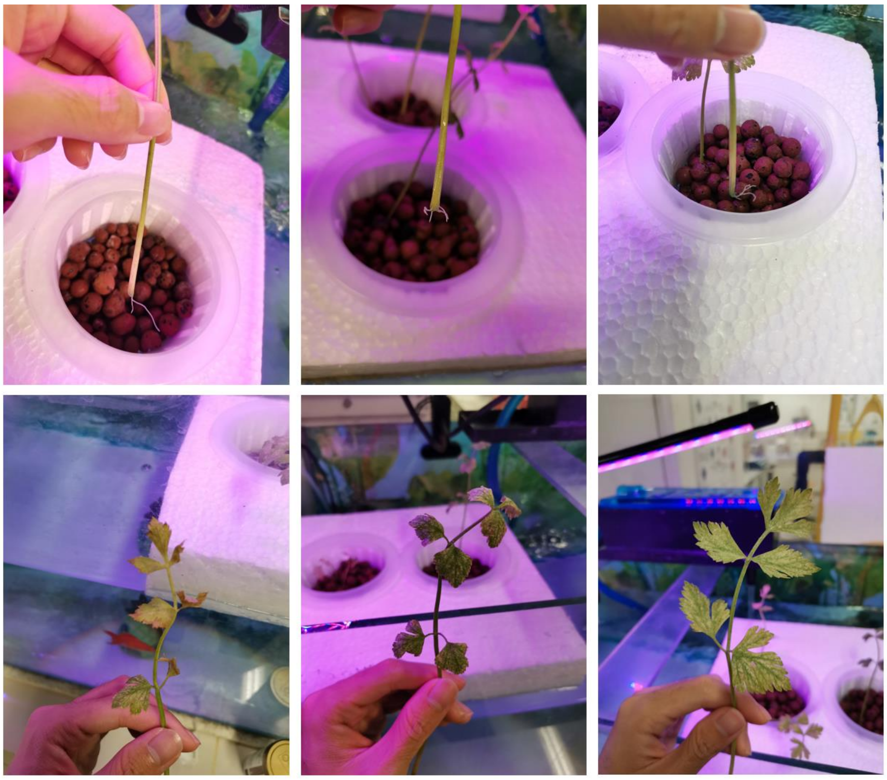

Figure 4.6: Roots Growth and Nutrient Deficiency Observed in Parsley.

4.4 Problems Encountered

There were several challenges faced during the operation of the mini aquaponic system. The problems that occurred directly affect the performance of the aquaponic system. The issues encountered are discussed in this section to provide the related information to other aquaponic hobbyists.

4.4.1 Ich Disease

Ich disease or white spot disease is one of the most prevalent diseases in freshwater fish. This disease is mainly infected by a ciliated protozoan known as *Ichthyophthirius multifiliis*. The outbreak temperature of this disease is 15 – 25 ℃ (Muhammad Imran et al., 2021). The immature parasite presence in the water attaches itself to the fish skin surface and develops between the fish epidermis and dermis. The matured parasite will fall off the host and replicate to produce a vast number of progenies in the water. Fish suffering from Ich disease will have white spots on the body, gills, or fins. Other symptoms include fast breathing, hiding behaviour, and rubbing the body against a rough surface. Immediate treatment for Ich disease is crucial to prevent fish mortality (Ade and Makode, 2021).

On day 10, it was noticed that one of the goldfish had white spots on the body, tail, and fins. The infected goldfish exhibited a hiding behaviour by dodging another goldfish when it moved near to the infected goldfish. Although the infected goldfish still consume feeds during the feeding period, the consuming rate was relatively slow compared to the uninfected goldfish. It was suspected that the goldfish might suffer from Ich disease with the symptom described above. According to Francis-Floyd and Reed (2013), adding copper sulphate and formalin are effective treatments for Ich disease. The Ich treatment solution was purchased from the nearby aquarium pet shop and introduced into the aquarium water based on the recommended portion. Providing treatment to the water will eliminate the premature Ich in the water body. As a result, the white spots had disappeared from the body of the infected goldfish on day 14. It is suggested to add the Ich treatment solution and cycle the water before introducing the goldfish into the aquaponic system. This precaution can prevent the fish from suffering ich disease during the system operation. Figure 4.7 shows the goldfish infected with Ich disease.

Figure 4.7: Goldfish Infected with Ich Disease.

4.4.2 Spider Mites

Spider mites were constantly noticed at the parsley plant throughout the experiment. It is one of the common pest problems in gardening plants. Spider mites are classified as an arachnid, closely linked to the spider due to their eight legs. The most obvious identification of spider mites is the webbing around the parsley leaves. Spider mites produce webs to protect themselves and their eggs against natural adversaries and environmental variations. These pests will injure the parsley by bruising the plant cells and consuming the sap. Damaged regions are generally marked with tiny spots and a speckled appearance. As a result, the stressed parsley leaves get discoloured and start to wither (Cranshaw and Sclar, 2014).

Some of the parsley cuttings were infested with spider mites. The spider mites were observed during the first-week operation of the mini aquaponics. It was predicted that the pests had started to develop at the main plant before transferring into the aquaponic system. Physical control was implemented frequently by spraying water around the parsley leaf to reduce the pest, webs, and eggs. This method is only sufficient to reduce the population but not entirely remove it. The most effective way to eliminate spider mites is to provide pesticides or insecticides (Cranshaw and Sclar, 2014). However, this method was not implemented as the chemical could harm the goldfish and beneficial microorganisms. It is suggested to provide chemical control before transplanting the parsley into the aquaponic system. Figure 4.8 illustrates the parsley plant infested with spider mites.

Figure 4.8: Parsley Plant Infested with Spider Mites.

4.5 Summary

The total cost utilised to set up the mini aquaponic system was RM 501.19, not including the material and equipment rented from the school laboratory. The recorded value of water temperature, pH, dissolved oxygen, ammonia level, nitrite level, nitrate level, general hardness, and carbonate hardness was 20 – 27 ℃, 6.23 – 7.50, 8.08 – 8.43 mg/L, 0 – 0.5 mg/L, 0 mg/L, 0 – 10 mg/L, 17.8 mg $CaCO_3$/L, and 17.8 – 35.6 mg $CaCO_3$/L, respectively, throughout the four weeks. The findings show that most water quality parameters are suitable for the goldfish and parsley plant except for the low water hardness. Besides, the outcomes show that the parsleys had assimilated some nutrients in the water for their root development. However, the nutrients deficiency symptoms exhibited by the parsleys during the late stage of system operation indicate the lack of phosphorus and potassium nutrients. Some of the problems encountered, such as Ich disease and spider mites' infestation, also directly affected the performance of aquaponics. The performance of the mini aquaponic system is moderate, considering that some enhancements are necessary to be implemented.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The study aims to develop a complete operation of a mini aquaponic system with an appropriate design and monitoring process. All the specific objectives to accomplish the aim of the study were achieved. The important aspects related to aquaponics, such as the system designs, fish and plant aspects, and water quality parameters were successfully reviewed in Chapter 2. The most common aquaponic system designs are Nutrient Film Technique (NFT), Media Bed, and Deep Water Culture (DWC). Each design has its advantages and disadvantages. For fish species, it is classified into edible and ornamental species, which is selected based on the aquaponic operational purpose. Other aspects, including fish nutrition, fish health and behaviour, are essential to provide appropriate fish care. Meanwhile, the typical plant species for aquaponics are leafy greens, herbs, and fruiting crops. A good understanding of the plant nutrients and pest management will highly encourage the plant's growth in aquaponics. Subsequently, the five main water quality parameters for aquaponics monitoring are dissolved oxygen, pH, water temperature, nitrogen composition, and water hardness. Each parameter has its impact on the aquaponics system, and it is critical to maintain it at the ideal range

After reviewing the design parameters and operational aspects, a mini aquaponic system was successfully designed. A combination of two goldfish and four parsley plants was implemented in the mini aquaponic system due to the similar growing criteria of the two species. The aquaponic design concept was based on the DWC method. The mini aquaponic system was operated for four weeks, and the water quality parameters were measured with appropriate test equipment at least twice a week.

The recorded value of water temperature, pH, dissolved oxygen, ammonia level, nitrite level, nitrate level, general hardness, and carbonate hardness was 20 – 27 °C, 6.23 – 7.50, 8.08 – 8.43 mg/L, 0 – 0.5 mg/L, 0 mg/L, 0 – 10 mg/L, 17.8 mg $CaCO_3$/L, and 17.8 – 35.6 mg $CaCO_3$/L, respectively, throughout the four weeks. Most of the water quality parameters are suitable for the goldfish and parsley plant except for the low water hardness. Besides, the parsleys had assimilated some nutrients in the water for their root development. However, the nutrients deficiency symptoms exhibited by the parsleys during the late stage of system operation indicate the lack of phosphorus and potassium nutrients. In short, the performance of the mini aquaponic system throughout the four weeks was moderate, considering that the system still requires amelioration.

5.2 Recommendations for Future Work

The project was not thoroughly studied due to the time restriction and cost limitations. The imperfect preparation works and lack of experience in the aquaponic operation could affect the study's outcome. Besides, the insufficient budget also restricted the materials and instruments used in the project. As a result, the following recommendations are suggested to enhance the future development of an aquaponic system:

1. The aquarium is recommended to be fully cycled before adding the fish and plants. A fully cycled tank means that the nitrifying bacteria are well developed in the system. With this, it benefits the health of fish and plants.
2. A quarantine tank should be prepared to isolate the fish infected with diseases and provide necessary treatment. New fish also should be quarantined before introducing into the main tank.
3. A spectrophotometer is suggested to test the concentration of ammonia, nitrite, nitrate, and water hardness for a more accurate reading. The colour test kit implemented in the study is only sufficient to estimate the value.
4. Ich solution should be added to the water before adding the fish to prevent the fish from suffering Ich disease.
5. Frequently inspect the fish and plant conditions and provide the necessary solution to cure the abnormal condition.

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APPENDICES

Appendix A: Figures of Water Quality Parameters Result Samples.

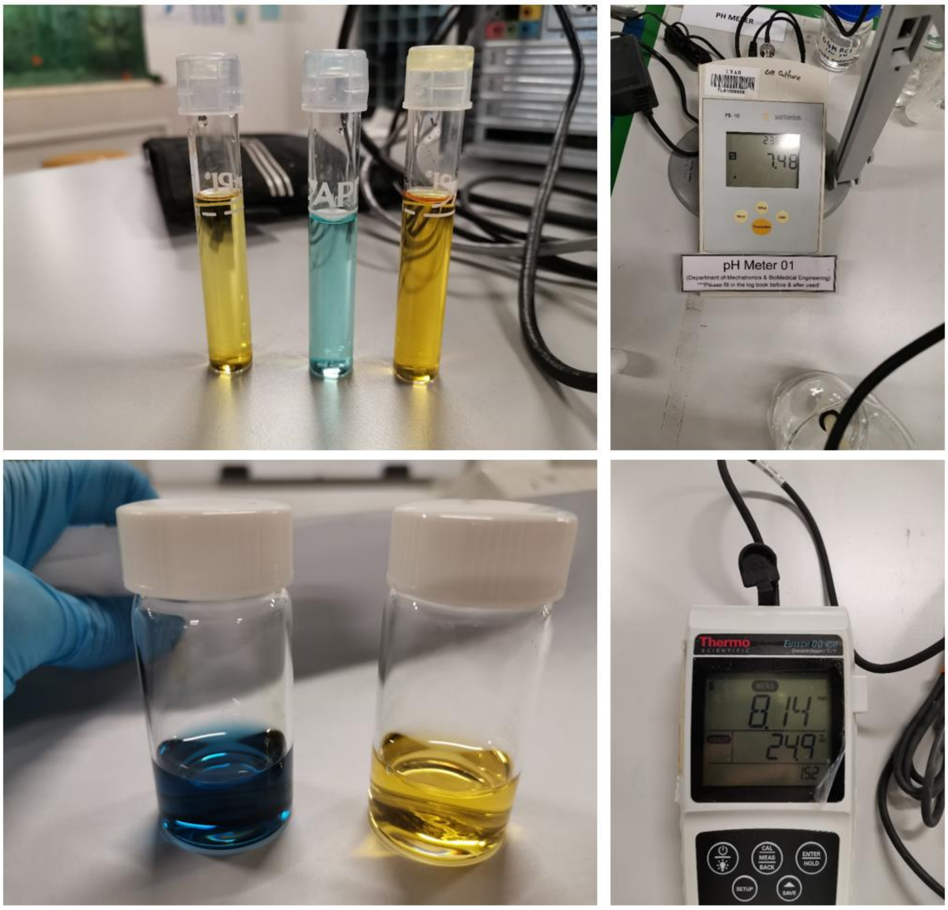

Figure A-1: Water Quality Parameters Result on Day 1.

Figure A-2: Water Quality Parameters Result on Day 2.

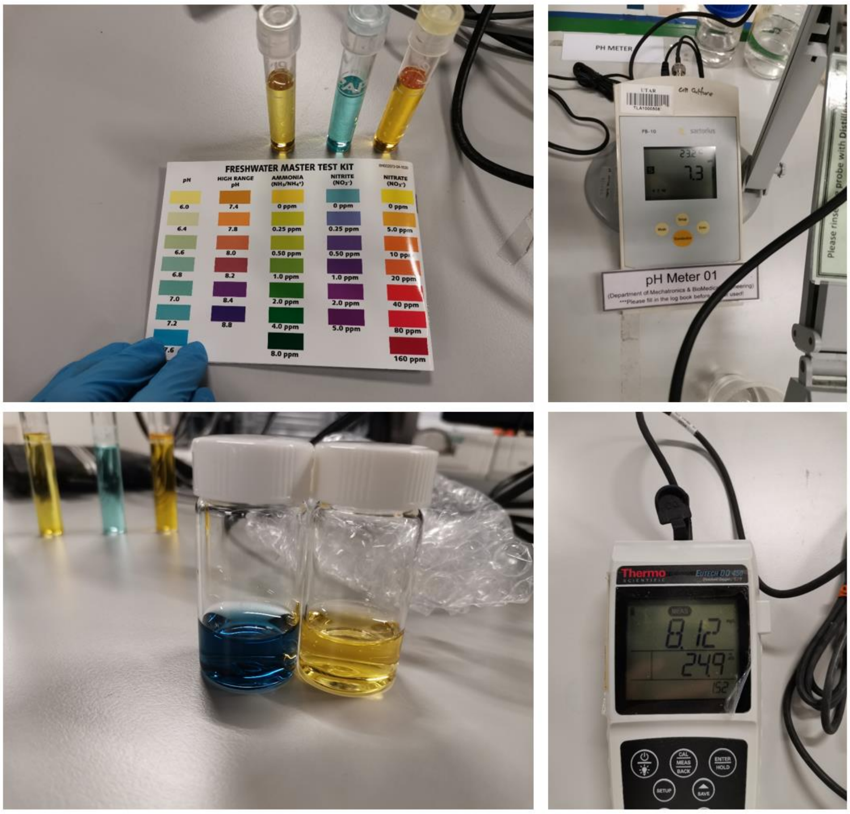

Figure A-2: Water Quality Parameters Result on Day 2.

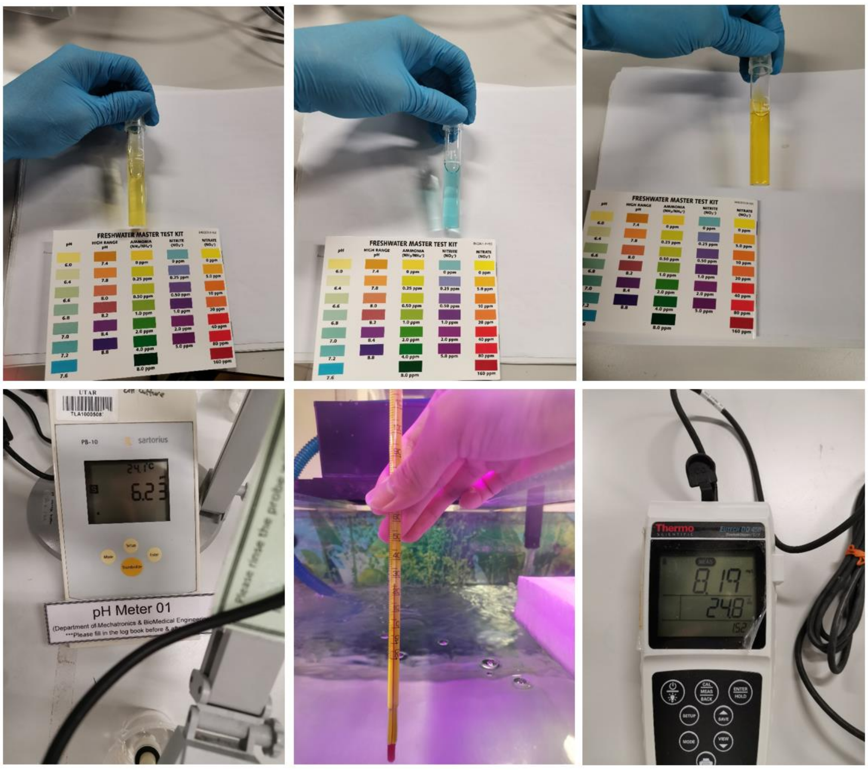

Figure A-3: Water Quality Parameters Result on Day 4.

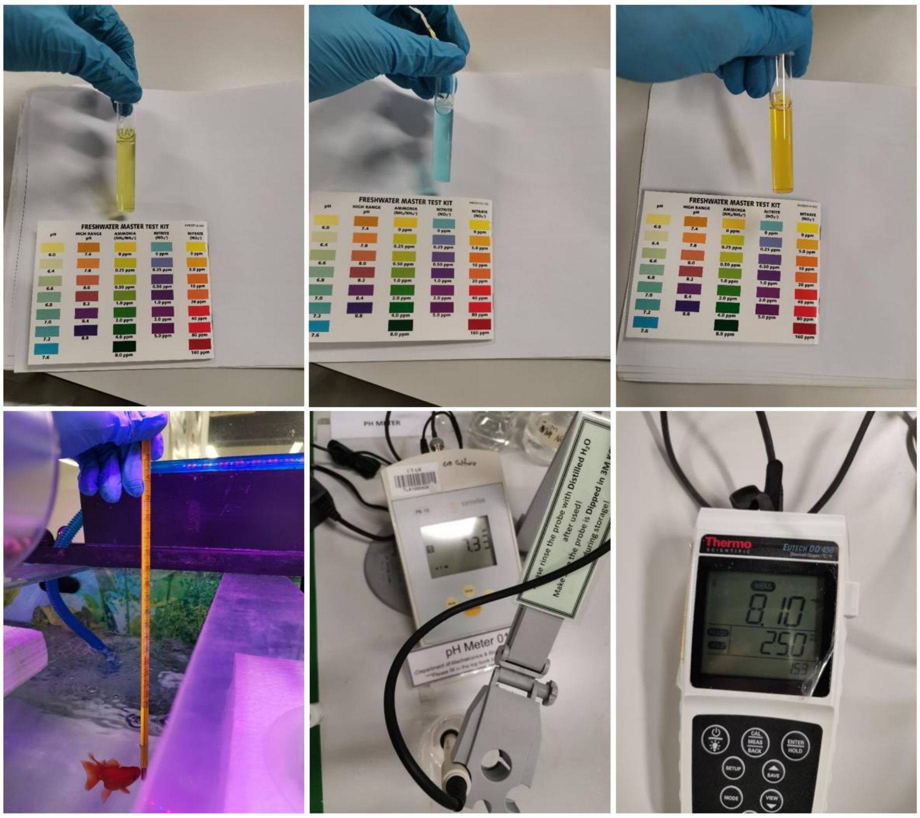

Figure A-4: Water Quality Parameters Result on Day 7.

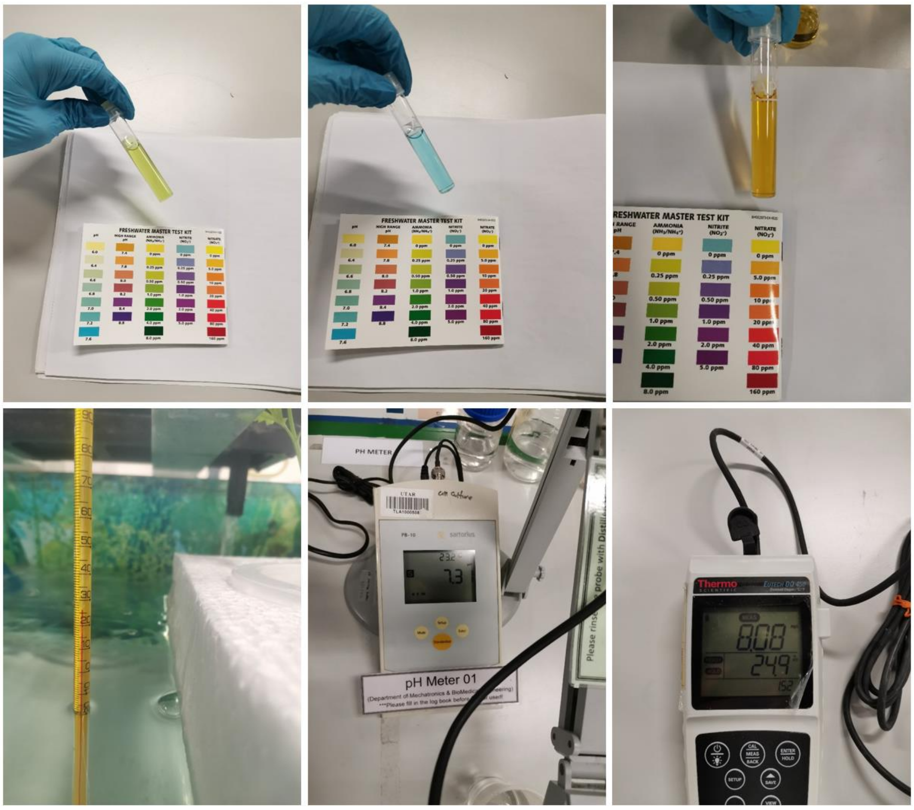

Figure A-5: Water Quality Parameters Result on Day 11.

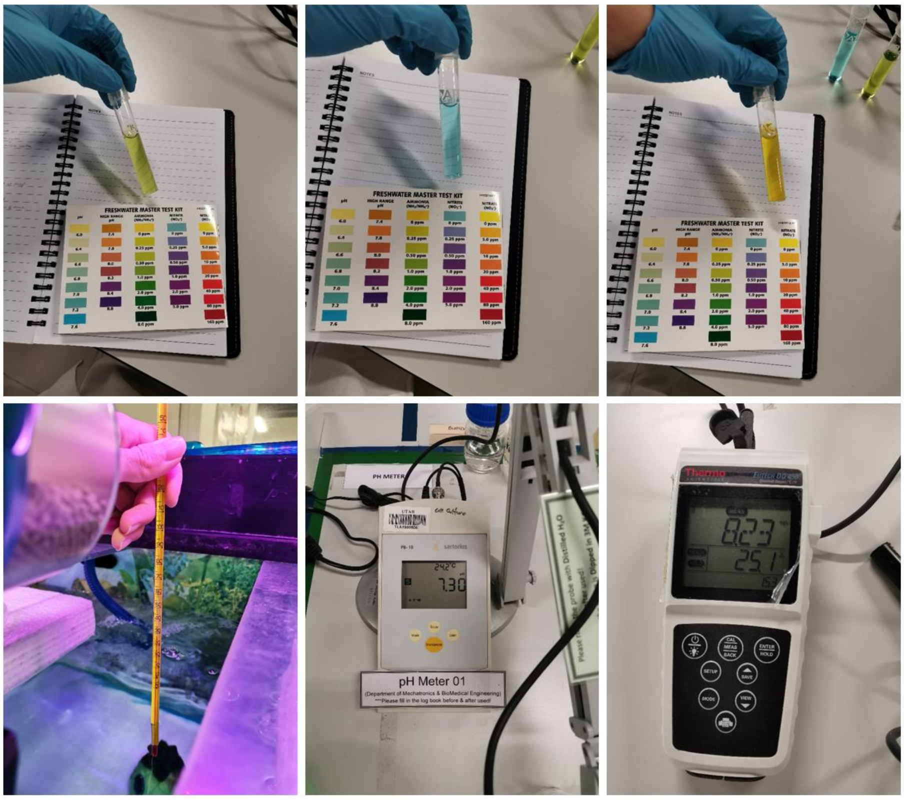

Figure A-6: Water Quality Parameters Result on Day 15.

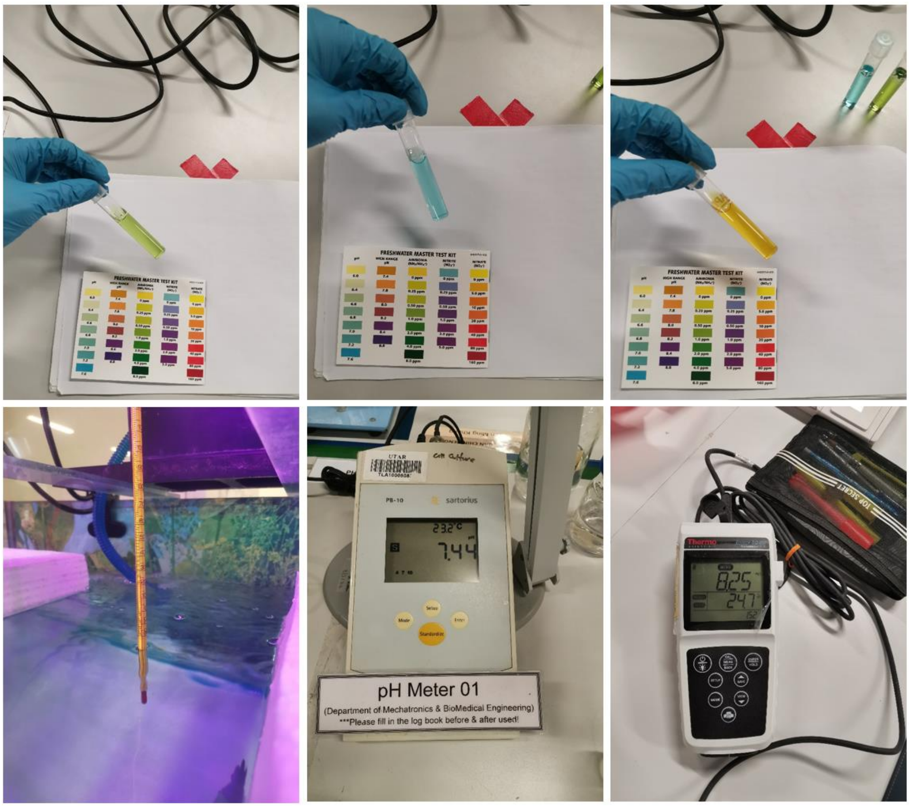

Figure A-7: Water Quality Parameters Result on Day 18.

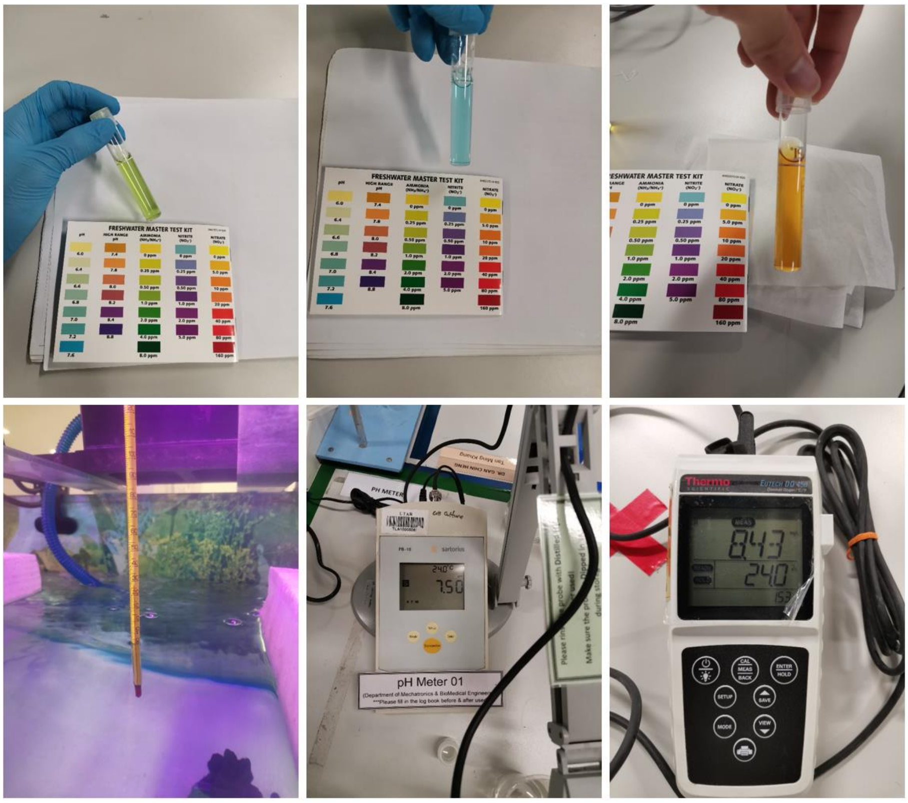

Figure A-8: Water Quality Parameters Result on Day 22.

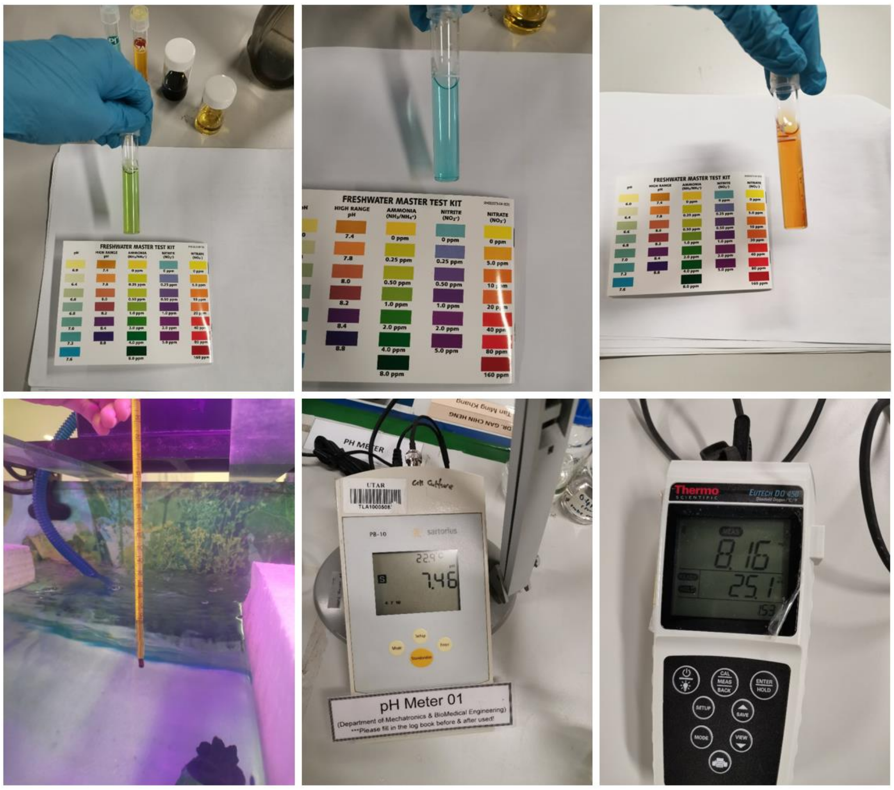

Figure A-9: Water Quality Parameters Result on Day 25.

Appendix B: Water Quality Parameters Result.

Table B-1: Water Quality Parameters Result.

Day / Parameters	**Water Temperature (°C)**	**pH**	**Dissolved Oxygen (mg/L)**	**Ammonia (mg/L)**	**Nitrite (mg/L)**	**Nitrate (mg/L)**	**General Hardness (mg $CaCO_3$/L)**	**Carbonate Hardness (mg $CaCO_3$/L)**
1	20	7.48	8.14	0	0	0	17.8	17.8
2	21	7.31	8.12	0	0	0	17.8	35.6
4	26	6.23	8.19	0	0	0	17.8	35.6
7	27	7.33	8.10	0.25	0	5	17.8	17.8
11	26	7.31	8.08	0.25	0	5	17.8	35.6
15	27	7.30	8.23	0.25	0	5	17.8	17.8
18	26	7.44	8.25	0.25	0	5	17.8	17.8
22	27	7.50	8.43	0.5	0	10	17.8	17.8
25	26	7.46	8.16	0.5	0	10	17.8	17.8

Appendix C: Saturation Monogram.

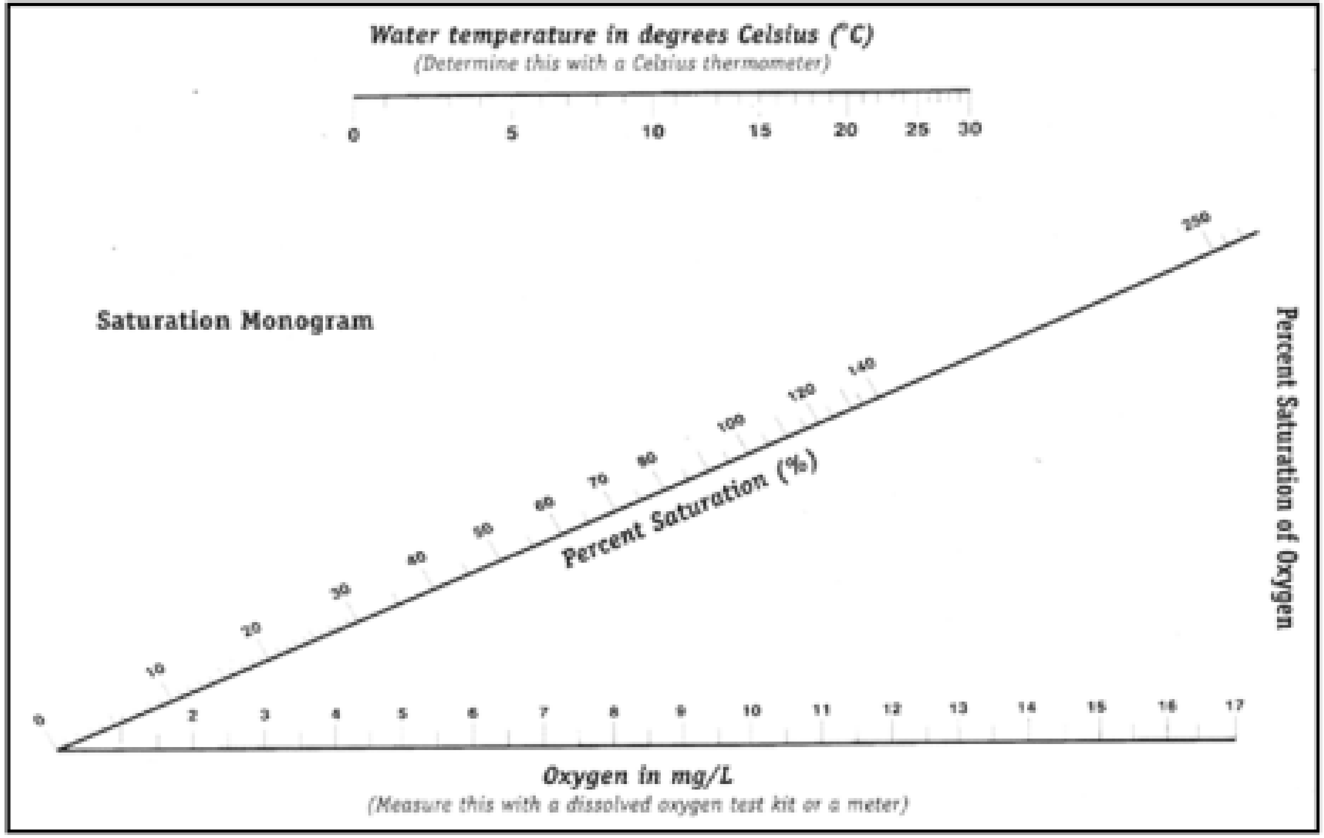

Figure C-1: Saturation Monogram (West Virginia Department of Environmental Protection, 2022).