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DESIGN AND DEVELOPMENT OF SMART VERTICAL GARDEN SYSTEM FOR URBAN AGRICULTURE INITIATIVE IN MALAYSIA

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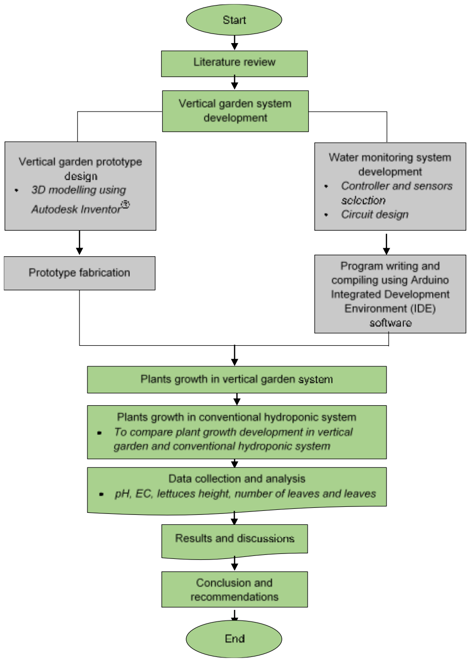
Graphical abstract



Abstract

Vertical garden system has the potential to increase vegetable production in the urban areas in Malaysia. This research designed and developed a compact and smart vertical garden system for the urban agriculture. It also analysed the growth performances of lettuce in the smart vertical garden system which involved two phases; the development of vertical garden system and the monitoring system for nutrient solution. The growth performances of different stacks of lettuce (Lactuca sativa) in the vertical garden system were observed and compared against the commercialised conventional hydroponic system. The growth performances of lettuce in the vertical garden system showed that the most bottom stack (stack 5) of lettuce achieved the maximum level of lettuce height, and had the highest number of leaves and leaves width. Nevertheless, from the overall ANOVA results, at different levels of the stacks of lettuce, only lettuce height was observed as having a significant difference ($P < 0.0001$) while no significant difference was found in the number of leaves ($P = 0.0002$) and leaves width ($P = 0.0046$). The growth development varied due to different amounts of water and light exposure. On the other hand, no significant difference was found when comparing between the vertical garden system and the commercialised conventional hydroponic system (lettuce height, $P = 0.4997$; number of leaves, $P = 0.5325$; and leaves width, $P = 0.5231$). In short, the smart vertical garden system can give the same performance as the commercial conventional hydroponic system.

Keywords: Vertical garden system, lettuces growth, lettuces height, leaves width, number of leaves

Abstrak

Sistem taman menegak mempunyai potensi untuk meningkatkan pengeluaran sayuran di kawasan bandar di Malaysia. Tujuan utama kajian ini adalah untuk mereka bentuk dan membangunkan sebuah sistem taman menegak yang lengkap dan sesuai untuk pertanian bandar serta mengkaji prestasi tumbesaran tanaman salad menggunakan sistem taman menegak yang direka. Penghasilan sistem taman menegak ini terbahagi kepada dua komponen utama: i) pembangunan sistem taman menegak dan ii) sistem pemantauan cecair nutrient. Perkembangan tumbesaran salad (*Lactuca sativa*) di setiap tingkat sistem taman menegak diperhatikan. Selain itu, perkembangan tumbesaran tanaman yang ditanam pada sistem yang dibina juga dibandingkan dengan tanaman yang ditanam menggunakan sistem hidroponik konvensional. Hasil kajian terhadap tanaman yang ditanam di taman menegak menunjukkan salad yang mepunyai ketinggian paling tinggi, lebar daun yang besar dan bilangan daun yang terbanyak berada pada tingkat paling bawah (tingkat 5). Secara keseluruhannya, analisi varians (ANOVA) menunjukkan hanya ketinggian salad mempunyai perbezaan ketara ($P < 0.0001$) di antara setiap tingkat manakala tiada perbezaan yang ketara ditemui pada keseluruhan bilangan daun ($P = 0.0002$) dan lebar daun ($P = 0.0046$) di setiap tingkat. Perbezaan tumbesaran salad di setiap tingkat adalah disebabkan jumlah air dan pendedahan cahaya yang berbeza. Ketika membandingkan tumbesaran pokok yang ditanam di taman menegak dan sistem hidroponik konvensional, tiada perbezaan ketara pada setiap parameter tumbesaran pokok (ketinggian salad ($P = 0.4997$); bilangan daun ($P = 0.5325$); dan lebar daun ($P= 0.5231$). Kesimpulannya, sistem taman menegak yang direka mampu memberikan prestasi yang sama dengan sistem hidroponik konvensional.

Kata kunci: Sistem tanaman menegak, tumbesaran salad, ketinggian salad, lebar daun, bilangan daun

1.0 INTRODUCTION

By the year 2025, it is estimated that almost 30% of global population will live in the urban areas [1]. This trend is expected to continue in line with the population growth and rapid urbanisation. In Malaysia, until 2015, around 74% of the citizens live in the urban areas, and that figure is projected to be increased gradually by the year 2025 [2] due to economic factors, land scarcity, and the migration of rural people to the cities. The migration of rural people to the cities has increased the population density of urban areas, hence leading towards a competing access of food supplies, nutrition, and security [2, 3].

Over time, food preferences have changed due to the increase of per capita income in developing countries, occupational changes, and global linkages. These trends, along with the rise of population over the years, are currently huge challenges to agricultural sector in Malaysia to produce more and better food supplies. Additionally, global environment and climate change has increased the challenge and has become an indispensable topic for those who are concerned about personal health and environment [4]. In this regard, the emergence of prosumer concept helps the urban areas in many countries to increase their production and sustainability [5]. The prosumer concept is applied when people have the ability to produce their own foods using the available resources, or when people consume the produces by themselves or share it with their community.

However, there are limitations in order to increase the productivity of agriculture using the current conventional techniques, for example land scarcity and threats to the environmental sustainability and health due to high dependence on chemical fertilizers and pesticides. These are the major issues that affect the food production and quality. On top of that, the advancement of science and technology, together with the global urbanisation, are two most important contributions in the evolution of agricultural research [6].

New innovations are inevitably needed and they should be integrated with the main stream of agriculture. In this sense, one way to achieve a sustainable urbanisation and food security is by practicing the urban farming [7]. Urban farming is highly significant and relevant to serve the needs of the urban residents, particularly those who are more vulnerable to the food crisis compared to the rural residents. Urban farming is also known as a cultivation practice beyond home consumption or educational purposes, such as cultivating, producing, processing, distributing, and marketing food and other products within the cities and town areas [8].

Nevertheless, urban farming has its own constraints, such as limited water supply and space, as well as in dealing with challenges involving the management and maintenance of farming system in the high-density populated areas. Therefore, integrating the vertical garden system in urban areas seems to be promising in order to solve the problems [9]. It is also one of the solutions for the shortage of food and arable land because the crops grow vertically hence more productions can be made [10, 11].

Vertical garden is defined as a plant-growing system that uses an assortment of support structures that stand upright and make the small space being utilised for more productions [10]. By contrast, growing plant in a horizontal system takes up the majority of a room or space. While other plants are typically grown at ground level, the vertical garden stands tall and upright. This makes harvesting crops a simple task, for instance less bending and kneeling.

Although there are several vertical gardens that have been developed, there are still very little information about plant growth in the vertical garden system. To date, there is no known research reporting about plant growth if, for example, the plants are grown in different stacks or levels in a vertical garden system. It is very important to determine the uniformity of plant growth to identify if the plants can adapt and survive well if they grow in different stacks or levels.

Most vertical gardens are fully integrated with hydroponic system. Hydroponic vertical garden system is a method of growing plants using water and nutrient solutions without soil in vertically stacked layers. Thus, monitoring and maintaining the water quality such as its pH and electrical conductivity (EC) are crucial for the plant growth. Currently, the water quality's checking process of vertical garden needs to be done manually, but this can be a hassle for the urban residents who are always busy and want a simple and complete planting system.

Based on the highlighted studies, this research designed and developed a smart hydroponic vertical garden system together with nutrient status (pH and EC) monitoring system to achieve the optimum level of plant growth. Additionally, this research determined the growth performances of lettuce (Lactuca sativa) and its leaves planted using the vertical garden and the commercialised conventional hydroponic system.

2.0 METHODOLOGY

This research designed and developed a vertical garden system for consumers to grow vegetables, herbs, and fruits easily and effectively at their homes especially in the urban areas. A simple water nutrient monitoring system was developed and implemented in the system to measure the pH and EC of the plant nutrient to ensure the quality of nutrient. The plant growth performances at the vertical garden system were monitored and recorded to verify the reliability of the designed system for planting purpose.

2.1 Design and Fabrication of Vertical Garden System

The principle of recirculating hydroponic system was chosen as the main core system for the vertical garden design. The vertical garden was developed by focusing in two main areas; the structural convenience and water-nutrient quality monitoring system. The structural design was focused on (i) optimising the arrangement for vertical garden parts and plants, and (ii) having a safe and visual appealing design for the users. Next, the detailed engineering designs were developed after the concept design of vertical garden was finalised. The CAD software known as Autodesk Inventor® was used as the main tool to produce all of the engineering designs and drawings for each component of the prototype. Generally, one of the advantages of using this 3D software is every part of the prototype can be view particularly and specifically noted the dimensional of components. The total height of the garden is 1.8 meter with the width of 0.5 meter (Figure 1), and its vertical structures consist of water tank, extendable pole with support, irrigation system, and five stacks. Every stack has eight growing pockets (Figure 2) and four caster wheels are fixed at the bottom of the tank to allow easy movement of the garden whenever necessary. Stainless steel is the material for the first prototype because of its strength and ideal corrosion-resistance that withstands long-term exposure to the environment and water.

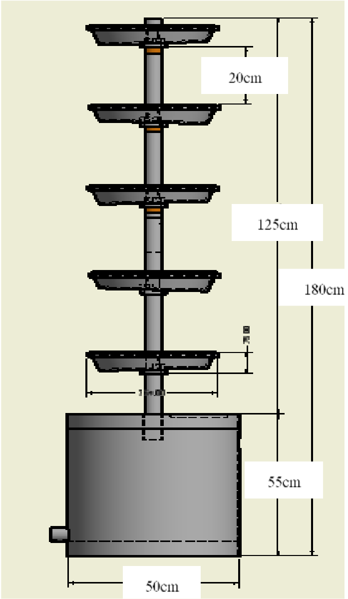


Figure 1 Dimensions of the vertical garden

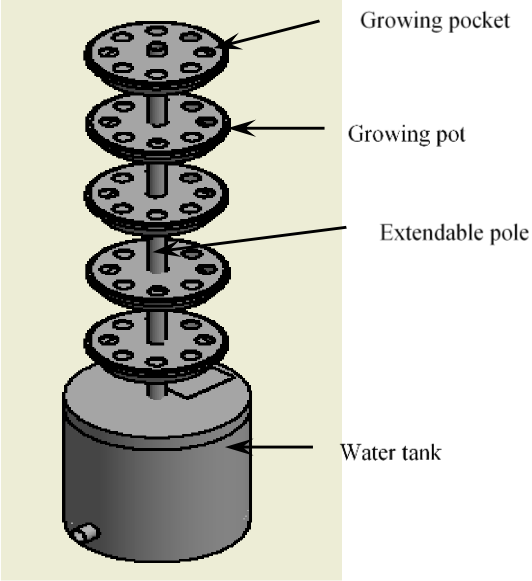


Figure 2 CAD drawing of the vertical garden

2.2 Development of Water Nutrient Monitoring System

The pH and EC of the water tank were monitored daily. The monitoring system for the nutrient solution of vertical garden used Arduino Uno microcontroller and two sensors. The sensors consisted of EC sensor (Conductivity Probe K 1.0, Atlas Scientific LLC, New York) to measure the EC and pH sensor (Atlas Scientific LLC, New York) to measure the pH value of nutrient. Figure 3 shows block diagram of water nutrient monitoring system for the vertical garden. The microcontroller was used as the central unit to measure the value of pH and EC of the water nutrient, which were detected by the pH and EC sensors. The values of pH and EC measured were displayed on LCD.

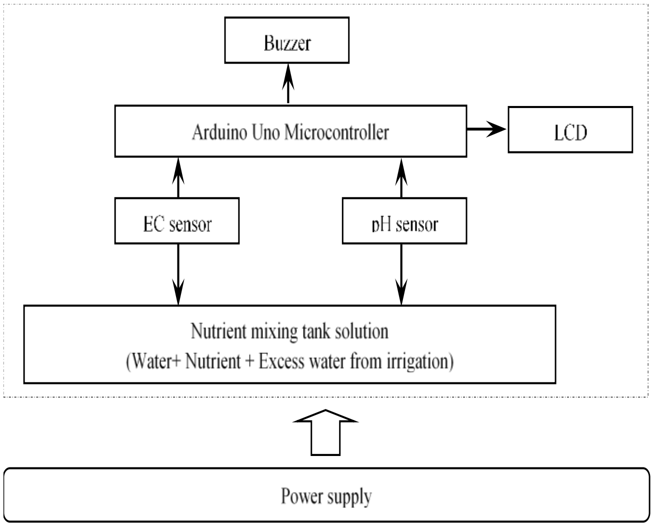


Figure 3 Block diagram of the water nutrient (pH and EC) for the vertical garden

During the experiment, the value of pH and EC were maintained in the range of 5.8 to 6.8 and 0.8 mS/cm to 1.2 mS/cm respectively. Those ranges were according to the ideal range for lettuce in a hydroponic system [12]. If the values of pH and EC of the nutrient solutions were outside of the desired range, the buzzer was activated to alert the user for changing the nutrient solutions.

2.3 Seedlings Preparation and Management

The experiment was conducted in the Bio- production and Machinery Laboratory, University of Tsukuba, Japan. As mentioned earlier, green leaf lettuce (Lactuca sativa) was chosen as the experimental plants throughout this project. In total, there were 40 lettuce plants being planted at the vertical garden, and each stack consisted of eight planting pots. The vertical garden was located inside the laboratory and planting process was done indoor with the room temperature ranged between 23°C to 29°C. Germination was done indoor where the seeds of green leaf lettuce were germinated in the potting soil as media. During germination stage, the seeds were watered once a day to keep them moist. After three weeks of germination process, the seedlings were then transplanted to small plastic cups filled with hydroponic clay pebbles as hydroponic media to support the plants roots before being placed to the vertical garden. Figure 4 illustrates the overall setup of the vertical garden system during the experiment.

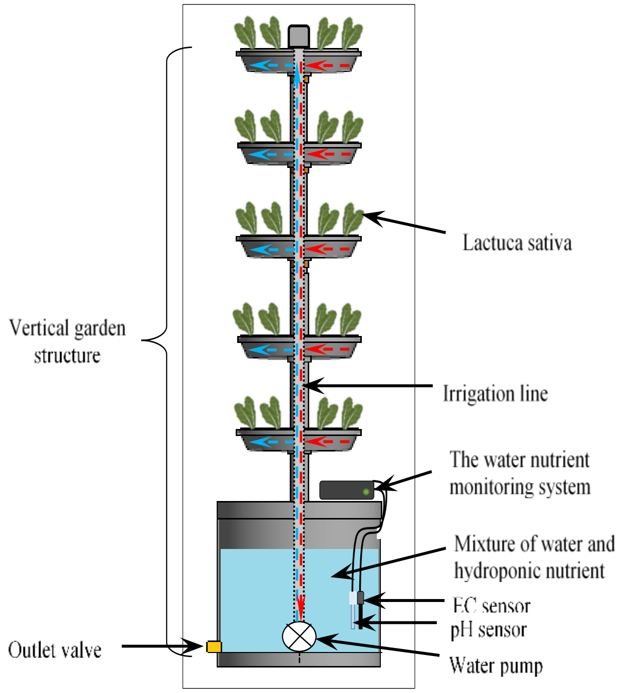


Figure 4 Overall setup of the vertical garden system during the experiment

2.4 Irrigation

The irrigation system for the vertical garden was facilitated by a pump to lift the nutrient from the tank to each stack of the garden. The nutrient solution used in this research was called AB mix comprising two separate nutrient stocks solution namely stock solution of A and B which were commonly used for hydroponic system. The mixture of water and nutrient solution was pumped onto the top stacks of plants through a central irrigation line, then continued to flow down to the next lower stacks by gravitational effect, until the five stacks were watered. The water was continuously recaptured and recirculated. A cycle timer (Digital Eco-timer ET55D, Revex, Japan) was used to operate the water pump. In this research, the timer was set to operate the pump for 10 minutes with 15 minutes of intervals daily.

Since the maximum height of the system was 1.8 meter, a pump that could at least pump double of the system height was required. A submersible pump (Ocean Runner 2500, Aqua Medic GmbH, Bissendorf, Germany) was selected to be used with 2.6 meter capacity of maximum head with the maximum flow of 2500 l/h (40 l/m). Additionally, its small and compact size can conserve space within the base unit and it did not require extra mounting to the structure.

2.5 Control Experiment using Conventional Hydroponic System

Another experiment also had been conducted to test whether the vertical garden system presents a viable alternative to horizontal crop production system. The designed vertical garden was compared against a commercialized conventional horizontal hydroponic system. The conventional hydroponic system (Kazz Hydroponic, Kazz Agro Valley Sdn. Bhd. Malaysia) was used for this experiment. The experiment using conventional hydroponic system was conducted in the Bio-system Laboratory, Universiti Putra Malaysia, Malaysia. The same type and amount of green leaf lettuce were planted at the conventional hydroponic system. The conventional hydroponic system utilised five water containers and five covers, with each cover has eight planting pockets respectively. The containers were arranged horizontally and located inside the laboratory (Figure 5).

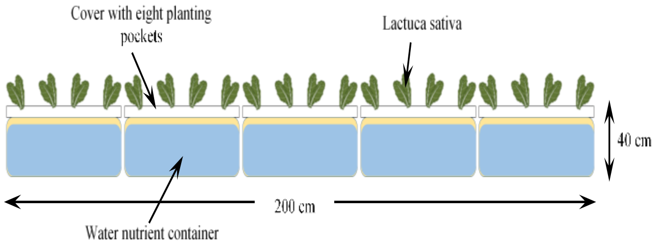


Figure 5 Schematic diagram of experimental setup of the conventional hydroponic system

2.6 Data Collection and Analysis

The plant growth and water nutrient quality were measured and recorded consistently every day. The data were taken for five weeks beginning from the first day after the seedlings were transplanted to the vertical garden system. The selected data collected in this experiment were pH, EC, plant height, number of leaves, and leaves width. Basic statistic for data collection were determined. The significant difference between the plant growth performances according to stacks and weeks were determined using ANOVA. The means of plant height, number of leaves, and leaves width according to stacks and weeks were compared using Duncan's Multiple Range Test (DMRT) at $P \leq 0.05$. SAS software (Version 9.3, SAS Institute, Cary, NC, USA) was used to conduct both the ANOVA and DMRT.

3.0 RESULTS AND DISCUSSION

3.1 pH Readings

As mentioned in the previous chapter, ideally, most plants grow well within a pH range of 5.8 to 6.8. At this range, nutrients are most available for plants to absorb. In this research, the pH values decreased gradually from day 1. The initial pH value was 6.8 and dropped to 6.0 at day 11. After that, the value increased slowly and maintained within the range of 6.2 to 6.5 (Figure 6).

Although the pH showed changes almost every day, pH still remained within the acceptable range for the green leaf lettuce to grow. Hence, no acid or base adjustment was added to the water nutrient throughout the planting period. One of the factors that varied the daily changes of the pH during the planting process was because in the hydroponic system, it was difficult to maintain a constant concentration of nutrient. It may decline over time due to the uptake of water and nutrient from the plants [13]. Since the vertical garden system had a small water tank, the changes of pH became rapid in comparison to a big-scale system [14].

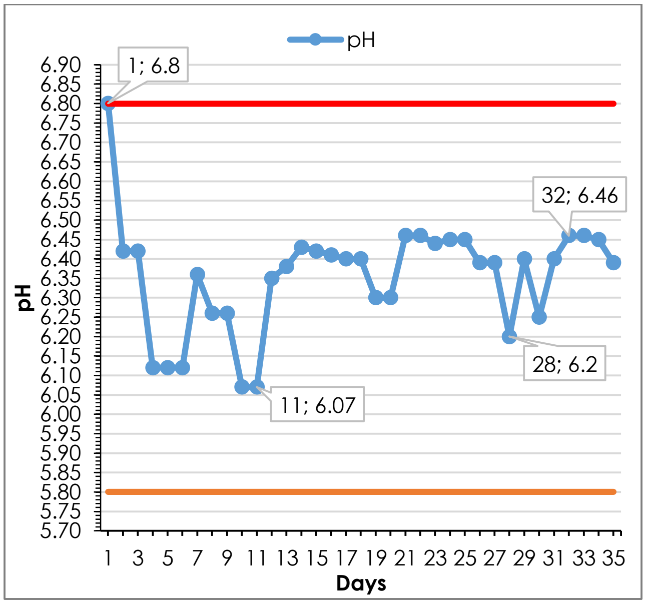


Figure 6 Variation of daily pH values in the water tank

3.2 Electrical Conductivity (EC) Readings

Similar to pH value, EC readings were also monitored frequently particularly in the closed hydroponic system. In this experiment, the range of electrical conductivity predetermined as ideal was from 0.8 mS/cm to 1.7 mS/cm as a maximum limit. The EC values were maintained within 1.17 mS/cm to 1.18 mS/cm from day 1 until day 6 before it fluctuated to 1.02 mS/cm at day 18 (Figure 7). The fluctuation occurred because of the changes in the temperature of the water nutrient in the tank. However, the EC values increased gradually after day 7 until the end day of planting period at day 35 with the last EC value of 1.18 mS/cm.

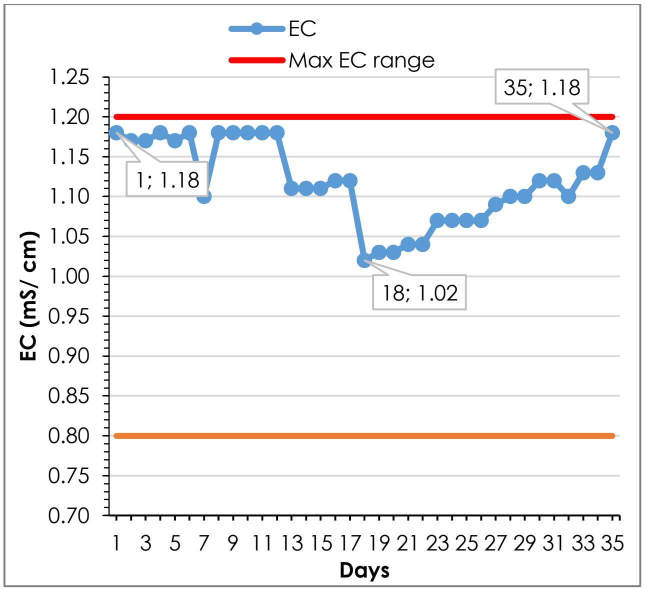


Figure 7 Variation of daily EC values in the water tank

The EC values increased further during the planting process, which is one of the common phenomena in the closed hydroponic system. Since the irrigation water was reused, the non-fertilizer salts and fertilizer ions assumed to remain in the nutrient solution. The accumulations of excess fertilizer and salt increased the EC of the water nutrient [15]. The changes in EC of the nutrient solution is in agreement with the observation of Mengel and Kirkby (1979) who found that the EC of the solution increases if plants absorb more water than nutrient elements [16]. In this experiment, daily measurement showed that EC was reasonably constant in the required range during the plant growth. Thus, it was unnecessary to replace the water nutrient during the growing period.

3.3 Lettuces Height

The ANOVA was conducted to compare the average lettuce height between five different stacks over five weeks of planting time. The statistical results summarised in Table 1 shows that both the stacks of vertical garden and planting weeks significantly affected the lettuce height (P < .0001).

Table 1 ANOVA for the lettuces height grown in the vertical garden

Factor	Degree of freedom	Mean square	F- value	Pr (>F)
Weeks	4	47.4126	1287.18	<.0001
Stacks	4	2.1476	3.01	<.0001

In order to further investigate the effects, DMRT was conducted to compare the lettuce height grown at each stack of vertical garden over five weeks of planting period. Based on the results shown in Table 2, there was a significant difference between the lettuces height over five weeks of the planting period. The mean of lettuce height increased from 5.16 cm to 12.68 cm as the planting period increased (Table 2).

Table 2 DMRT on the lettuces height grown in the vertical garden

Parameters	Factors	Mean square
Lettuces height (cm)	Week 1	5.16^{a}
	Week 2	6.06^{b}
	Week 3	8.06^{c}
	Week 4	10.28^{d}
	Week 5	12.68^{e}
	Stack 1 (Top)	8.62^{b}
	Stack 2	8.30^{b}
	Stack 3	8.16^{bc}
	Stack 4	7.70^{c}
	Stack 5 (Bottom)	9.46^{a}

*Values followed by the same letter within the same column are not significantly different from each other (p>0.05).

On the other hand, the lettuce height decreased from the top to the middle stacks (stacks 2, 3, and 4) of vertical garden. The mean height at stack 1 was 8.62 cm and the lowest height was at stack 4 with 7.70 cm. The reason for the relatively high yield from the top stack (stack 1) was due to higher sunlight exposure compared to the lower or middle stacks. This result was consistent with the study done by Touliatos *et al*. (2017) that reported the top part of vertical garden received more sunlight exposure compared to the bottom part [17].

However, the lettuce at stack 5 had the highest mean, 9.46 cm (Table 2). Water and nutrient supply also had impacts on the plant growth and thereby affecting the yield and crop size [18, 19]. Plants at the most bottom stack (stack 5) received the most water and nutrient because the plants received all the excessive water nutrient from the above stacks during the irrigation process before the water came back to the main tank. This makes the lettuce height from the upper stacks (stacks 1, 2, 3, and 4) were slightly lower than stack 5 as the plants might lose more water and nutrient due to the gravitational effect of irrigation system.

3.4 Number of Leaves

From the ANOVA test, the number of leaves produced in the vertical garden showed that there was a high significant difference (P < .0001; Table 3) with the planting duration (weeks). In order to further investigate the difference, the DMRT at each week of planting period was performed to compare the mean number of leaves produced in the vertical garden (Table 4). The mean number of leaves in week 1 was 5.60 cm and this increased to 13.80 cm in week 5. This shows that the plants had grown positively as the number of leaves increased across the weeks.

Table 3 ANOVA for the number of lettuces leaves produced in the vertical garden

Factor	Degree of freedom	Mean square	F- value	Pr (>F)
Weeks	4	53.7600	139.64	<.0001
Stacks	4	4.1600	10.81	0.0002

On the contrary, there was no significant difference found in the overall number of leaves produced at different levels of stacks (P = 0.0002; Table 3). However, DMRT analysis of number of leaves among the stacks shows that stack 5 had the highest number of leaves compared with other stacks but was not significantly different with stacks 1 and 2 (Table 4). The lowest number of leaves was found in stack 4 which was significantly different with stacks 1, 2, and 5 but was not significantly different with stack 3. The slight difference in the number of leaves between the stacks occurred because each plant at each stack did not receive a uniform amount of water and sunlight exposure.

Table 4 DMRT on the number of lettuces leaves produced in the vertical garden

Parameters	Factors	Mean square
Number of leaves	Week 1	5.60^{e}
	Week 2	6.80^{d}
	Week 3	8.40^{c}
	Week 4	10.80^{b}
	Week 5	13.80^{a}
	Stack 1 (Top)	9.40^{ab}
	Stack 2	9.40^{ab}
	Stack 3	8.60^{bc}
	Stack 4	7.80^{c}
	Stack 5 (Bottom)	10.20^{a}

*Values followed by the same letter within the same column are not significantly different from each other (p>0.05).

3.5 Leaves Width

ANOVA and DMRT proved that there were highly significant difference in the means of leaves width over the five weeks of planting periods (P < .0001; Table 5). The mean of leaves width increased from 1.72 cm to 3.70 cm, however the leaves width showed no significant dependency on the levels of stacks (P = 0.0046; Table 5). Based on the DMRT analysis, only the leaves width recorded at stack 5 (3.06 cm) was found to be significantly different from other stacks. The lowest leaves width was obtained at stack 1 with 2.54 cm but was not significantly different with leaves at stacks 2, 3, and 4 (Table 6).

Table 5 ANOVA for the leaves width of lettuces grown in the vertical garden

Factor	Degree of freedom	Mean square	F- value	Pr (>F)
Weeks	4	3.1050	76.67	<.0001
Stacks	4	0.2330	5.75	0.0046

Table 6 DMRT on the leaves width of lettuces grown in vertical garden

Parameters	Factors	Mean square
Leaves width (cm)	Week 1	1.72^{e}
	Week 2	2.16^{d}
	Week 3	2.74^{c}
	Week 4	3.18^{b}
	Week 5	3.70^{a}
	Stack 1 (Top)	2.54^{b}
	Stack 2	2.60^{b}
	Stack 3	2.74^{b}
	Stack 4	2.56^{b}
	Stack 5 (Bottom)	3.06^{a}

*Values followed by the same letter within the same column are not significantly different from each other (p>0.05).

3.6 Comparison of the Smart Vertical Garden System and Conventional Hydroponic System

Table 7 summarises the similarities and differences between the vertical garden system and the conventional hydroponic system used in this research. In both systems, soil is not necessary and the plants are grown with supports received from clay pebbles as the media with added nutrient solution. The excessed nutrient solution is recirculated and the nutrient concentrations are monitored and adjusted accordingly. However, for the conventional system, the nutrient status needs to be monitored manually unlike for the vertical garden, where the system is equipped with automated nutrient monitoring system. The vertical garden system can produce four times more plants than the conventional hydroponic system in the same size of growing area. The vertical garden system can occupy 160 plan/m^2, while the conventional system can only occupy 40 plants/m^2.

The initial development cost for the prototype of the vertical garden system developed in this study was higher than the cost of conventional hydroponic system. However, if the vertical garden can be produced in mass production with lower cost material such as PVC, eventually, the cost can be reduced hence making it more attractive for the consumers.

Table 7 Comparison between the smart vertical garden and conventional hydroponic system

	Smart Vertical Garden	**Conventional Hydroponic System**
Number of plants/ m^2	160 plants/ m^2	40 plants/ m^2
Recycle (Media/ water)	Yes	Yes
Automated	Yes (Monitoring water quality)	No
Urban areas	Yes	Yes
Dimensions	0.5m x 0.5 m x 1.8 m	2m x 0.5m x 0.4m
Development cost	RM 1200	RM 250
Cost/ plant	RM 7.50	RM 6.25

3.7 Plant Growth Development of the Smart Vertical Garden System and Conventional Hydroponic System

The height of the lettuce grown in the conventional hydroponic system had an average height of 9.01 cm compared to an average of 8.45 cm in the vertical garden system (Table 8). The leaves width of lettuce in the conventional hydroponic system was 2.84 cm, which was slightly higher compared to the vertical garden system with the average of 2.70 cm. This was explained by the differences in the amounts of light and nutrient received by the plants in both systems. The main difference between the conventional hydroponic system and the vertical garden system was that each plant of conventional hydroponic system received nutrient solution directly from individual container, while in the vertical garden system, the nutrient solution was delivered to the top stack and was gravity-driven fed to the other bottom stacks before the excessive water was collected back into the tank and reused again.

Table 8 Comparison of the plant growth performance of the vertical garden system and conventional hydroponic system

Planting technique	**Lettuce height**	**Number of leaves**	**Leaves width**
Vertical garden	8.4480^a	9.0800^a	2.7000^a
Conventional hydroponic	9.0080^a	8.5200^a	2.8400^a
Pr > F	0.4997	0.5325	0.5231

*Values followed by the same letter within the same row are not significantly different from each other (p>0.05).

Additionally, the conventional hydroponic system received a uniform amount of light intensity as the system was horizontal in nature and the plants received nutrients continuously from each individual container. This makes it produced a slightly better lettuce quality than the vertical garden system. However, despite these differences, the ANOVA results showed that there were no significant difference in each of the lettuce quality as measured by the lettuce height, number of leaves, and width leaves grown either in the vertical garden system or the conventional hydroponic system (Table 8).

In short, the designed vertical garden system has the potential in delivering the same performances as the commercial conventional hydroponic system. In fact, more plants can be planted within small spaces using this smart vertical garden system compared to the conventional hydroponic system. Other than that, the water quality monitoring system that was embedded together with the vertical garden eased the growers to alert when they should check the water pH and EC. Nevertheless, several improvements towards the vertical garden system regarding the irrigation strategy and for a more even light exposure are needed to produce better performances.

4.0 CONCLUSION

In the experiment, the pH in the water tank was remained within the range of 6.0 to 6.8 during the growing period. Since the vertical garden was operated with closed hydroponic system, the EC was also changed with time. The EC recordings were maintained within the range of 1.02 mS/cm to 1.18 mS/cm. Both pH and EC did not show any abrupt changes during the experiment and were maintained constantly within the ideal range of plant growth. As the plants were always different in the uptake rate of water and nutrient, the daily pH and EC drifting up or down were normal in the hydroponic system.

Apart from the determinations of the pH values and EC status, the growth development of lettuce at all stacks of the vertical garden were observed. The lettuce at each stack showed different growth progress during the five weeks of planting duration. The highest number of lettuce were produced at the bottom stack which was stack 5 (13.2 cm), followed by lettuce at stacks 1, 2, 3, and 4. The utmost number of leaves and leaves width, on the other hand, were also produced at stack 5. However, based on the overall ANOVA results, there was no significant difference found in terms of the number of leaves and width leaves between the five stacks. Only the lettuce height demonstrated a statistically different result when grown at the different stacks due to the non-uniform distribution of water flow at different stacks and sunlight exposure. Thus, for future studies, several improvements in regard to the irrigation strategy and for a more even light exposure are needed to produce better performances.

An experiment to evaluate and differentiate the plant growth performance planted using the designed vertical garden and using the commercialized conventional hydroponic was conducted. The highest lettuce height was obtained when grown in conventional hydroponic system with an average height of 9.01 cm compared to an average of 8.45 cm in the vertical garden system. Besides, the leaves width was found to be slightly higher in the conventional hydroponic system (2.8 4cm) compared to the vertical garden system (2.70 cm). Next, the number of leaves in the vertical garden was higher compared to the conventional hydroponic system. Nevertheless, the ANOVA results found that there was no significant difference between lettuces grown in the vertical garden and the conventional hydroponic system in all observed variables.

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