doi:10.14720/aas.2022.118.2.2272 Original research article / izvirni znanstveni članek

# Open vertical farms: a plausible system in increasing tomato yield and encouraging natural suppression of whiteflies

Suleiman MUSTAPHA [1, 2, 3], Abdulrasak Kannike MUSA [1], Oluropo Ayotunde APALOWO [4], Abdrahaman Adebowale LAWAL [1], Olaniyi Israel OLAYIWOLA [5], Helen Olaide BAMIDELE [1], Robert Omotayo UDDIN II [1]

Received July 07, 2021; accepted March 21, 2022.
Delo je prispelo 7. julija 2021, sprejeto 21. marca 2022

**Open vertical farms: a plausible system in increasing tomato yield and encouraging natural suppression of whiteflies**

**Abstract:** This study evaluated the effectiveness of open vertical farming in increasing tomato yield and also recruiting the presence of ecological service providers in the control of whiteflies. The experiment compared the horizontal farming approach to novel outdoor vertical farm design. Using both raised and flatbeds to represent horizontal farm, tomato plants were grown in a spacing of 3.6 and 2.4 m$^2$ respectively while the vertical farm covered a land space of 1.8 m$^2$ having three arrays with array 1 at ground level, array 2 and 3 were elevated at 110 and 220 cm high respectively. Data collected included the numbers of *Bemisia tabaci* (Gennadius, 1889) and predatory spiders and; tomato fruit yield (g). Results indicated that the mean number of predatory spiders in the vertical farm from 6 – 10 weeks after transplanting were able to supress *B. tabaci* populations when compared to the horizontal farm. The total fruit yield harvested indicated that the vertical farm produced more tomato fruit yield compared to the horizontal farm. It is plausible that the practice of outdoor vertical farming may be a step approach solution to land shortages and also a sustainable system for integrated pest management.

**Key words:** Vertical farm; *Bemisia tabaci*; predator-prey interaction; biological control; tomato; insect pest

**Navpični način gojenja: racionalen sistem za povečanje pridelka paradižnika in vzpodbuda za sonaravno zatiranje tobačnega ščitkarja**

**Izvleček:** V raziskavi je bilo ovrednoteno gojenje paradižnika v navpičnem sistemu z namenom povečanja pridelka in kot način ekološkega uravnavanja tobačnega ščitkarja. V poskusu sta bila primerjana dva načina gojenja in sicer običajen vodoraven in navpičen sistem gojenja na prostem. Pri vodoravnem načinu gojenja so bile uporabljene visoke in navadne grede, kjer je posamezna rastlina paradižnika pokrivala 3,6, oziroma 2,4 m$^2$. Pri navpičnem načinu gojenja je posamezna rastlina zavzemala 1,8 m$^2$ v treh višinah in sicer na tleh (1), na višini 110 cm (2) in 220 cm (3). Parametri, ki so bili merjeni so obsegali število osebkov škodljivca (*Bemisia tabaci* (Gennadius, 1889) in predatorskih pajkov ter pridelek paradižnika (g). Rezultati so pokazali, da je številu predatorskih pajkov v navpičnem sistemu gojenja v 6 do 10 tednih po sadnji bolje uspelo zatreti populacijo škodljivca v primerjavi z vodoravnim načinom gojenja. Tudi celokupen pridelek paradižnika je bil pri navpičnem načinu gojenja večji kot pri vodoravnem. Iz izsledkov lahko zaključimo, da je gojenje paradižnika v navpičnem načinu gojenja na prostem racionalen korak pri reševanju pomanjkanja zemljišč kot pri trajnostnem uravnavanju škodljivcev.

**Ključne besede:** navpišni način gojenja**;** *Bemisia tabaci*; interakcija plenilec-plen; biološki nadzor; paradižnik; škodljive žuželke

1 Department of Crop Protection, University of Ilorin, Nigeria
2 Division of Crop Protection, ICAR-Indian Institute of Horticultural Research, Bengaluru, India
3 Corresponding author, e-mail: juniorsuleiman78@gmail.com
4 Department of Crop Science and Horticulture, Nnamdi Azikiwe University, Awka, Nigeria
5 Institute of Global Food Security, School of Biological Sciences, Queen's University Belfast, UK

## 1 INTRODUCTION

Food insecurity is fast becoming an increasingly vital matter worldwide (Al-Kodmany, 2018). It has been predicted that the urban population will constantly rise in the coming decades. At the same time, land experts (i.e., ecologists, agronomists, and geologists) warn of intensifying shortages of farmland (Corvalan et al., 2005; Healy and Rosenberg, 2013; Thomaier et al., 2015). With a rapidly expanding population and changing climate, pressures on food production systems are expected to increase in the coming years (FAO, 2018). Traditional farming methods cannot produce enough food to feed the world's growing population and may fail in future (Despommier, 2013, Touliatos et al., 2016; Muller et al., 2017). Therefore, there is urgently the need for transformative solutions in food production. Vertical farming has been proposed as a way out in addressing the problem of farmland shortages because of its promises in maximizing small spaces to grow more crops and its sustainability to the environment (Corvalan et al., 2005; Despommier, 2014; Healy and Rosenberg, 2013; Thomaier et al., 2015) although, the effects it has on different insect pest complex is still not fully studied.

Herein, we examined how outdoor vertical farming might be used to increase yields and also in the sustainable management of insect pests by investigating the fruit crop tomato which easily adapts to this technique. Tomato, having lots of culinary and nutritional benefits is attacked by different pests a major of which are the whiteflies (Varela et al., 2003; Waiganjo et al., 2006). Whiteflies are highly polyphagous and are also known vectors of the tomato yellow leaf curl viruses (TYLCV) (Scholthof et al., 2011). The whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae) larvae produces honeydew on which sooty moulds grows, reducing the photosynthetic capabilities of the plant and resulting in defoliation and stunting (European and Mediterranean Plant Protection Organization, 2004). The primary method used to control the insect pest is by the application of insecticides which unfortunately being practiced mainly in traditional horizontal farming has led to the development of resistance to numerous types of insecticides, reduction of beneficial arthropods and causing negative impacts on human health and the environment at large (Denholm et al., 1998; Matthews, 2008).

Natural enemies are helpful in curtailing the destructiveness of the insect pest with previous reports on predators such as wasps, lacewings, mites and also spiders effective in bringing whitefly population down (Gerling, 2001). Although, with limited information on its application and implication in vertical farming approach (Roberts et al., 2020). It is also not clear if the technique of vertically growing crops outdoors could be useful in checking the population of *B. tabaci* by natural intervention of predators as observed in other farming practices. Therefore, the current study is an attempt to answer the following questions: Can outdoor vertical farms increase the yields of crops?, and, would it be sustainable enough to support natural suppression of key insect pests?

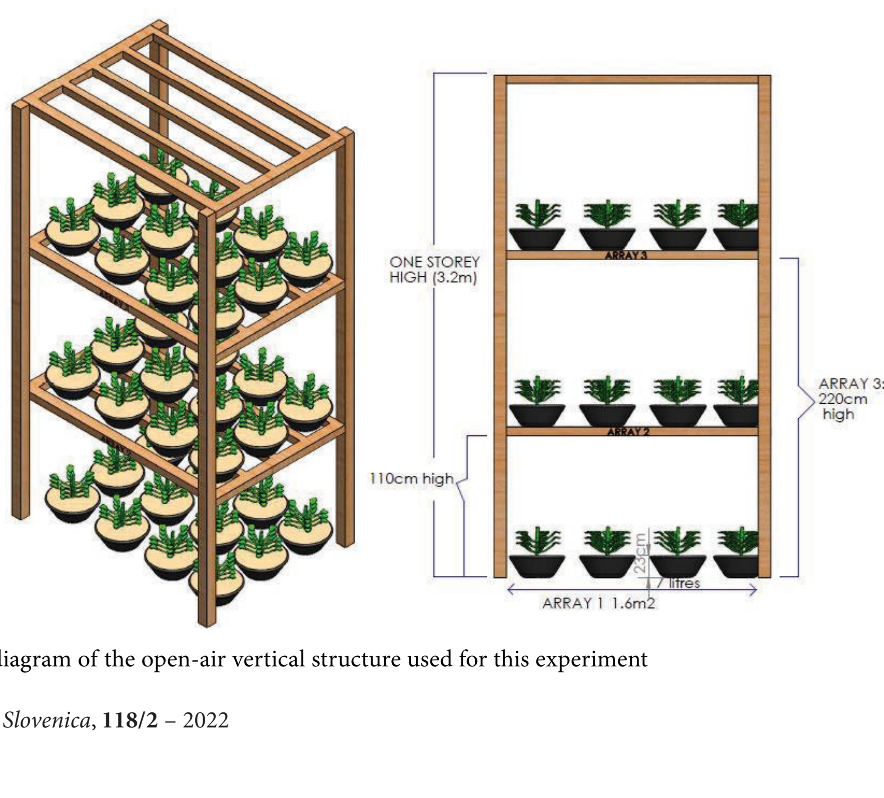


**Fig. 1**: Schematic diagram of the open-air vertical structure used for this experiment

## 2 MATERIALS AND METHODS

### 2.1 STUDY SITE

The study was conducted at the Department of Agronomy, Faculty of Agriculture, University of Ilorin (latitude 8º29'9N and longitude 4º35'38E), Kwara State. This area is located in the Southern Guinea Savannah Ecological Zone of Nigeria. The area was characterized by a bimodal rainfall with peaks in June and September and an annual rainfall between 1000-1240 mm. The study was carried out from December 2016 to March 2017.

### 2.2 ARRANGEMENTS FOR THE HORIZONTAL AND VERTICAL FARMS

The flatbeds were made in a size of 150 cm × 160 cm (2.4 $m^2$) each with an inter-bed spacing of one metre (1 m). The plot spacing for each raised bed was 240 × 150 cm (3.6 $m^2$) with an inter-bed spacing of one metre (1 m). The vertical farm was built using open-air vertical structures (Fig. 1) 3.2 m high using 8 cm wide and 5 cm thick wood (Garg and Balodi, 2014). It was built in a spacing of 120 × 150 cm (1.8 $m^2$) with an inter vertical farm spacing of 1 m apart.

### 2.3 TREATMENTS AND EXPERIMENTAL DESIGN

The experiment was laid out in a randomized complete block design with four replicates. The horizontal farm was made into two types of beds; raised beds and flatbeds, these served as the treatments in the horizontal farm. While the vertical farm was made having three arrays; with Array 1 at ground level (GL), Array 2 at 110 cm high and Array 3 at 220 cm high and these served as treatments in the vertical farm.

### 2.4 LAND PREPARATION AND PLANTING ON THE HORIZONTAL AND VERTICAL FARMS

The raised and flatbeds in the horizontal farm were prepared on farmland previously cultivated for tomato having sandy loam soil that was well drained. The tomato variety used for this study was UC82B packaged and supplied by the trademark company Technisem. Tomato seedlings were grown in the nursery in a screen house and were transplanted 4 weeks after sowing on the horizontal farm at a spacing of 50 × 80 cm on both beds according to the manufacturer's spacing instruction, with each bed containing a total of twelve tomato seedlings and 36 seedlings for the three replicates per bed type. In the vertical farm, tomato seedlings were transplanted from the nursery into 7 litre buckets with a diameter of 25 cm and a height of 23 cm filled with sandy loam soil with also history of tomato cultivation. Each vertical array contained twelve (12) buckets with a total of thirty-six (36) buckets per vertical farm and 108 buckets for the three replicates. Tomato seedlings that were introduced to the third array of a growing height of 220 cm high were gradually introduced to this height from ground level to 110 cm high and finally to 220 cm high within four days interval.

At 2 weeks after transplanting (WAT), tomato seedlings were lightly pruned by cutting off a few branches to encourage its growth and acclimation in both the vertical and horizontal farm. N.P.K (15-15-15) fertilizer was applied at the rate of 120 kg $ha^{-1}$ 3WAT to boost the growth of the crops in both farms. The fertilizer was applied by ring placement into drills 5 cm deep and 7 cm away from the plant and covered with soil (Olaniyi et al., 2010). Watering of tomato was done daily in both the vertical and the horizontal farm at 8:00 am using a watering can.

### 2.5 COLLECTION AND IDENTIFICATION OF ASSOCIATED ARTHROPODS

Adult whiteflies were collected using aspirator and yellow sticky traps while a x10 magnifying lens was used for the observation of the presence of puparia or pupal cases underneath tomato leaves before taking leaf samples for viewing under a stereo microscope. All collected whitefly samples were identified to the species level on the basis of morphological characters of adults, puparium and/or pupal case (Simala et al., 2009).

The observed spiders in this experiment were not identified to species, genus, nor family level due to the lack of taxonomist specialized in arachnology in the country hence difficulties were experienced in speciating spiders.

#### 2.5.1 Data collection

Nine (9) tomato plants were selected at random from each replicate from both the horizontal and vertical farm and data was collected for the number of adult whiteflies, predatory spiders and total fruit yield (g). The numbers of whiteflies were estimated by dividing the crop canopy into three layers: upper (> 40 cm), intermediate (20-40 cm) and lower (0-20 cm) and selecting five leaves from each layer per plant which were gently turned over to the abaxial side to count the total number of adult whiteflies (Sequeira and Naranjo, 2008; López et al. 2010). This was performed from 7:30-9:30 am. Numbers of spiders were estimated by counting the total number of spiders seen per crop. This was carried out from 7-9:30 pm when spiders were observed to be very active and could be easily spotted with a flashlight. The number of *B. tabaci* on the tomato plants in both the vertical and horizontal farm were determined to have reached action threshold when above 5 of the insect were counted per leaf according to Ellsworth and Martinez-Carrillo (2001). Tomato fruits harvested from both farms at the end of the experiment were measured on a weighing scale calibrated in grams.

#### 2.5.2 Data Analysis

Data was presented in mean and standard error of mean (SEM) and significant differences between means were separated according to Kruskal-Wallis one-way analysis of variance by allocating ranks to means. Spearman correlation analysis was done to determine the association between population of spiders, *B. tabaci* and fruit yield using SPSS 20$^{th}$ Edition.

## 3 RESULTS

### 3.1 *Bemisia tabaci* ON BOTH HORIZONTAL AND VERTICAL FARMS

Table 1 shows that the infestation of *B. tabaci* started at 1 week after transplanting (WAT) in both the horizontal and vertical farms with the flatbed having a significantly (H (4) = 11.500, $p$ = 0.021) higher mean number of 12.81. There were no significant differences between the mean rank of *B. tabaci* in both the horizontal and vertical farms from 2 to 4 WAT. The horizontal farm, on the other hand, reached its peak population of *B. tabaci* at 5 WAT in the flat bed with a mean number of 14.69 (H (4) = 11.360, $p$ = 0.023) and 9 WAT in the raised bed with a mean population of 13.35 (H (4) = 13.745, $p$ = 0.008) significantly higher than the vertical farm (Table 1). Throughout the experiment, the horizontal farm experienced the most numbers of *B. tabaci* adults affecting tomato plants when compared to the vertical farm as seen in Table 1.

### 3.2 SUPPRESSION OF *Bemisia tabaci* BY SPIDERS

Table 2 shows that there were no significant differences between the mean rank numbers of the predatory spiders observed at 3 (H (4) = 6.222, p = 0.183) and 4 (H (4) = 8.038, p = 0.090) WAT in both the vertical and horizontal farms. Even though a significant population of predatory spiders was observed at 5 WAT (H (4) = 10.678, p = 0.030) in the vertical farm, it was not able to bring the population of *B. tabaci* below the action threshold (Tables 1 and 2).

Tables 1 and 2 also revealed that biological suppression by natural intervention of spiders (Fig. 2) was initially achieved only in the vertical farm at 6 WAT and started with the mean spider number of 13.00 in Array 3 significantly (H (4) = 12.616, p = 0.013) able to bring down the population of *B. tabaci* to the mean number of 0.00 (Table 1). This continued further as the number of spiders gradually increased in the vertical farm from 7 to 10 WAT and reached its peak at 10 WAT in array 3 with the mean number of 35.00 which was highly significantly (H (4) = 12.994, p = 0.011) effective in suppressing the population of *B. tabaci* below the action threshold when compared to the horizontal farm which was above it throughout the period of the experiment (Table 1 and 2), this was as a result of the

**Table 1**: Number of *Bemisia tabaci* on the vertical and horizontal farm

| | | Population of *B. tabaci* in horizontal and vertical farms (WAT) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Farm Type | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Horizontal | Raised bed | 9.15$^{d}$ | 8.61$^{c}$ | 7.26$^{b}$ | 11.75$^{e}$ | 13.22$^{d}$ | 9.54$^{d}$ | 8.28$^{b}$ | 9.51$^{c}$ | 13.35$^{c}$ | 8.84$^{b}$ |
| | Flat bed | 12.81$^{e}$ | 9.75$^{d}$ | 10.64$^{d}$ | 10.51$^{c}$ | 14.69$^{e}$ | 11.84$^{e}$ | 9.12$^{c}$ | 7.04$^{b}$ | 9.38$^{b}$ | 10.80$^{c}$ |
| Vertical | Array 1 | 8.72$^{c}$ | 7.75$^{b}$ | 13.79$^{e}$ | 6.54$^{a}$ | 7.64$^{c}$ | 4.99$^{c}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| | Array 2 | 6.52$^{b}$ | 7.68$^{a}$ | 6.96$^{a}$ | 8.87$^{d}$ | 7.38$^{b}$ | 3.73$^{b}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| | Array 3 | 5.30$^{a}$ | 11.00$^{e}$ | 8.08$^{c}$ | 6.33$^{b}$ | 5.80$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| SEM | | 0.82 | 0.50 | 1.44 | 1.35 | 1.24 | 1.05 | 1.28 | 0.98 | 0.60 | 0.61 |

Superscripts within column indicates mean rank number according to Kruskal-Wallis Test, with a = rank 1, b = rank 2, c = rank 3, d = rank 4 and e = rank 5; 1 being the lowest to 5 the highest rank, SEM = Standard error of mean

**Table 2**: Number of predatory spiders on the vertical and horizontal farm

| | | Population of predatory spiders in horizontal and vertical farms (WAT) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Farm Type | | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Horizontal | Raised bed | 0.00[a] | 0.33[a] | 0.00[a] | 0.67[a] | 1.00[b] | 1.00[b] | 6.30[b] | 0.00[a] |
| | Flat bed | 0.00[a] | 0.33[a] | 0.33[b] | 0.67[b] | 1.70[a] | 0.30[a] | 4.30[a] | 0.00[a] |
| Vertical | Array 1 | 0.00[a] | 0.33[a] | 9.33[e] | 5.00[c] | 15.00[c] | 21.00[c] | 23.70[e] | 16.30[b] |
| | Array 2 | 0.67[c] | 1.00[b] | 7.67[c] | 10.33[d] | 20.30[d] | 22.30[d] | 21.70[d] | 20.00[c] |
| | Array 3 | 0.33[b] | 3.33[c] | 8.67[d] | 13.00[e] | 34.00[e] | 27.00[e] | 21.00[c] | 35.00[d] |
| SEM | | 0.19 | 0.73 | 1.25 | 1.10 | 4.02 | 2.49 | 3.61 | 2.31 |

Superscripts within column indicates mean rank number according to Kruskal-Wallis Test, with a = rank 1, b = rank 2, c = rank 3, d = rank 4 and e = rank 5; 1 being the lowest to 5 the highest rank, SEM = Standard error of mean

significantly low numbers of spiders recorded in the horizontal farm which were less than that of the vertical farm as shown in Table 2.

### 3.3 MASS OF TOMATO FRUIT YIELD IN HORIZONTAL AND VERTICAL FARM

The total tomato fruit yield (g) harvested from both the horizontal and vertical farms are shown in Table 3. There was no significant (H (4) = 7.767, p = 0.101) differences between the vertical and the horizontal farm. Further observations on the mean rank of the fruit mass indicated that array 3, array 2 and array 1 of the vertical farm had the highest tomato fruit mean mass of 67.10, 61.20 and 55.10 respectively when compared to the horizontal farm (Table 3).

### 3.4 CORRELATION BETWEEN NUMBER OF *B. tabaci*, NUMBER OF SPIDERS AND FRUIT YIELD

Significantly negative correlation ($R_s$ = -0.999) was observed between the number of spiders and the number of *B. tabaci* in the vertical farm as shown in Table 4. The horizontal farm, on the other hand, the numbers of spiders observed did not have a significantly negative correlation effectively enough to reduce the population of *B. tabaci* ($R_s$ = -0.318) compared to the vertical farm.

Table 4 also showed that the fruit yield in both the horizontal and vertical farm was affected by the population of *B. tabaci* having a negative correlation of -0.28 and -0.813 respectively. However, the correlation of the number of spiders in the vertical farm with the fruit yield ($R_s$ = 0.806) showed that the presence of the spiders positively influenced the fruit yield in the vertical farm compared to the horizontal farm which had a negative correlation of -0.256 in its fruit yield as seen in Table 4.

**Table 3**: Mass of tomato fruits (g) in both horizontal and vertical farms

| Farm Type | | Mass of tomato fruit (g) |
|---|---|---|
| Horizontal | Flat bed | 16.90[a] |
| | Raised bed | 30.50[a] |
| Vertical | Array 1 | 55.10[a] |
| | Array 2 | 61.20[a] |
| | Array 3 | 67.10[a] |
| SEM | | 14.03 |

## 4 DISCUSSION

The current study is a novel approach in indicating the usefulness of outdoor vertical farming technique in sustainable crop production. Despommier as described by Corvalan et al. (2005) and Al-Kodmany (2018) hinted that vertical farming system will succeed only if they function by imitating natural ecological processes. The outdoor vertical farming system could be useful in supporting the practice of growing crops organically. The design allows for the natural use of sunlight and also encourages the natural interactions with ecological service providers as observed in this research. The experiment indicated that spiders acted as positive service providers in terms of natural suppression against whiteflies affecting tomato grown using open-air vertical farms. The technique of outdoor vertical farm unlike the indoor ultra-modernized versions allows for the interaction of plants with beneficial arthropods. Plants' evolutionary response to pest damage is to emit

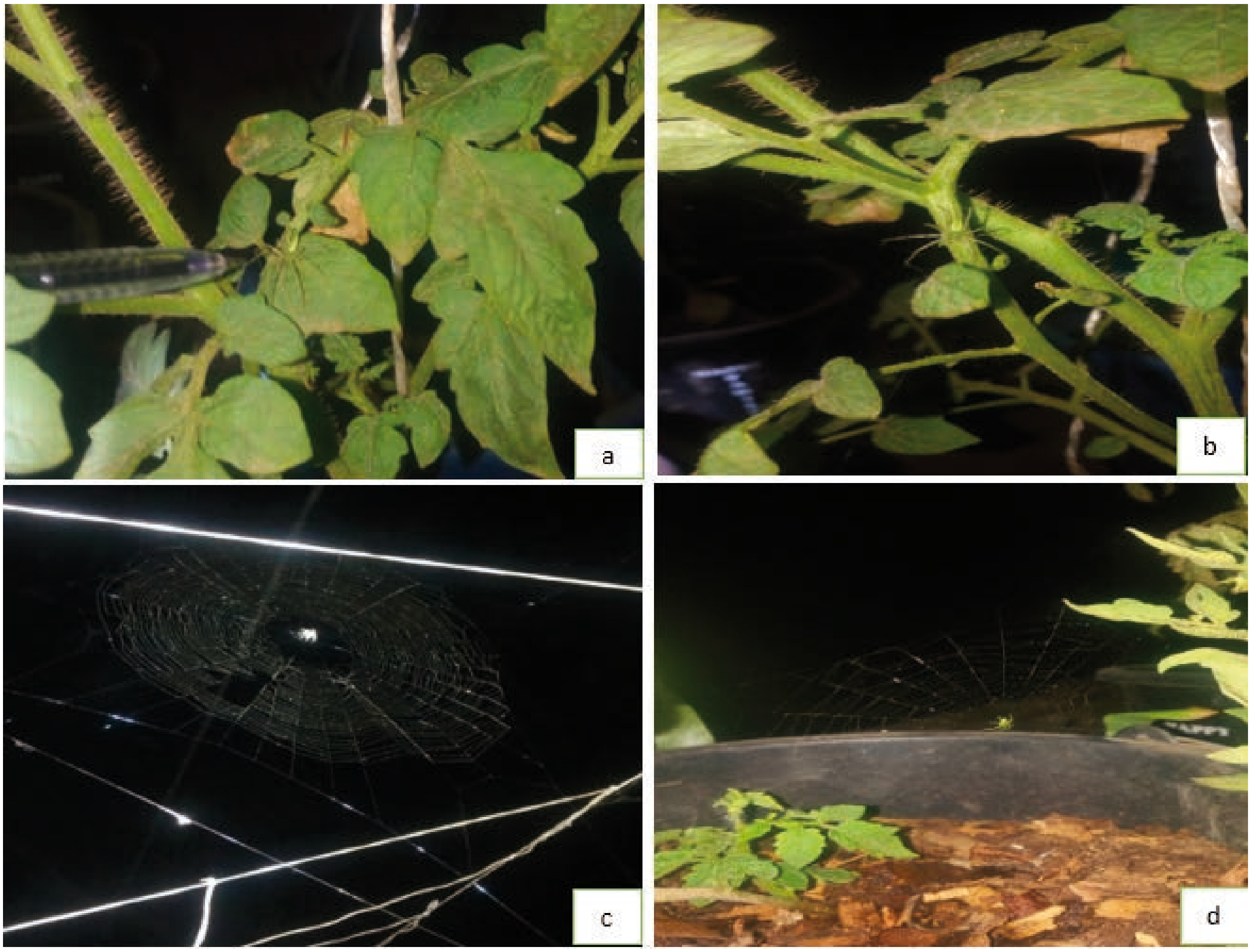


**Figure 2: S**howing presence of spiders in the vertical farm. Pictures a, b: green spiders observed using camouflage to hunt for preys; pictures c, d: two different species of spider on their web to capture prey

**Table 4**: Correlation between no. of *B. tabaci*, no. of spiders and fruit yield in the vertical and horizontal farm

| | | Horizontal farm | | Vertical Farm | |
|---|---|---|---|---|---|
| | | BTH | SPH | BTV | SPV |
| Horizontal farm | BTH | - | - | - | - |
| | SPH | -0.318 | - | -0.788 | - |
| | FYH | -0.28 | -0.256 | 0.693 | -0.699 |
| Vertical farm | BTV | 0.363 | - | - | - |
| | SPV | -0.333 | 0.802 | -0.999** | - |
| | FYV | -0.083 | 0.303 | -0.813 | 0.806 |

*Correlation is significant at the 0.05 level (2 tailed), ** Correlation is significant at the 0.01 level (2-tailed)
BTH=*B. tabaci* horizontal farm, BTV= *B. tabaci* vertical farm, SPH= Spiders horizontal farm, SPV= Spiders vertical farm, FYH= Fruit yield horizontal farm, FYV= Fruit yield vertical farm, - = no correlation

a unique chemical signal known as herbivore induce plant volatiles- a distress signal to recruit the services of predatory arthropods who feed off these pest (Karban and Baldwin, 1997; Thaler, 1999; Kessler and Baldwin, 2001; Lou et al., 2006; Pickett et al., 2006). This study positively indicated that the ability of crops to emit this substance is not restricted using open vertical farming techniques. The vertical farm created a favourable niche for the increase in the population of spiders by having adequate platforms where spiders could set up webs and could easily move around to reach and capture their prey within the varying heights (Jayakumar and Sankari 2010). Spiders, being a carnivorous arthropod, typically preying on insects, positively provided an important service in keeping the population of *B. tabaci* below the action threshold by natural intervention in the vertical farm in all three arrays (Marshall, 2006; Oyeniyi and Oyeseyi, 2014).

Sahu et al. (1996) and Jayakumar and Sankari (2010) studied the predatory efficiency of spiders in the suppression of pests in some field crops. In their study, there was no comparison to different growing heights to the predatory potential of spiders as shown in this research that growing heights using vertical farm could also be resourceful in influencing the increase of spiders to control pests. Correlation analysis also revealed that the rise in the population of spiders has a strong effect in suppressing the population of *B. tabaci* in the vertical farm when compared to the horizontal farm. The increased population of spiders in the vertical farm limited the population of whiteflies (Jayakumar and Sankari, 2010). The practice of vertical farming is considered to promote sustainable agricultural practices more than that adopted by conventional farming method (horizontal farm), which refers to large scale, outdoor agriculture that embraces techniques that engage heavy irrigation, intensive tillage and excessive use of fertilizers, and pesticides (Despommier, 2007; Healy and Rosenberg, 2013).

The fruit yield data collected from both the vertical and horizontal farm indicated that even though the horizontal farm produced fruit yield that was not significantly different from the different arrays of the vertical farm, the same was not enough yield in comparison to the vertical farm that gave better fruit yield. The increased fruit yield harvested from the vertical farm may be due to the ability of the farm to grow crops in arrays in limited space by stacking crops above each other which is an advantage over the horizontal farming method that makes use of huge expanse of land (Garg and Balodi, 2014; Hossain et al., 2015). With a little utilized space of about 1.8 square metre in the vertical farm, more fruit yield was gotten when compared to the horizontal farm space of 3.6 square metre and this is indicative of the facts that this technique could be used to increase food yield where land is fast becoming a limited resource. Also, the different heights of the vertical arrays in an outdoor situation would ensure that elevated plants have greater and better access to ambient amount of sunlight which will positively affect the performance of the crop to produce more fruit (Garg and Balodi, 2014).

By vertically growing crops, it would not only mitigate the need for more land, it would also produce available growing space in the air where crops could be grown in arrays to get more yield as shown in this study (Sarkar and Majumder, 2015; Hossain et al., 2015; Despommier, 2009; Garg and Balodi, 2014). This method also ensured the maximum use of land for tomato production without wastage and could address the loss of cultivable land by utilizing the spaces around households by suspending crops vertically and may eliminate the need to create additional farmland and also help create a cleaner environment with the use of less crop protection products such as pesticides that contaminates the environment and by encouraging the activities of natural enemies like spiders against the activities of insect pests (Despommier, 2009; Hossain et al., 2015).

We would like to put some caution on the interpretation of our result. While we did not identify the species of spiders and also report direct consumption of whiteflies by them through molecular analysis of their gut contents, the increased presence of spiders in the vertical farm may have had a threatening effect on the whiteflies and as such reduced their numbers significantly. Similarly, Southon et al. (2019) in an experiment they conducted by studying biological control of predatory wasps against the insect pest fall armyworm, observed that the presence of wasps negatively affected the feeding habit of fall armyworm, reduced their body mass and also kept them in hiding. It is plausible to infer here that whiteflies may have noticed the increasing population of spiders in the vertical farm and as such felt threatened and would rather derived nutrition elsewhere far from the presence of predators.

## 5 CONCLUSION

This study observed the use of open vertical farming in increasing the presence of predatory arthropods such as spiders in the natural suppression of *B. tabaci*, a major pest of tomato and also to increase yield. Since vertical farming is fast becoming an acceptable trend worldwide due to the overwhelming population increase, the technique could be practiced to produce crops in tight spaces to boost yield to feed the growing populace. Horizontal farming, on the other hand, is just not sufficient enough to meet the needs of this ever-increasing population due to the rapid rate of urbanization. Outdoor vertical farming in comparison to the traditional horizontal technique indicated that natural suppression by ecological service providers could be plausible on crops grown using the technique. Although this is just a pilot trial, further investigations are necessary to ascertain the level of effectiveness open vertical farms will pose in the future to ensure continuous sustainable production of food as an alternative to the dwindling agricultural land resources. The practice could be encouraged to minimizing the dependency on chemical pesticides which have been studied to have deleterious effects. Also, the presence of predatory arthropods could be further influenced for future integrated pest management in open vertical farms. There is, therefore, the need to begin considering this technique as an urban approach to the lack of cultivable lands for food production.

## 6 CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## 7 REFERENCES


Al-Kodmany, K. (2018). The vertical farm: a review of developments and implications for the vertical city. *Buildings*, *8*(24), 2-36. https://doi.org/10.3390/buildings8020024

Corvalan, C., Hales, S. & McMichael, A. J., (2005). *Ecosystems and human well-being: Health synthesis;* World Health Organization: Geneva, Switzerland.

Denholm, L., Cahill, M., Byrne, F. J. & Devonshire, A.L. (1996). Progress with documenting and combating insecticide résistance in *Bemisia*. In: Gerling, D. and Mayer, R.T., (eds.), *Bemisia 1995: Taxonomy, Biology, Damage, Control and Management,* Intercept Ltd. Andover, Hants. UK, pp. 577-603.

Denholm, L., Cahill, M., Dennehy, T. J. & Horowitz, A. R. (1998). Challenges with managing insecticide résistance in agricultural pests, exemplified by the whitefly *Bemisia tabaci*. *Philosophical Transactions of the Royal Society* (Lond. B), *353*:1757-1767. https://doi.org/10.1098/rstb.1998.0328

Despommier, D. (2007). The vertical farm essay 1: Reducing the impact of agriculture on ecosystem function and services. Retrieved November 8, 2011, from http://www.verticalfarm.com/more?essay1

Despommier, D. (2009). The rise of vertical farms. *Scientific American*, *301*, 80-87. https://doi.org/10.1038/scientificamerican1109-80

Despommier, D. (2010). *The Vertical Farm: Feeding the World in the 21st Century*; Thomas Dunne Books: New York, NY, USA.

Despommier, D. (2013). Farming up the city: The rise of urban vertical farms. *Trends in Biotechnology*, *31*, 388–389. https://doi.org/10.1016/j.tibtech.2013.03.008

Despommier, D. (2014). *Encyclopedia of Food and Agricultural Ethics (Vertical Farms in Horticulture)*; Springer: Dordrecht, The Netherlands. https://doi.org/10.1007/978-94-007-0929-4_88

Ellsworth, P. C. & Martinez-Carrillo, J. L. (2001). IPM for *Bemisia tabaci*: a case study from North America. *Crop Protection*, *20*, 853-869. https://doi.org/10.1016/S0261-2194(01)00116-8

European and Mediterranean Plant Protection Organization (2004). Diagnostic protocols for regulated pests. *Bulletin*, *34,* 281–288. https://doi.org/10.1111/j.1365-2338.2004.00729.x

FAO, 2018. Food and Agriculture Organization of the United Nations: FAOSTAT. http://www.fao.org/faostat/en/#data/EL (last access: 9 March 2018).

Garg, A. & Balodi, R. (2014). Recent Trends in Agriculture: Vertical Farming and Organic Farming. *Advances in Plants & Agriculture Research*, *1*(4), 142-144. https://doi.org/10.15406/apar.2014.01.00023

Gerling, D., Alomar, O. & Arnô, J., (2001). Biological control of *Bemisia tabaci* using predators and parasitoids. In Naranjo, S. E. and Ellsworth, P. C. (eds.), Spécial Issue: Challenges and Opportunities for Pest Management of *Bemisia tabaci* in the New Century. *Crop Protection*, *20***,** 779-799. https://doi.org/10.1016/S0261-2194(01)00111-9

Healy, R. G. & Rosenberg, J. S. (2013). *Land Use and the States*; Routledge: New York, NY, USA. https://doi.org/10.4324/9781315064406

Hossain, E., Nabi, S. N. & Kaminski, A. (2015). Vertical agriculture: Homestead horticulture suspended in sacks. Penang, Malaysia: WorldFish, Program Brief

Jayakumar, S. & Sankari, A. (2010). Spider population and their predatory efficiency in different rice establishment techniques in Aduthurai, Tamil Nadu. *Journal of Biopesticides*, *3*, 020-027.

Karban, R. & Baldwin, I. T. (1997). *Induced Responses to Herbivory*. Chicago University Press, Chicago, Illinois, USA. https://doi.org/10.7208/chicago/9780226424972.001.0001

Kessler, A. & Baldwin, I. T. (2001). Defensive function of herbivore-induced plant volatile emissions in nature. *Science*, *291*, 2141–2144. https://doi.org/10.1126/science.291.5511.2141

López, R., Carmona, D., Vincini, A. M., Monterubbianesi, G. & Caldiz, D. (2010). Population dynamics and damage caused by the leafminer *Liriomyza huidobrensis* Blanchard (Diptera: Agromyzidae) on seven potato processing varieties grown in temperate environment. *Neotropical Entomology*, *39*(1), 108-114. https://doi.org/10.1590/S1519-566X2010000100015

Lou, Y., Xiaoyan, H., Turlings, T. C. J., Cheng, J., Xuexin, C. & Gongyin, Y. (2006). Differences in induced volatile emissions among rice varieties result in differential attraction and parasitism of *Nilaparvata lugens* eggs by the parasitoid, *Anagrus nilaparvatae* in the field. *Journal of Chemical Ecology*, *32*, 2375–2387. https://doi.org/10.1007/s10886-006-9151-7

Marshall, S. A. (2006). *Insect: Their Natural History and Diversity*. Firefly Books

Matthews, G. A. (2008). Attitudes and behaviours regarding use of crop protection products—A survey of more than 8500 smallholders in 26 countries. *Journal of Crop Protection*, *27*, 834-846. https://doi.org/10.1016/j.cropro.2007.10.013

Muller, A., Ferré, M., Engel, S., Gattinger, A., Holzkämper, A., Huber, R., Müller, M. & Six, J. (2017). Can soil-less crop production be a sustainable option for soil conservation and future agriculture? *Land Use Policy*, *69*, 102–105. https://doi.org/10.1016/j.landusepol.2017.09.014

Olaniyi, J. O., Akanbi, W. B., Adejumo, T. A. & Akande, O. G., (2010). Growth, fruit yield and nutritional quality of tomato varieties. *African Journal of Food Science*, *4*(6), 398–402.

Oyeniyi, A. O. & Oyeseyi, J. O. (2014). Diversity and distribution of spiders in southwestern Nigeria. *Natural Resources*, *5*, 926-935. https://doi.org/10.4236/nr.2014.515079

Pickett, J. A., Bruce, T. J. A., Chamberlain, K., Hassanali, A., Khan, Z. R., Matthes, M. C., Napier, J. A., Smart, L. E., Wadhams, L. J. & Woodcock, C. M. (2006). Plant volatiles yielding new ways to exploit plant defence. In: Dicke, M., Takken, W. (Eds.), *Chemical Ecology: From Gene to Ecosystem*. Springer, Netherlands, pp. 161–173. https://doi.org/10.1007/978-1-4020-5369-6_11

Roberts, J. M., Bruce, T. J. A., Monaghan, J. M., Pope, T. W., Leather, S. R. & Beacham, A. M. (2020). Vertical farming systems bring new consideration for pest and disease management. *Annals of Applied biology*, *176*, 226-232. https://doi.org/10.1111/aab.12587

Sahu S., Sing, R. & Kumar, P. (1996). Host preference and feeding potential of spiders predaceous in insect pests of rice. *Journal of Entomological Research*, *20*(2), 145-150.

Sarkar, A. & Majumder, M. (2015). Opportunities and challenges in sustainability of vertical eco farming: A review. *Journal of Advanced Agricultural Technologies*, *2*, 98-105. https://doi.org/10.12720/joaat.2.2.98-105

Scholthof, K. B. G., Adkins, S., Czosnek, H., Palukaitis, P. & Jacquot, E. (2011). Top 10 plant viruses in molecular plant pathology. *Molecular Plant Pathology*, *12,* 938–954. https://doi.org/10.1111/j.1364-3703.2011.00752.x

Sequeira, R. V., Naranjo & S. E. (2008). Sampling and management of *Bemisia tabaci* (Genn.) biotype B in Australian cotton. *Crop Protection*, *27*, 1262–1268. https://doi.org/10.1016/j.cropro.2008.04.002

Šimala, M., Milek, T. M. & Korić, B. (2009). Whitefly species (Hemiptera: Aleyrodidae) recorded on imported ornamental plants in croatia from 2005–2008. *Institute for plant protection in agriculture and forestry of Republic of Croatia*, 389-396.

Southon, R. J, Fernandes, O. A., Nascimento, F. S. & Sumner, S. (2019). Social wasps are effective biocontrol agents of key lepidopteran crop pests. *Proceedings of the Royal Society B. Soc. B.*, 286, 20191676. https://doi.org/10.1098/rspb.2019.1676

Thaler, J. (1999). Jasmonic acid mediated interactions between plants, herbivores, parasitoids and pathogens: a review of field experiments in tomato. In: Agrawal, A. A., Tuzun, S., Bent, E. (Eds.), *Induced Plant Defenses Against Pathogens and Herbivores* (pp.319-334). APS Press, St. Paul, Minnesota.

Thomaier, S, Specht, K, Henckel, D, Dierich, A, Siebert, R, Freisinger, U. B & Sawicka, M. (2015) Farming in and on urban buildings: Present practice and specific novelties of zero-acreage farming (Z Farming). *Renewable Agriculture and Food Systems*, *30*, 43–54. https://doi.org/10.1017/S1742170514000143

Touliatos, D., Dodd, I. C. & McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and Energy Security*, *5*, 184–191. https://doi.org/10.1002/fes3.83

Varela, A. M., Serf, A. & Lohr, B. (2003). *A guide to IPM in tomato production in eastern and southern Africa.* International Centre of Insect Physiology and Ecology

Waiganjo, M. M., Wabule, N. M., Nyongesa, D., Kibaki, J. M., Onyango, I., Wepukhulu, S. B. & Muthoka, N. M. (2006). *Tomato production in Kirinyaga district*, Kenya. A baseline Survey report. 3-4.