DESIGN AND DEVELOPMENT OF VERTICAL AEROPONIC SYSTEM

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ABSTRACT

Aeroponics farming system offers many advantages in crop planting compare to conventional planting methods. Furthermore, it uses less water compare to hydroponics systems as the roots are exposed to the air and nutrient-rich mist. In this study new prototype of a vertical aeroponic system was designed and developed with an interchangeable planting wall to facilitate the transplanting, maintenance and harvesting process. The prototype consists of the main structure frame, irrigation system and monitoring and control system. The upper part of the main frame structure is made from aluminium while the bottom part is made from mild steel to ensure a stronger support to the whole structure. To maximize plant capacity, the structure has been designed with a hexagon shape where a total of six interchangeable planting walls can be used at one time. WIFI type pump was used to set the required water pressure according to the pressure specification of the sprayer. This system is also equipped with temperature and humidity sensors to record the effect of external environment parameters on the system. The timer was used to control the misting interval. The functional test of the system was carried out by planting 4 types of crops which are Japanese choy sum, Chinese broccoli, Pak choi and lettuce. As a result, all crops were successfully grown and the weight of the crops was recorded to study the uniformity of the crop growth between each wall.

Keywords: Vertical aeroponics, interchangeable planting wall, lettuce

INTRODUCTION

Aeroponic farming is a method of growing plants without the use of soil. Plants are suspended in air and their roots are misted with a nutrient-rich solution (Gopinath et al., 2017). Aeroponics systems are mainly comprised of the three main component, including growth chamber, plant supporting portion, and nutrient supply system. In aeroponic systems, plants are typically supported by a plant supporting portion that holds them in place while their roots are exposed to a fine mist or spray containing water, nutrients, and oxygen. Unlike traditional farming methods, aeroponics does not use soil as a growing medium. Instead, plants receive nutrients directly through misting. Nutrient solutions are typically delivered to the plant's roots in the form of a fine mist. This ensures that the roots receive an optimal balance of water, nutrients, and oxygen. The exposed roots in aeroponic systems have high access to oxygen. This technique promotes faster nutrient absorption and healthier plant growth (Eldridge et al., 2020). Aeroponic systems allow for precise control of environmental factors such as temperature, humidity, and nutrient concentration. This level of control leads to increased crop yields and faster growth rates (Khan et al., 2020). Compared to traditional soil-based farming, aeroponics typically uses less water and fertilizer because the misting system can be optimized for efficient nutrient delivery and minimizing wastage (Yang et al., 2022; Ritter et al., 2001; Farran & Minggo, 2006). Since plants are not in contact with soil, the risk of soil-borne diseases is reduced. However, the risk of diseases affecting the exposed roots still exists, so maintaining proper hygiene in the system is crucial. Previous researcher also reported that, the aeroponics system increased stomatal conductance of leaf, intercellular CO_2 concentration, net photosynthetic rate and photochemical efficiency of leaf (Kumar & Kumar, 2019). While aeroponic farming offers several advantages, it also requires careful monitoring and management of the system. Proper nutrient levels, pH balance, and maintenance of equipment are essential for successful aeroponic cultivation. Aeroponic systems can be designed vertically or in stacked configurations, making them suitable for urban and indoor farming where space is limited. In general, aeroponic system structure has four types, including seedbed type, vertical barrel type, prototype, and pyramid type (Lakhiar et al., 2018).

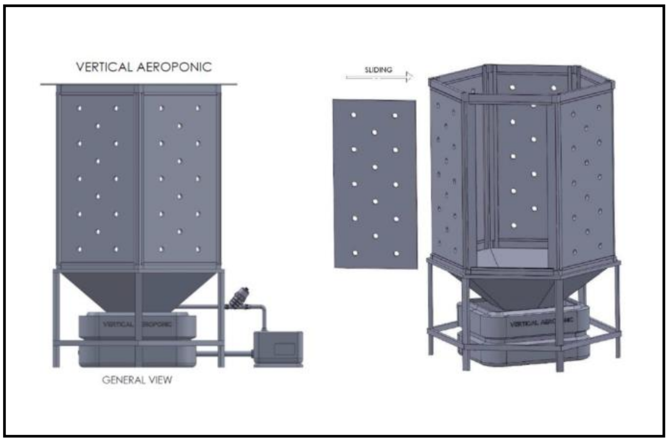
Until now, the system is not popular among the local farmers, but the concept is dominated in the literature for laboratory-scale plant cultivation. The aeroponic has not yet been adopted on a broader scale because still many information about the system is hidden, such as the maintenance tasks and development of the aeroponic system. This paper discusses the development of a vertical aeroponic system with interchangeable planting walls complete with a controlled system to ensure the crop receives optimum water and nutrient levels. The vertical farming concept was selected as more productivity can be achieved in a limited land size (Chaudhry et al., 2019). Vertical type structure also offers several benefits, including independence from arable land, year-round growing capacities, and improved crop predictability. (Khalil & Wahhab, 2020; Benke & Tomkins, 2017). The interchangeable wall was selected to facilitates usage and maintenance of the system.

MATERIALS AND METHODS

System Design

The main criterion for the overall design of the system is the interchangeable planting wall with a high-density planting capacity. An interchangeable planting wall design was selected to facilitate the transplanting, maintenance and harvesting process. The operator just needs to slide the planting wall to remove and place the wall in the working area to do the work and when the work is completed, they can slide back the planting wall onto the main structure. The overall design of the prototype is shown in Figure 1. The main component of the prototype consists of the main structure, interchangeable planting wall, fertigation system and monitoring and control system. The main structure is a hexagonal shape that can fit 6 units of planting wall. Each planting wall was designed to fit at least 50 plants.

Figure 1: Design concept of the Vertical Aeroponic System with Interchangeable Planting Wall



Crop planting experiment

To test the functionality of the system, a crop planting experiment was carried out. Different crops were planted on each wall to test the compatibility of the system to different types of crops. The crops used in the experiment are shown in Table 1.

Table 1: Crops planted on each wall

Wall number	Crop
1	Pak choi
2	Japanese Choy Sum
3	Chinese broccoli
4	Pak choi
5	Lettuce (four season)
6	Chinese broccoli

RESULT AND DISCUSSION

Aeroponic tower prototype

The completed prototype of the vertical aeroponic system with interchangeable planting walls is shown in Figure 2. The main components include the main structure, interchangeable wall, fertigation system and monitoring and control system.

1) The main structure

The aeroponic structure is designed based on the height of polystyrene panels commonly used in MARDI plant factories, which are 2' (width) x 4' (height) x 1.5" (thickness) in size. The height of the structure is also taken into account for the general height of the Asian operator to make it easier for the operator to handle the transfer, care and harvesting of crops. Therefore, the total height of the structure from the floor to the roof is 2 meters. The material of the main frame structure is made of aluminium and the bottom part is made from mild steel to support the structure so that it does not easily sway when hit by strong wind or heavy rain. The roof is covered with polycarbonate material and the water-collecting funnel back to the tank is made of rust-proof galvanized iron material.

Figure 2: Vertical Aeroponic System with Interchangeable Planting Wall Prototype

Figure 3: The main structure of the system

2) Interchangeable wall

To maximize plant capacity, this aeroponic structure has been designed with a hexagon shape where as many as 6 polystyrene panels can be fit into the main structure (figure 4). The advantage of the interchangeability of this panel facilitates the transplanting, maintenance and harvesting process. The interchangeable wall also facilitates the study of suitable space for selected plants. In the crop planting experiment, the panels are perforated according to the size and distance of the MARDI plant factory panel which can accommodate 50 trees for each panel.

Figure 4: The interchangeable wall concepts

3) Fertigation system

This structure is equipped with a WIFI type pump to set the required water pressure according to the pressure specification of the sprayer (figure 5 (a)). The pressure is adjustable and the maximum pump pressure is 4 bar. In the crop planting experiment, the pressure was set to 3.0 bar. This fertigation system is also equipped with an AZUD 100-type water filter system to prevent the nozzle system from clogging. The nozzle is shown in Figure 5(b). The nozzle used is a 4-way misting nozzle kit with an orifice size of 0.5mm. 2 unit of nozzles were used for the system as shown in figure 5 (c).

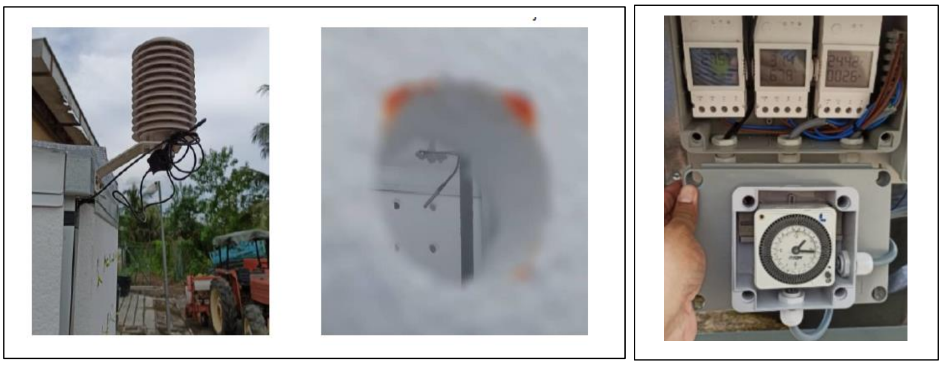
Figure 5: The fertigation system component (a) water pump (b) mist nozzle

(a) (b) (c)

4) Data monitoring system

This structure is equipped with sensors to collect data on parameters that affect the aeroponic system. An internal waterproof temperature sensor (DS18B20) is placed inside the spray chamber while a temperature and humidity sensor (THS01) are placed on the outside of the structure. Figure 6(a) shows the position of the sensor in this system. The spraying process is set using a mechanical timer model Hager EH711 as shown in figure 6 (b). Based on the initial study in the crop planting experiment, the interval of the misting was set at 20 minutes on and 20 minutes off during day time from 8.00 am to 7.00 pm and 10 minutes on in each hour during night time from 7.00 pm to 8.00 am These setting is crucial as to ensure the roots do not dry out easily and the water supplied is enough to last until the next spray.

Figure 6: The data monitoring system components (a) temperature and humidity sensors (b) timer



(a) (b) (c)

Crop Growth Result

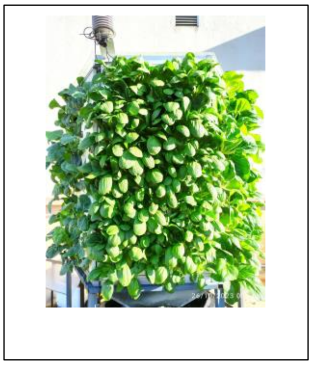
Figure 7 shows the crop's condition on each of the planting walls just before harvesting time. The average weight from 5 samples of the plant on each wall is shown in Table 2

The result shows that all the test crops which are Japanese choy sum, Chinese broccoli, pak choi and lettuce were succesfully grown on the system. However, there is a variation in the average weight of the same crop planted on different planting walls. Table 2 shows that the average weight of pak choi planted on wall 1 is higher compared to park choi planted on wall 4. For Chinese broccoli also that the average plant weight on wall 6 is higher compared to wall 3. This variation is expected due to the different amounts of solar radiation received by each wall. The results show that crop planted on a wall facing east which is walls 1,5 and 6 grew better compared to a wall facing west which is walls 2,3 and 4. As the structure was place beside a building, only one side of the structure which is wall 1,5 and 6 directly exposed to the sun while wall 2, 3 and 4 received no direct sunlight througout the day.

The interchangeble wall was proven make a process to clean the internal growing chamber from algae as shown in Figure 8 much easier as the wall can be taken out from the structure and cleaning process can be carried out.

Figure 7: Crops condition on each wall (a) wall 1(Pak choi) (b) wall 2 (Japanese Choy Sum) (c) wall 3 (Chinese broccoli) (d) wall 4 (Pak choi) (e) wall 5 (lettuce) (f) wall 6 (Chinese broccoli)

(a) Wall 1

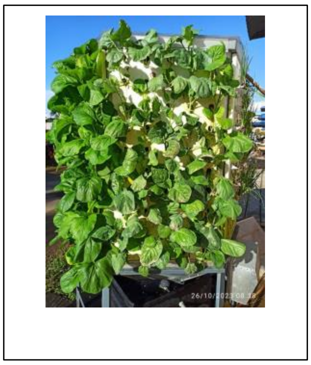


(b) Wall 2

(c) Wall 3

(d) Wall 4

(e) Wall 5



(f) Wall 6

Table 2: The average weight of crops planted on each wall

Wall number	Crop	Weight (g)
1	Pak choi	158.71
2	Japanese Choy Sum	69.08
3	Chinese broccoli	15.14
4	Pak choi	91.26
5	Lettuce (four season)	42.06
6	Chinese broccoli	24.28

Figure 8: Algae inside the growing chamber at the planting wall

CONCLUSION

The prototype of a vertical aeroponic system with an interchangeable planting wall was successfully designed and developed. With the selected setting on water pressure and misting interval, Japanese choy sum, Chinese broccoli, pak choi and lettuce were proven able to be grown by using the developed system. However, the results show that the growth of the crops was not even between walls due to other parameters such as the position of the wall according to the sun's direction. Therefore, in the future, further study needed to be carried out to optimize the effect of the wall position on the crop's growth.

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