Design and Prototype Development of Aportable Vertical Aquaponic System for High Residential Application

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ABSTRACT
Most commercially available aquaponic systems are the horizontal system with larger space requirements. This study aims to design and develop a portable vertical aquaponic system. This system is specifically directed to the application of the high residential area where space is limited. The prototype features double aquaponic towers with multiple vegetable pots equipped with angle bar for handling and wheel for mobility. The performance of the vertical aquaponic system was evaluated using Chinese cabbage as well as Tilapia and Koi fish as the aquatic species. Evaluation of plant height and leaf width showed an increasing plant growth over time. This study indicates the prototype could be explored as a small-scale aquaponic systems for educational or ornamental purposes.

Keywords: Aquaponic; Vertical aquaponic system; Mechanism design; Prototype development

INTRODUCTION
Aquaponic is an integrated farming concept that combines aquaculture and hydroponic in a recirculation water system (Delaide et al., 2017). Aquaculture is the most popular technique for fish farming especially in the East Asia region to cater the demand global consumption for fish. However, this method has increased the eutrophication burden of food cultivation by flushing nutrient-rich wastewater into surrounding ecosystem (Cohen et al, 2018). On the other hand, in aquaponic practice the fish water which contains fish wastes is enriched with nutrients and will be used as the feed for the plants after a nitrification process. The plants, which act as a biofilter that will cleanse the water before recirculating it back into the fish tank. Nutrient removal by plants might improve the quality of effluent and enhance fish production (Kyaw & Ng, 2017). The application of aquaponic is advantageous compared to traditional farming due to the low land requirement, improving food security, sustainable food source and water efficient process (Saha et al., 2016).

Generally, an aquaponic systems consists of a recirculated system for fish aquaculture and hydroponics for plant production. The essential element in a aquaponic system are the fish-rearing tanks, solid removal components (mechanical filtarion), biofilters (nitrification unit), hydroponic component and a sump (Palm et al., 2018). A pump is needed to recirculate the water constantly and oxygen will be supplied by air blower while the temperature is being controlled (Delaide et al., 2017).

A vertical aquaponic system is a concept for the aquaponic system which incorporated a vertical farming technique. In this system, the plants grow in a vertical hanging structure rather than spread across a horizontal surface (Hong, 2016). This system allows the efficient use of space and possible application in limited space areas such as the greenhouse, building, rooftop or even window (Bareja, 2016). The most common products in vertical farms are lettuce, leafy greens, herbs, strawberries and cucumber (Kalantari et al., 2017).

Therefore, the aim of this study is to design and develop a prototype of a portable vertical aquaponic system (VAS) for the community living in the high residential such as apartment and condominium. The small size and portable design of VAS allows the system to be used in small and cramped area. Hence, this will promote the urban farming lifestyle and provide natural environment within the community. In addition to that, the evaluation of plant growth using VAS prototype was also studied to investigate the working performance of the VAS prototype.

DESIGN METHODOLOGY

Design Concept

Initially, there were two designs for the VAS system including Design A and Design B as illustrated in Figure and Figure 2, respectively. Design A features a simple design that is similar to the existing product in the market. On the other hand, Design B was designed based on the tiffin concept, ergonomic features with an aquaponic tower to support the PVC pipes and equipped with wheels for movement.

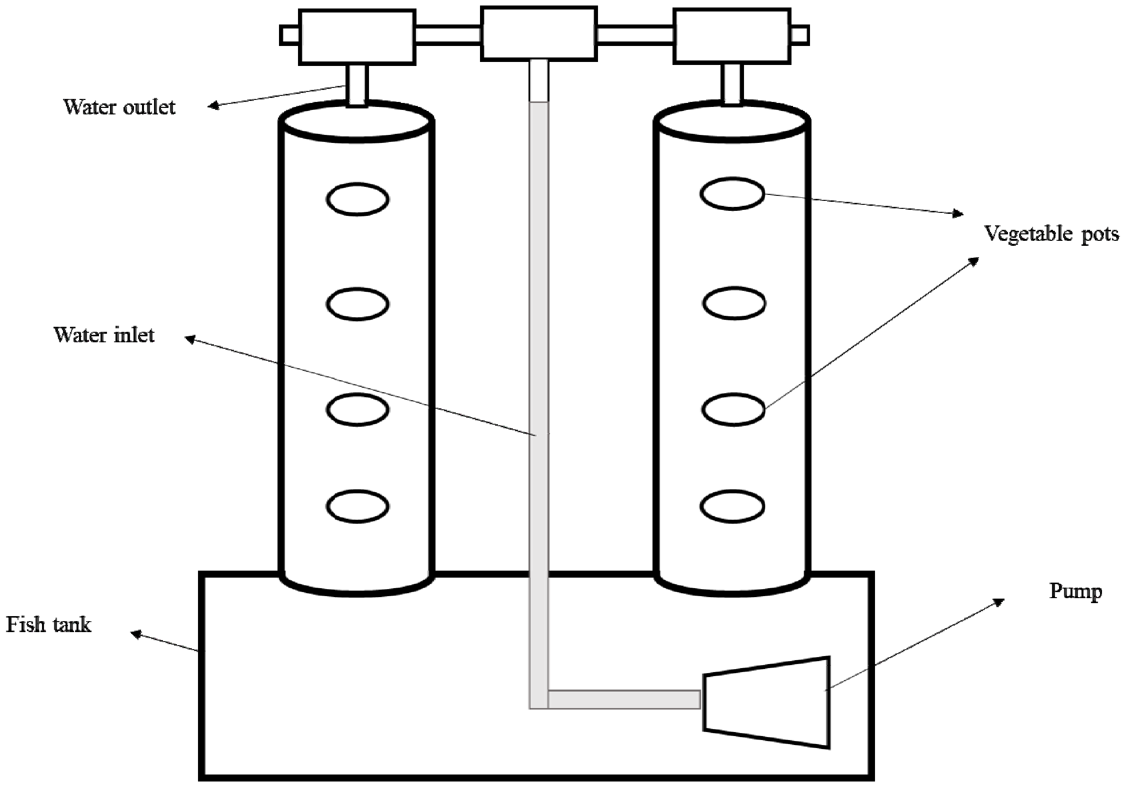

Figure 1 Conceptual design for Design A

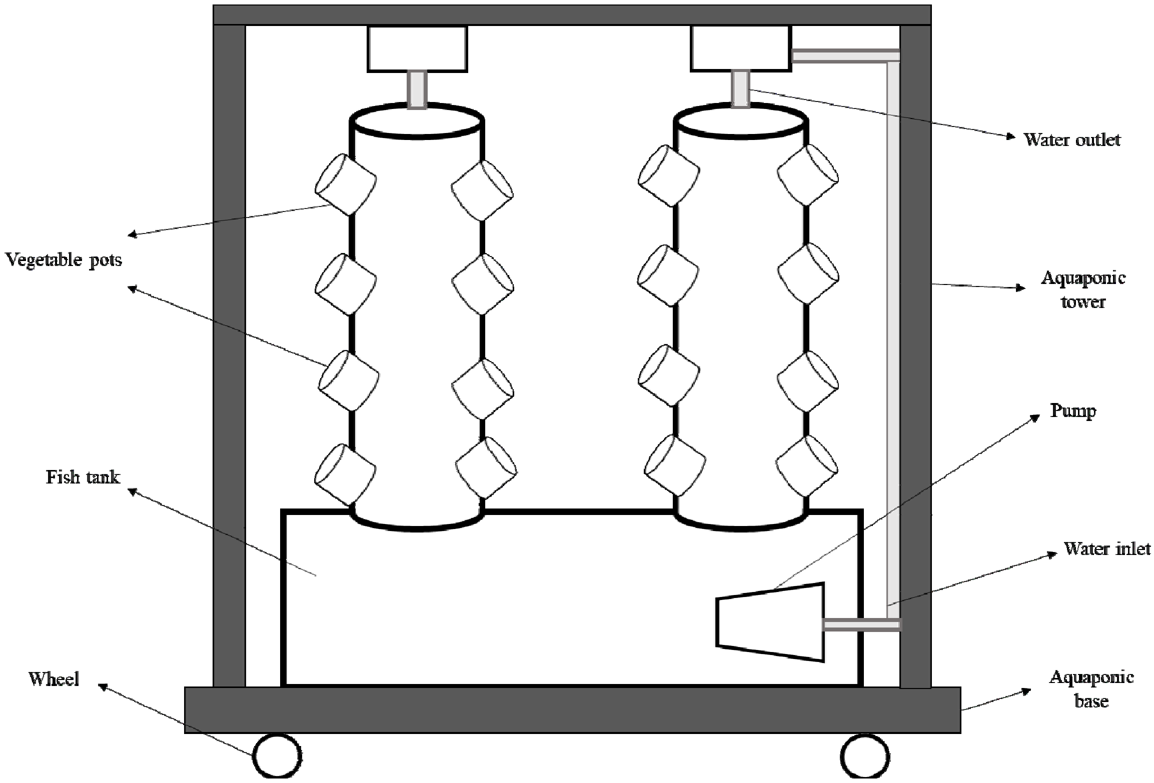

Figure 2 Conceptual design for Design B

Concept screening and a scoring test was conducted to select the best design concept for VAS prototype. The general purpose of VAS is to provide for the community who lived in a highly residential area such as condominium and apartment. Therefore, VAS must have certain criteria such as easier operation, low maintenance, light and easy to be moved around, easier for the user to assemble and disassemble by themselves as well as ergonomic and attractive design. Table 1 presents the result for concept screening and scoring test for the determination of suitable design for VAS system. For each selection criteria, the design was then judged as either better (+), worse (-) or same (0) for comparison. Total for the (+) sign and (-) sign was given for each design. From the analysis, design B was chosen due to an easier operation, mobility, ergonomic and more attractive design features as compared to design A.

Table 1 Concept screening and scoring test for VAS system

Selection Criteria	Design A	Design B
Ease of handling	-	+
Ease of maintenance	-	-
Light	0	0
Mobility	0	+
Ease of assembly and disassembly	+	+
Ergonomic	-	+
Attractive	-	+
Sum of (+)	1	5
Sum of (0)	2	1
Sum of (-)	4	1
Selection	No	Yes

DESIGN DEVELOPMENT OF VERTICAL AQUAPONIC SYSTEM (VAS)

Figure 3 shows the final product of the VAS prototype. The VAS prototype was built with an approximate width of 2 ft. and height of 7 ft. It consists of a few major components including double aquaponic towers, vegetable pots and fish tank. In addition, it is equipped with a wheel for mobility and angle bar for ease of handling. The main components of the VAS prototype are listed in Table 2. The selection of material was done in accordance with the function of each VAS components and their characteristics.

Figure 3Final product of VAS prototype

Table 2 Main components of VAS prototype

Parts	Material	Function	Characteristic
Angle bar	Steel	• As a support for the VAS system	• High strength
Aquaponic tower	PVC	• Vertical tower to hold the vegetable pots	• Waterproof • Easy to use
Vegetable pots	PVC	• As a place to grow plants or vegetables	• Waterproof • Easy to use
Fish tank	Glass and acrylic, aquarium	• As a cultivation tank for fish	• Air tight and waterproof • Non toxic substances
Aquarium cover	Acrylic	• To prevent from contamination	• Rigid • Good impact strength
Aquarium base	Steel	• As a support for fish tank	• High strength
Water recycling system	PVC	• To provide water inlet from fish tank to vegetable pots	• Waterproof • Easy to use
Jet sprayer		• To supply water to the plants	• Durable
Water filter		• To filter water • To prevent pump and pipe clogging	• Durable
Pump	Stainless	• To supply water	• Durable

	steel	from fish tank to plants	
Wheel		• For movement	• High strength • Durable

Vegetable Pots and Tower System

The vegetable pots and aquaponic tower were made from PVC materials. It serves as the area that plants or vegetables grow. The use of PVS is advantages since it is a light material, waterproof and easy to be used. The aquaponic tower consists of two PVC pipes that contain eight pots per cylinder. A steel angle bar was used as a tower to hold both pipes. For planting process, jiffy cocoa peat was used as a growth medium to increase the porosity of the potting mix. In addition, it improves the water holding capacity that ensures that the plant does not suffer any over watering of under watering. Chinese cabbage was used as the plant in this study.

Fish Tank and Water Recirculation System

VAS prototype uses an aquarium as a fish tank due to non-toxic material of aquarium that will not affect the pH and ammonia levels in the system. Additional ventilation was added to maintain a clean environment for fish cultivation. Two types of fish were studied using the VAS system including Tilapia and ornamental fish which is Koi. For a water recirculation system, a 160GPH submersible water pump was used in the system. The pump was connected to a PVC pipe which directly connected to the aquaponic tower to allow water to flow down through each pot in the pipes.

PERFORMANCE OF VERTICAL AQUAPONIC SYSTEM (VAS)

Plant Growth Evaluation

To assess the overall system performance, data on the fish and plant growth were collected. Plant growth was monitored by measuring the plant height and leaf width of all Chinese cabbage in the duration of five weeks. Figure 4 shows the variation in plant height on weekly basis using VAS prototype. The result shows a positive plant growth as indicated by increasing plant height by weeks. A linear regression model was employed on the evaluation of plant height and the coefficient of determination, R^2 value was calculated to measure the goodness of fit of the model. The linear regression model of $y_h = 2.5x - 0.56$ with R^2 value of 0.9785 was formulated for the plant height over time, where y_h is the plant height (cm) and x is the number of the week.

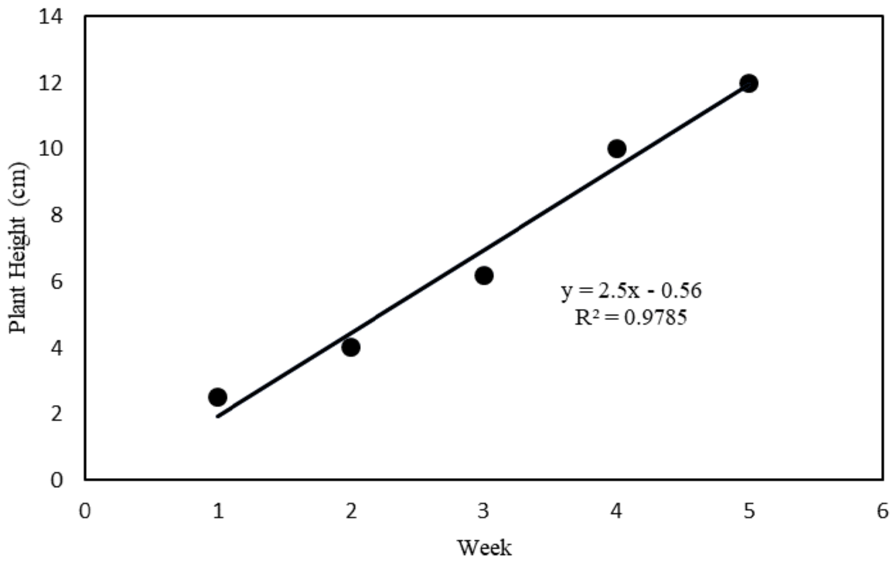

Figure 4 Variation in plant height by week

Figure 5 illustrates the variation in leaf width by week. From observation, the leaf width of Chinese cabbage is increased over time indicating a good growth environment provided by the VAS prototype. Linear regression analysis was computed on the leaf width and resulted in the generation for the linear model of $y_w = 1.61x - 0.51$ where y_w is the leaf width and x is the number of the week. The linearity of the established model was confirmed with a high R^2 value of 0.9183.

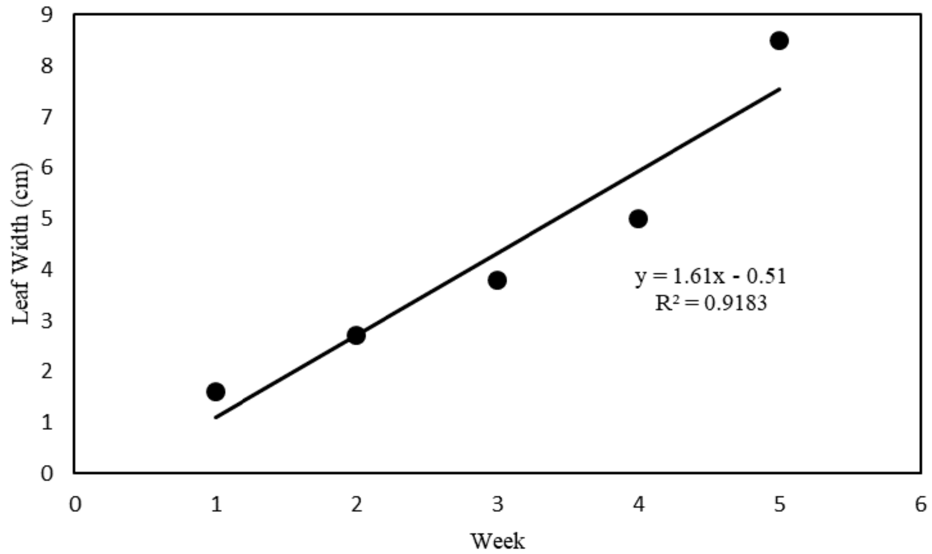

Figure 5 Variation in leaf width by week

Plant Growth Comparison using Tilapia and Koi fish

In this study, two types of fish were used namely Tilapia and Koi (ornamental). The plant height of Chinese cabbage was recorded on weekly basis for the duration of five weeks and presented in Figure 6. The result indicates that the plant height is increased in the duration of five weeks by using either Tilapia or Koi fish. Both types of fish provide a sufficient amount of nutrient for plant growth. This indicates that the VAS prototype is not only capable to be used as a small agricultural production but also as a decorative aquarium for ornamental purposes.

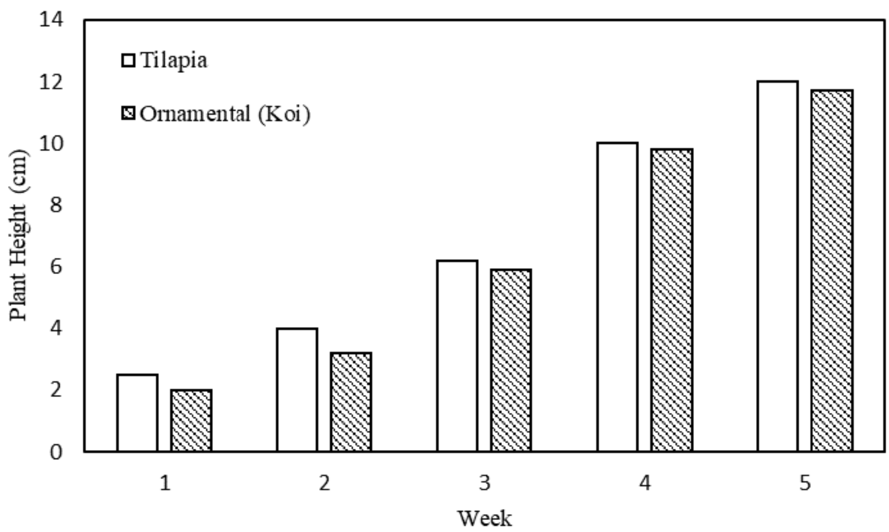

Figure 6 Plant height of Chinese cabbage using Tilapia fish and ornamental (Koi) fish by week

The plant growth rate using VAS prototype on weekly basis were recorded. Figure 7 shows the comparison of plant growth rate using VAS prototype with Tilapia and Koi fish. Weekly height measurements of the Chinese cabbage showed a consistently higher growth pattern for VAS prototype using Tilapia fish compared to Koi fish. Tilapia is widely used in aquaponic systems due to a good level of tolerance in various environmental conditions (Effendi et al., 2017). In addition, Tilapia are fast growing species and efficient at converting food into body mass (Effendi et al., 2018). The fish waste served as the primary nutrient source for the plant growth. However, it can be observed from the figure that there is a fluctuation in the growth rate in the duration time. The slightly lower growth rate was observed in week 2 using either Tilapia or Koi fish. Nevertheless, the growth rate of Chinese cabbage found in this study (1.6 – 2.45 cm/week using Koi fish and 2 – 2.5 cm/week using Tilapia fish) fall within the range reported using different types of plants (Endut et al., 2010). Overall observation during the five-week period indicates that the plants grew actively and did not identify any signs of nutritional deficiencies or mineral imbalances.

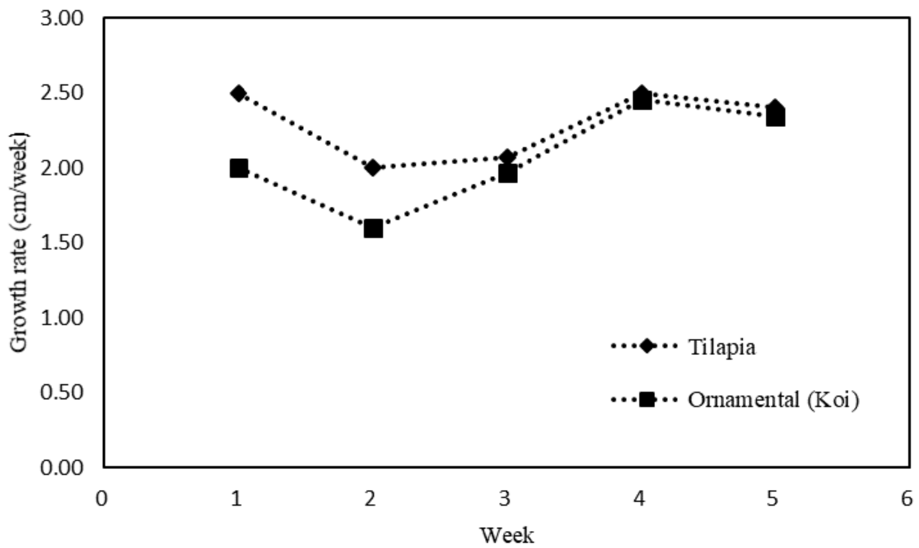

Figure 7 Comparison of plant growth rate using VAS prototype with Tilapia and Koi fish

CONCLUSION

This study provided a detailed discussion of the concept design and prototype development of VAS system. The proposed design of the VAS prototype showed a vertical unit of the aquaponic system that is space saving with a portable feature that make it easier to be moved around from one place to another. In addition to that, the VAS prototype was ergonomically designed with steel angle bar to provide support to the system as well as for easier handling to the consumer. The results reported on working performance showed the good potential of VAS prototype in fish cultivation as well as plant growth. Overall, the proposed VAS prototype provides reliable data as a small-scale aquaponic system.

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