EFFECT OF SCREEN SIZES ON PERFORMANCE OF AN ADAPTED GREENHOUSE FOR TOMATO PRODUCTION IN THE HUMID TROPICS

(Pengaruh Ukuran Screen Terhadap Kinerja Rumah Tanam Teradaptasi untuk Budidaya Tomat di Daerah Tropis)

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ABSTRACT

High internal temperatures as well as intrusion of serious diseases by insect are the main problem in tomato production in the tropics. The concept of an adapted greenhouse which had a large ventilation opening covered by UV-stabilized net had been proposed and tested. The main goal of the study was to determine the effect of net sizes on the performance of the adapted greenhouse. Microclimate, ventilation rates, crop performance and biological plant protection were used to evaluate the greenhouse's performance. The results revealed that the use of different mesh-sizes of nets as cladding materials over ventilation opening has a significant effect on microclimate, ventilation rate, total yield, fruit quality, and pest exclusion. Compared to the 40 mesh greenhouse, ventilation rates in the 78 and 52 mesh greenhouses were reduced by 50% and 35%, respectively. Consequently, the internal air temperature was also increased by 1 to 3 °C. Regarding air temperature o nly minor differences have been observed. However, differences in absolute humidity were much more pronounced and statistically significant. Humidity in the 78 mesh greenhouse was two times higher than in the 40 mesh greenhouse. The 52 mesh was chosen as a compromise size of nets to be appropriately used for tropical greenhouse due to its advantages to the others.

Keywords: ***Adapted greenhouse, mesh-sizes of nets, microclimate, tomato, humid tropics.***

ABSTRAK

Tingginya suhu udara didalam *greenhouse* dan tingkat serangan hama tanaman merupakan masalah utama dalam budidaya tomat di daerah tropis. *Adapted greenhouse* adalah suatu konsep rumah tanam dengan bukaan ventilasi sangat besar dan ditutup dengan net tipe UV untuk meningkatkan laju ventilasi, menjaga iklim mikro dan menekan masuknya hama (insect) ke dalam *greenhouse*. Konsep tersebut telah dikembangkan dan dikaji untuk dievaluasi secara teknis, agronomis and entomologis dengan berbagai ukuran net. Tujuan dari penelitian ini adalah untuk melihat pengaruh ukuran *net* terhadap kinerja dari *greenhouse* tersebut. Hasil penelitian menunjukkan bahwa *greenhouse* yang menggunakan tiga jenis ukuran *net* (40, 52 dan 78 mesh) untuk dindingnya mempengaruhi secara nyata terhadap suhu dan kelembaban, laju ventilasi, total produksi dan mutunya serta tingkat serangan hama di dalam greenhouse. Laju ventilasi akan turun masing-masing 50% dan 35 % bila menggunakan jenis *net* yang lebih halus (78 mesh dan 52 mesh) dibanding dengan *greenhouse* yang menggunakan 40 mesh. Akibatnya suhu udara di dalam juga meningkat antara 1 – 3 °C. Meskipun beda suhu antara di dalam dan luar greenhouse hanya kecil, akan tetapi kelembaban mutlak di dalam *greenhouse* dengan 78 mesh dua kali lebih besar dari *greenhouse* dengan 40 mesh net. Secara umum, *greenhouse* dengan 52 mesh net menunjukkan kinerja yang terbaik ditinjau dari beberapa parameter penting tersebut diatas.

Kata kunci: **Rumah tanam teradaptasi, ukuran *net*, iklim mikro, tomat, tropis basah.**

INTRODUCTION

The development of worldwide greenhouse to produce horticultural products with relatively safe and health products for human life has increased due to the increase of demand for fruits/vegetables (as increasing world population), and rising standard of living. Recently, development of greenhouse is also expanding from highland (cooler) and temperate areas to lowland and warmer regions such as in sub-tropic or tropical region in order to fulfil the above demand. Growing vegetables in the tropical greenhouse has many challenges because it has some specific conditions such as: high temperature, high humidity, and abundant solar radiation even though it is possible to cultivate crops along the year due to the availability of solar radiation. Moreover, both higher temperature and humidity have become a serious problem for crop cultivation under tropical greenhouses. Plants stress and significant yield reduction can be caused by this temperature rise. Therefore, some efforts to reduce high temperature and humidity should be made in order to provide an optimum condition for growing plants in the greenhouse.

The concept of adapted greenhouse for tropical region has been proposed and recently tested. The greenhouse was designed to be a relatively simple structure, easy in operation, cheaper and low cost in maintenance. The material for building up the greenhouse should be locally available with relatively longer period of life use (mostly between 3 and 5 years). A naturally ventilated greenhouse is mostly common practice to meet these requirements. In addition, the ventilation opening area should be maintained to be as large as possible in order to achieve an internal air temperature close to the ambient temperature (von Zabeltitz, 1999), and it has become a cooling tool for crops inside the greenhouse in terms of microclimate management. In order to avoid the possibility of poor conditions in case of an extreme temperature in the greenhouse, the appropriate exhaust fans had been installed.

In the frame of integrated pest management (IPM) involved in the adapted greenhouse, some selected insect proof nets were used in greenhouse to exclude some insect pests. It is reported that insect pest is one of major problems in greenhouses located in humid tropics region (Murai et al., 2000). Therefore, the use of insect-proof nets for cladding material in the greenhouse has become very important because it can prevent crop damage by insects and other diseases. The practice to exclude insect disease by using the net as cladding material over the ultra-violet (UV) plastic film in the greenhouse is also known as protected cultivation. Moreover, insect screening reduces the number of insects entering a greenhouse and reduces the need for pesticides.

Even though nets are effective in protection from insect, the net can cause a restriction to the air flow. Therefore, a larger screened area is needed to permit the same air flow as originally existed. Many authors (Bailey et al., 2003; Tanny et al., 2003; Klose and Tantau, 2004; Munoz et al., 1999) investigated that there is a reduction of air flow rate when the insect net was applied on greenhouse. Reduction of air flow rate in greenhouse due to the effect of insect screens can lead to increase air temperature and humidity.

Bethke (1990) recommended using the appropriate mesh size of nets for different insect pest exclusion, but the knowledge about the effect of nets on the climate inside the greenhouse and crops production is still few. The selection of a certain mesh size of nets to be used in the greenhouse was mainly based on the size of insects to be excluded, the stage of insects and their behaviours while they were flying or migrating into the greenhouse.

Some efforts on controlling microclimate under naturally ventilated greenhouse will be focused on applying the different widths of net meshes and installing the emergency ventilation by exhaust fans. With regards to the treatment, measuring ventilation rate and other climatic parameters (using both direct measurements and a model) has to be adapted. Therefore, the optimization of mesh-size of nets to be used to the adapted greenhouse for the humid tropics would then be possible.

MATERIALS AND METHODS

The experiment was conducted at the greenhouse complex in the Asian Institute of Technology, Bangkok, Thailand (13.06^o N latitude and 100.62^o E longitude at an altitude of 2.7 m) from June 2003 to April 2004 (rainy and cool seasons of the year). Three identical greenhouses covered with different net types i.e.: 40 mesh (Econet M, anti leaf miners), 52 mesh, (anti whiteflies) a nd 78 mesh (Econet T, anti thrips) were used for the experiment.

All screens (nets) used for the experiment were rectangular types and their sizes were described in mesh (defined as a number of threads per inch length for each direction). The higher number mesh between two directions is usually used to consider as the size of screen. The technical specification of all screens used in this study is presented in Table 1.

Each greenhouse measured 10 m wide × 20 m long had an East-West orientation. An ultraviolet (UV) stabilised PE film was used to cover every greenhouse roof, gables and lower part of the sidewalls (up to a height of 0.8 m above the ground). The sidewalls and the ventilation openings on the roof were covered with the insect proof nets mentioned above (one mesh size per greenhouse). In addition, each greenhouse was equipped with two exhaust fans with a total capacity of 1,100 m^3 min^{-1}, 2.2 kW power (Fig. 1). The fans were only used in case of emergency when internal temperature was > 35 °C, however during the experiment all fans were switched off in order to maintain a naturally ventilated system. Black plastic mulch was spread on the floor of each greenhouse.

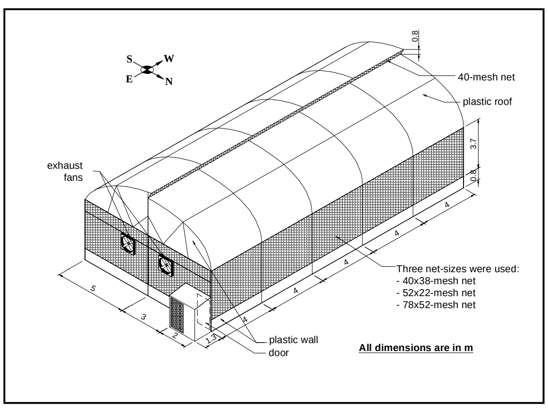

Figure 1. Isometric View of The Adapted Greenhouse Structure Used for The Experiment.

Air temperature and relative humidity inside the greenhouse were measured using aspirated psychrometers with K-type thermocouple sensors (0.5 mm diameter). Two psychrometers were positioned in the middle of the greenhouse at a distance of 10 m between them and maintained at a height of 0.5 m above the plants during the growth period. Incoming solar radiation was measured by a solarimeter CM 11/14 type (Kipp and Zonen, Delft, The Netherlands) with signal output between 4 and 6 μV W^{-1} m^{-2} and the accuracy of 2% measurement. The solarimeter was placed at the centre of greenhouse at a height of 2.5 m above the floor. Soil temperature was measured using a thermocouple sensor similar to the one used for air temperature.

Outside climatic data were measured using several sensors installed in a meteorological station located 25 m away from the greenhouses. Dry and wet bulb temperature and global radiation were measured using the same sensors described above. Wind speed and direction were measured using a cup anemometer and wind direction transmitter (Thies Klima GmbH, Germany), respectively. They were placed at a height of 6.9 m above the ground level. All sensors, both in the greenhouse and at the meteorological station, were connected to a data logging system developed at the Institute of Horticultural and Agricultural Engineering (ITG), University of Hannover, Germany. The climatic data were measured at an interval of 15 s, and then average values were stored every minute on the disk for further evaluations. All sensors were calibrated prior to use.

Ventilation rate was measured using water balanced method and it was calculated based on the crop transpiration rate measurement, as follows (Harmanto et al., 2006):

$$G(t) = \frac{\rho_w [W_{fi}(t) - W_{fo}(t)]}{A_f [X_i(t) - X_o(t)]} \quad \ldots\ldots \quad (1)$$

Where : *G(t)* is the measured ventilation rate per unit greenhouse surface floor area over period of time (t) in m^3 s^{-1} (m^{-2}), ρ_w is water density (≈1.0 kg ℓ^{-1}), $[W_{fi}(t) - W_{fo}(t)]$ is crops transpiration rate which is measured using water flux meter (FTB603 model, Omega Engineering, USA) incoming to and outgoing from the greenhouse during t time in ℓ s^{-1}, A_f is greenhouse surface floor area in m^2, and $[X_i(t) - X_o(t)]$ is absolute humidity difference between inside and outside the greenhouse over period of time (t) in kg m^{-3}. The calculation of ventilation rates was conducted by averaging of measurements during daytime over certain period of time from 8:00 to 17:00h (9 hours).

Tomato (*Lycopersicon esculentum*, cv. King Kong II) seedlings were transplanted, three weeks after sowing, into large pots (one plant per pot) filled with soil substrate (28% organic matter) with a pH of 5.3. The soil texture was 30% sand, 39% silt and 31% clay. In each greenhouse, a total of 300 tomato plants were planted within six rows with spacing of 1.5 m between the rows and 50 pots for each row (density of 1.5 plants m^{-2}). An assumption was made that water vapour transpired from each plant was uniform for all points in the greenhouse. Plant height was measured each week while tomato yield and fruit quality were recorded every week after harvesting time.

Table 1. Technical specification and geometric characteristics of the screens used for this study

Screens (nets)	*Hole size*		*Thread diameters, mm*	*Light transmission, %*	*Porosity (ε)*	*Discharge coefficient (C_d)*
	Length, mm	*Width, mm*				
Anti-*Leaf miners*	0.44	0.39	0.25	87	0.41	0.31
Anti-*Whiteflies*	0.80	0.25	0.31	70	0.38	0.28
Anti-*Thrips*	0.29	0.18	0.19	86	0.30	0.21

The crops were cultivated and maintained at a similar practice for each treatment. In order to accommodate non-stressed condition of tomato crops, irrigation water (about 30% over actual water requirement) was given based on light integral from global solar radiation. This arrangement was also directed to obtain an accurate measurement of crop transpiration rate using water balance model.

Since insect pest infestation is mostly a major problem for vegetable crops (tomato) in humid tropical region (Murai *et al.*, 2000), population of two important pests *i.e.*: whiteflies (*Bemisia tabaci sp.*) and thrips (*Thysanoptera: Thripidae sp.*) in each greenhouse were monitored. Four blue and four yellow coloured sticky traps (a size of 12 cm × 10 cm) were mounted at various randomly selected locations in each greenhouse to capture these insect pests. All the traps were hanged at the height of similar to the plant height. Insects were counted every week and fresh traps were used to replace the older ones.

The statistical analysis of PROC GLM-LSD (General Linear Model-Least Square Difference) tool from the SAS software (SAS Institute, 2003) was used to evaluate the performance of adapted greenhouse at different mesh sizes of nets.

RESULTS AND DISCUSSION

Effect of Mesh Size of Nets on Ventilation Rates and Microclimate

Table 2 shows the effect of different mesh-sizes of nets placed on the ventilation openings on the ventilation rates and microclimate condition in the greenhouse. The means of those were compared using analysis of variance (ANOVA) (GLM procedure; SAS Institute, 2003). The results revealed that there was a significantly effect of different net-sizes on the ventilation rate despite the very big ventilation opening (ratio of vent opening to the surface floor area is 1.02) was applied. The greenhouse with finest hole-size (78 mesh) showed the lowest means of ventilation rate compared to the two greenhouses with 40 and 52 mesh, respectively. The reduction of ventilation rate up to 50% (for 78 mesh) and 35% (for 52 mesh), respectively were measured if it was compared to the 40 mesh greenhouse. Therefore, the use of insect-proof net with finer hole-size would significantly reduce the ventilation rate.

Concerning to the microclimate condition, the means of some important parameters are also compared (Table 2). The air temperature in the greenhouse covered by 78 mesh had only significantly increased by 1 ℃ (or 3% increment) compared to the 40 mesh greenhouse, but in the 52 mesh greenhouse was almost the same as in the 40 mesh greenhouse. The means of relative humidity for each treatment was not significantly different as the experiments were carried out in rainy season, except at the 78 mesh greenhouse. The relative humidity was significantly different ($P < 0.003$, $N = 88$) and it was higher in the 78 mesh greenhouse compared to the 52 and 40 mesh greenhouses. This result is in line with the finding of empirical equation from Ajwang and Tantau (2005).

Even though there was no significantly difference of air temperatures inside the greenhouses covered by 52 and 40 mesh (Table 2), the diurnal air temperature for typical day taken from October 10, 2003 (Figure 2) showed that internal air temperature was significant different for each greenhouse mostly during day time from 8:00 to 17:00 h. It is clear that internal air temperature in the 78 mesh greenhouse was dramatically higher than that in the 52 and 40 mesh greenhouses, while the increase of air temperature in the 52 mesh was quite less even it was similar to the one in the 40 mesh greenhouse. However, during night time their air temperatures (for all greenhouses) were quite similar.

In terms of humidity, there was a significant effect of the use of higher mesh-size net on absolute humidity for each treatment of greenhouse at confident level of 95% as shown in Table 2. Under natural ventilation, the greenhouse covered with 78-mesh, the humidity difference between inside and outside the greenhouse was almost 50% and this led to increase air temperature by 1 to 2 ℃ compared to the 40-mesh greenhouse even though their relative humidity seem very close to each other. On the contrary, the water vapour density in the greenhouse covered with 40 mesh was very close to the ambient condition (about 1 to 2 g m^{-3}), while for the greenhouse with 78 mesh their differences were up to 5 g m^{-3}. This may have a potential problem with the incident of fungal diseases and decrease in the yield. The accumulated water vapour could not be transported out from the greenhouse due to lower ventilation rate.

Mesh Size of Nets Related to Ventilation Rate and Temperature Rise

Since nets are available in different types, they are normally described by mesh sizes which give the number of threads per inch length for each direction. In scientific manner, screen porosity is used as important parameter to describe the screen types (Table 1). The effect of screen porosity on the ventilation rate is presented in Figure 3(a). It is clear that ventilation rate was reduced when a lower porosity of net was applied. Ventilation rate seems an exponential function against the porosity and their correlations were good in agreement (R^2 = 0.923 and R^2 = 0.822 for mature and young plants, respectively).

Table 2. Mean (± Standard Error, SE) ventilation rate, air temperature, relative humidity and absolute humidity difference in the greenhouses at three different mesh-sizes of net.

Screens (mesh)	*Ventilation Rate (m^3 m^{-2} s^{-1})*	*Air Temperature (℃)*	*Relative Humidity (%)*	*Absolute Humidity Difference(g m^{-3})*
40 mesh	0.0719[a] ± 0.0025	30.8[b] ± 0.1	69.7[b] ± 0.3	1.05[c] ± 0.08
52 mesh	0.0461[b] ± 0.0019	31.1[b] ± 0.1	70.3[b] ± 0.3	1.63[b] ± 0.09
78 mesh	0.0361[c] ± 0.0022	31.9[a] ± 0.1	74.1[a] ± 0.3	2.21[a] ± 0.12

[a] *Within column, means followed by the same letters are not significantly different at P = 0.05, LSD Test.*

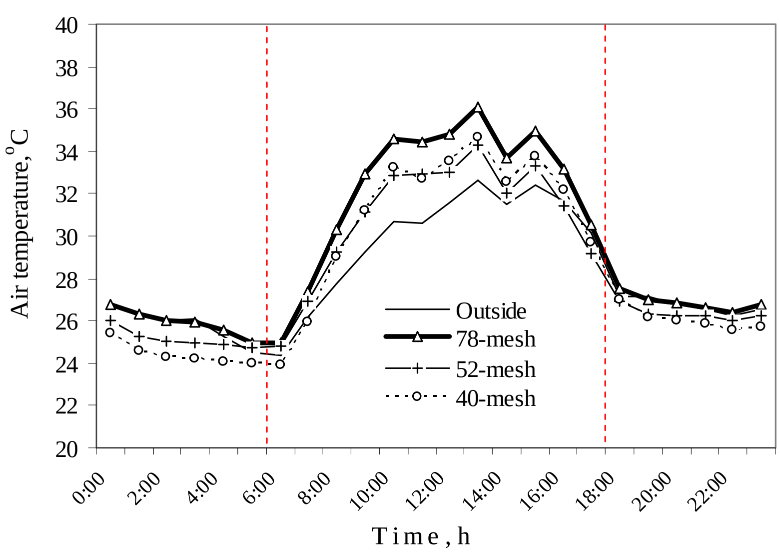

Figure 2. Diurnal air temperature in each greenhouse and ambient for the typical day.

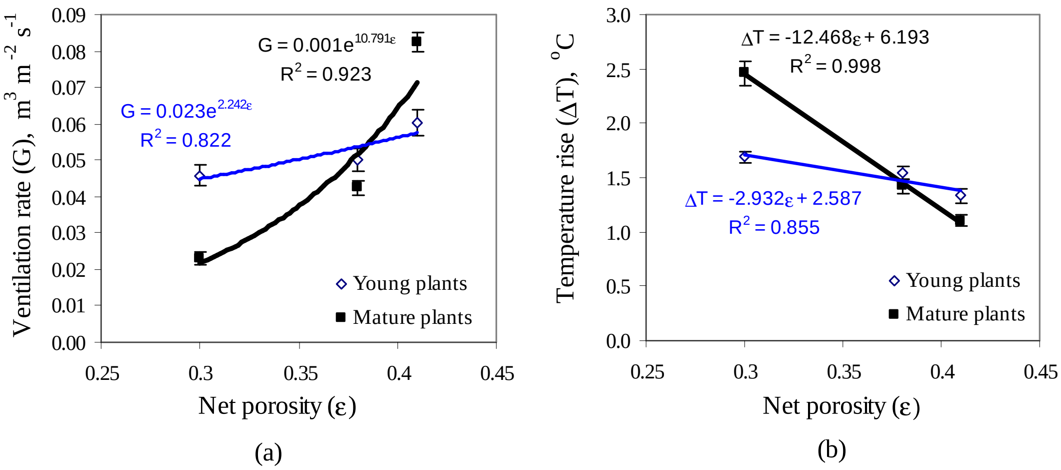

Figure 3. The relationships between (A) net porosity and ventilation rate and (B) net porosity and temperature rise in tropical greenhouses; R^2, coefficient of determination.

Figure 3(b) shows the relationships between screen porosity and temperature rise in the greenhouse. Again, the temperature rise in such greenhouse was more if lower porosity of net (78 mesh) was used to cover vent opening. The temperature rise was a linear function of screen porosity. In general, a good agreement between two was also obtained. From the experiment, correlation between two parameters was better if the measurement was carried out in the greenhouse with mature plants (LAI of 1.5 to 3.0). Since its coefficient correlation, R^2 was 0.998, it can be said that a better agreement was achieved. Therefore, it is important that the simple equation deduced from this study might be very useful to predict the temperature rise if such new nets would be applied to the greenhouse.

Despite the number of screen types used for this study was limited (only three), such equations can be deduced to predict ventilation rate and temperature rise. Screen porosity was used as the main parameter to predict these parameters. As lower porosity of nets was used, ventilation rates were exponentially reduced as well as linearly increasing the temperature rises in greenhouse. This finding is in accordance with the result from Fatnassi et.al (2003) who investigated the linearity of air exchange rate against discharge coefficient (C_d) of insect-proof net. Since a good correlation was mostly obtained from the experiment, the simple equation achieved from the study would be useful to the grower.

Effect of the net types used on plant growth and yield

During the experiment, some agronomic parameters, such as: the rate of plant height, tomato yield and fruit quality were also recorded. Table 3 shows the result of these measurements that there was no significant difference in the growth rate of tomato among the greenhouses covered with different net-size at the rate of 0.27 m per week (F=0.38; N=7; P = 0.6832).

Table 3. Mean (± SE) of Weekly plant growth rate, total yield and tomato quality in the greenhouses covered by three different mesh sizes of nets

Screens	*Plant growth rate (m week^{-1})*	*Tomato yield (t ha^{-1} week^{-1})*	*Fruit quality (unmarketable, %)*
Anti-*Leaf miners* (40 mesh)	0.27 [a] ± 0.06	4.66 [b] ± 0.72	16.98 [a] ± 0.93
Anti-*Whiteflies* (52 mesh)	0.27 [a] ± 0.08	7.33 [a] ± 0.77	12.12 [ab] ± 0.91
Anti-*Thrips* (78 mesh)	0.27 [a] ± 0.07	5.50 [b] ± 0.79	8.26 [b] ± 0.85

[a] *Within column, means followed by the same letters are not significantly different (P = 0.05, LSD multiple range test [SAS Institute, 2003])*

However, the tomato yield obtained every week from each greenhouse was significantly different at confident level of 5% using ANOVA (F-test) (F = 4.46; N = 7; P = 0.0025). The total yield produced from the 52 greenhouse at 7.33 t ha^{-1} gave a better result compared to the other greenhouses of 4.66 t ha^{-1} and 5.50 t ha^{-1} for the 78 mesh and 40 mesh treatments, respectively (Table 3).

The number of defected fruit known as “unmarketable fruit” from the total fruit was also analyzed using ANOVA one-way test and the result showed there was a significant effect of applied different mesh-size of net on percentage of unmarketable fruit (F = 3.81, N = 7; P = 0.0171). Based on the weekly measurement, the percentage of unmarketable tomato in the finer mesh-size (from the 78 mesh greenhouse) assured a better fruit quality at about 95% (on average) compared to the 52 mesh and 40 mesh greenhouses at about 80%. However, growing tomato in the greenhouse covered by 52 mesh of net gave a little bit good results in terms of growth rate, total yield and longer period of cultivation (Harmanto et al., 2006). The results from the study reveals an important finding that the wise and proper choice of mesh sizes of nets to be used to tropical greenhouse may play a vital role in order to achieve the optimum condition for crop growth and to maximize crop yield.

Effect of the net types used on the incident of insect infestation

In order to further evaluate the performance of the nets used for the experiment, their ability to exclude insect disease infested to the greenhouse was examined. Table 4 reveals the number of two species of insects i.e.: whiteflies and thrips, as the serious diseases for humid tropical tomatoes, per traps (0.12 m^2) observing in two conditions of young and mature plants. It is shown that the 40 mesh greenhouse was unable to exclude the whiteflies compared to other greenhouses (with 52 and 78 mesh nets). For both conditions i.e.: young and mature plants, the number of whiteflies per trap in 40 mesh greenhouse was about 0.43 and 1.46, respectively and it was significant different to the other greenhouses which almost had no insect infestation (N = 7; P = 0.0340 and P = 0.0625 for young plants and mature plants, respectively).

In term of thrips infestation, only a few insect was captured in both 52 and 78 mesh greenhouses (< 1 thrips per trap) while in the 40 mesh greenhouse was about 2 species per trap. When the plants were mature, the insect abundances were significantly increased. Thrips can not be ultimately blocked using all types of the nets. Despite Bethke (1990) recommended 132 mesh net to totally exclude thrips, it is not possible to apply this net for tropical greenhouse due to a significant temperature rise and reduction of ventilation rate. In the present study, 78 mesh net was used as a compromise size as thrips barrier mentioned above, however it is shown that the 78 mesh net was also unable to entirely exclude thrips infestation especially in the mature crops condition (Table 4). In comparison to the 40 mesh greenhouse, the use of 52 mesh net can significantly reduce thrips population by a half while the application of 78 mesh net can decrease the number of thrips by a quarter.

Table 4. Mean (± standard error, SE) values of insect diseases infestation in the greenhouses covered by three different mesh sizes of nets

Screens	*Number of whiteflies per trap*		*Number of thrips per trap*	
	Young plants	*Mature plants*	*Young plants*	*Mature plants*
Anti-*Leaf miners* (40 mesh)	0.43 [a] ± 0.20	1.46 [a] ± 0.76	2.08 [a] ± 0.52	76.88 [a] ± 42.38
Anti-*Whiteflies* (52 mesh)	0.00 [b] ± 0.00	0.08 [b] ± 0.05	0.63 [b] ± 0.15	42.44 [a] ± 20.97
Anti-*Thrips* (78 mesh)	0.00 [b] ± 0.00	0.04 [b] ± 0.04	0.55 [b] ± 0.18	20.75 [a] ± 6.34

[a] *Within column, means followed by the same letters are not significantly different (P = 0.05, LSD multiple range test [SAS Institute, 2003])*

CONCLUSION

1. The use of different net-sizes placed on the greenhouse ventilation openings showed a significant effect on the ventilation rates and internal microclimate. Compared to the 40-mesh greenhouse, ventilation rates were reduced by 50% and 35%, respectively when the 78- and 52-mesh of nets were applied. Consequently,

the internal air temperature was increased by 1 to 3 °C. Even though, a small difference of temperature rise was observed, the absolute humidity among treatments was significantly different. Higher mesh-size of net used resulted in more humidity. It was clear that internal humidity was double when bigger mesh size of net (from 40 to 78 mesh) was applied during daytime.

2. Ventilation rate and temperature rise in such greenhouse covered by the nets were strongly correlated to its net porosity. Since their correlations were good in agreement (R^2 = 0.998), the simple equation derived from the experiment might be useful to the grower to predict expected temperature rise when a new net (to exclude a certain insect) will be applied to the greenhouse.

3. Since the 52 mesh greenhouse performed a similar microclimate with the 40 mesh greenhouse and its ability to exclude the most harmful insects (whiteflies and thrips) was very close to the 78 mesh greenhouse, it is suggested that the 52 mesh is a compromise size of nets to be appropriate used for greenhouse located in the humid tropics. This is because all selected nets used for the experiment were not ultimately proofed against thrips. Moreover, crop yield and fruit quality were better from the 52 mesh greenhouse than from the others. However, a significant increase of ventilation rate due to the use of this net needs to be adequately solved.

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