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Impact of greenhouse height on growth, physiological changes, and yield of two cherry tomatoes (*Solanum lycopersicum*) cultivars

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Abstract

Background and Objective: Cherry tomato is a vegetable that has high commercial demand. The objective of this study was to compare the growth, physiological changes, and yield of tomatoes grown in different heights of the greenhouse and in 2 cultivars of cherry tomatoes.

Methodology: The experimental design was a split plot in a completely randomized design. The main plot was two types of greenhouses (3 m height and 4 m height greenhouses), and the sub-plot was two cultivars of cherry tomato ('Dang Komen' and 'Red Cherry 603').

Main Results: The heights of the greenhouse and cultivars did not affect stem height and amount of inflorescences/plant. Measurement of physiological changes found that the maximum quantum efficiency of photosystem II (F_v/F_m) of tomato plants grown in the 3 m height greenhouse (0.67 ± 0.03) was significantly lower than those grown in the 4 m height greenhouse (0.70 ± 0.02) at $P < 0.05$. In addition, the F_v/F_m of tomato 'Dang Komen' (0.67 ± 0.03) was significantly lower than tomato 'Red Cherry 603' (0.70 ± 0.02) at $P < 0.05$. After harvesting, tomato 'Red Cherry 603' had a significantly higher percentage of fruit set/plant (15.12 ± 2.26%) and the total yield/plant (322.59 ± 59.90 g) than tomato 'Dang Komen' (3.20 ± 0.58% and 80.72 ± 19.97 g, respectively) at $P < 0.05$. Furthermore, tomato 'Red Cherry 603' grown in a 3 m height greenhouse exhibited the highest ascorbic acid, lycopene, and β-carotene contents (341.25 ± 14.93, 11.44 ± 0.08, and 5.88 ± 0.10 mg/kg FW, respectively).

Conclusions: Cherry tomatoes grown in a 4 m height greenhouse showed a high level of quantum efficiency. Tomato 'Red Cherry 603' exhibited the highest yield. Growing tomatoes in a 3 m height greenhouse caused the highest content of ascorbic acid, lycopene, and β-carotene.

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most popular vegetables consumed worldwide (Gemici *et al*., 2006). Tomatoes are economically important and can be cultivated in all areas. In addition, tomatoes are important for human nutrition since they contain carbohydrates, organic acids, vitamin C, vitamin A, lycopene, carotenoids, and others (Gharezi *et al*., 2012). Among the different groups of tomatoes, cherry tomatoes are popular and high priced because they are tasty due to their high contents of sugar, organic acid, and volatile substances (Pérez-Marín *et al*., 2021). For this reason, cherry tomatoes often have a high level of soluble solids that have a sweet taste and an aromatic smell (Islam *et al*., 2019). In Thailand, there are several cultivars of cherry tomatoes that are popular to grow in commercials, such as 'Tony TA104' and 'Tabtimdaeng T2021' from Know-You Seed (Thailand) Co., Ltd., 'Sweet Girl' and 'Sweet Boy 1' from Chia Tai Co., Ltd., and 'CH154' from Tropical Vegetable Research Center (TVRC), Kasetsart University.

The cultivation of cherry tomatoes usually grows in greenhouses since it is easier to control and manage environmental factors than field cultivation, for example, the control of diseases and insects. In addition, greenhouse cultivation protects crops from external factors such as rain and wind (Hemming *et al*., 2019). Cherry tomatoes can grow in all types of greenhouses, but they require suitable management and enough light intensity (Atherton and Rudich, 1986). Generally, the height of the greenhouse from the basement to the beam should be 3.5–4.5 m for good ventilation (Kumar, 2011). The disadvantage of greenhouse cultivation was the increase in temperatures inside the greenhouse up to 40°C, which exceeded the optimal temperature for tomato plants (Sato *et al*., 2000). Most tomato cultivars were not tolerant of high temperatures. Therefore, heat stress was an important limitation for tomato cultivation. If those tomato varieties were sensitive to high temperature stress, they would reduce yields due to heat stress (Sato *et al*., 2000). In addition, high temperatures caused suboptimal growth (Villareal and Lai, 1979; Scott *et al*., 1986) and reduced the chances of pollination (Van Ploeg and Heuvelink, 2005). The impact of high temperatures on tomatoes not only reduced flowering and fruit set but also decreased yield and fruit quality (Alsamir *et al*., 2021).

The increase in temperature inside the greenhouse could be solved in several ways. For example, using a 50% shading net to modify the greenhouse at 2.5 m height (Sethi *et al*., 2009). Hirich and Choukr-Allah (2017) reported that the 5 m height greenhouse was recommended for growing plants in the desert climate to conserve water and energy. Planting tomato cultivars that could tolerate high temperatures was a choice. Therefore, this research study focused on the growth and yield of cherry tomatoes that were grown in greenhouses with heights of 3 m and 4 m. In addition, two cultivars of cherry tomato, 'Dang Komen' and 'Red Cherry 603', were compared. Cherry tomato 'Dand Komen' was developed by the National Center for Genetic Engineering and Biotechnology (BIOTEC), Thailand, and was previously registered as tomato 'PC3 (A9)' (Department of Agriculture, 2017). After that, seeds of tomato 'Dang Komen' were commercially produced by the Organic Seed Production Learning Center, Maejo University. The fruit of the tomato 'Dang Komen' has a cylindrical shape with a firm texture, and the total soluble solids are about 8–9%. This cultivar has indeterminate growth and tolerates the tomato yellow leaf curl virus (Nokkaew, 2023). Another cultivar, tomato 'Red Cherry 603' was a new F1 hybrid cherry tomato from the Tropical Vegetable Research Center (TVRC), Kasetsart University. Tomato 'Red Cherry 603' has an indeterminate growth. Its fruit has an oval shape with a dark red color. This cultivar is recommended by TVRC to grow in the greenhouse. Therefore, the objective of this research was to compare the growth, physiological changes, and yield of cherry tomatoes grown in different types of greenhouses and to serve as a guideline for selecting suitable cherry tomato cultivars for production in the greenhouse.

MATERIALS AND METHODS

Tomato Cultivation

Seeds of tomato 'Dang Komen' (Organic Seed Production Learning Center, Maejo University, Thailand) and 'Red Cherry 603' (TVRC, Thailand) were sown in trays using peat moss as the planting material. Seedlings were transplanted in 10-inch white plastic pots with mixed coconut coir: chopped coconut husk at 1:1 by volume at 21 days after sowing. Seedlings grow in 6 × 12 m greenhouses with 3 m or 4 m in height, depending on treatment. Both greenhouses were constructed with 32-mesh anti-insect nets. In addition, greenhouses have a double roof covered with polyethylene to allow air ventilation between the inside and outside of the greenhouse. The greenhouses were located in the experimental field I, Department of Horticulture, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand (13°51'13.5" N 100°34'09.2" E). Then, the Resh's Tropical Dry Summer (Resh, 2012) was applied to plants as the nutrient solution at an electrical conductivity (EC) of 0.6 mS/cm and then increased to an EC of 1.2 mS/cm at 14 and 21 days, respectively. Subsequently, the concentration of the nutrient solution was increased to the EC of 2.4 mS/cm and 3.0 mS/cm at the vegetative growth stage and fruit set stage, respectively. The nutrient solution was provided 3 times/day, and each time for 2 min. Finally, tomato plants received 1,270 mL of nutrient solution/day. Lateral branches were pruned every week, and only the first and second lateral branches were kept. Growing cherry tomatoes was done between December 2022 to April 2023. The temperature inside the greenhouse at 2 m above the basement was recorded every 30 min throughout the experiment. In addition, the relative humidity and light intensity were recorded. The 3 m and 4 m height greenhouses showed the same relative humidity and light intensity at 49.62–63.42% and 714.30–1,403.20 μmol/m^2/s, respectively, throughout the tomato cultivation.

Experimental Design

The experimental design was a split plot in a completely randomized design (CRD). The main plot was two types of greenhouses (3 m height and 4 m height greenhouses), whereas the sub-plot was two cultivars of cherry tomatoes (tomato 'Dang Komen' and 'Red Cherry 603'). The experiment was done with 5 replications/treatments and a plant/replication.

Data Collection

Growth of cherry tomato plants, consisting of the stem height (cm) and stem diameter (cm), was recorded weekly from 4 weeks after transplanting (WAT) to 8 WAT. The height of the main stem was measured from the area where the cotyledons were located to the shoot tip using a measuring tape. The stem diameter was measured at the area where the cotyledons were located using a vernier caliper. The number of flowers/inflorescences was randomly selected to count flowers from 3 inflorescences/plant at 4 and 6 WAT. The number of inflorescences/plant was observed by counting only the newly emerged inflorescences at 4 to 8 WAT, and then the total number of inflorescences/plant was calculated from the sum of the new inflorescences in each week.

Physiological changes consisting of the maximum quantum efficiency of photosystem II (F_v/F_m), the net photosynthetic rate, and the leaf greenness index were measured at the fruit setting stage (13 WAT). The tomato leaf at the 5th position from the highest leaf of the main stem at that time was used for all physiological measurements to represent the whole plant. The F_v/F_m was measured using a pulse amplitude modulation fluorometer (MINI-PAM-II, Walz, Germany) during 08:00–12:00 AM. The minimal and maximal fluorescence yields of the dark-adapted state (F_m) in the leaves were assessed after 30 min of dark adaptation. After that, leaves were illuminated with actinic light (800 μmol/m^2/s) for 15 s. Then, F_v/F_m was calculated according to Maxwell and Johnson (2000). The net photosynthetic rate was measured using a portable photosynthesis system (LI-6800 Gas Exchange System, LI-COR Inc., USA) during 08:00–11:00 AM by setting the air flow rate at 600 μmol/s, the light intensity at 800 μmol/m^2/s, the CO_2 concentration at 400 μmol/mol, and the leaf chamber temperature at 40°C. Lastly, the leaf greenness index was measured using a chlorophyll meter (SPAD-502, Minolta, Japan). The leaf greenness index was recorded three times in three leaflets, and these values were averaged.

Cherry tomatoes began to produce fruit at approximately 13 WAT. After tomato fruits were ripened, red fruits were harvested every 7 days until the end of production. The fruit quantity of cherry tomatoes was evaluated from the percentage of fruit set, fruit weight/fruit, and the total yield/plant. Tomato fruits were randomly selected 5 fruits/plant 3 times. Then, each fruit was weighed and averaged to the fruit weight/fruit. The total yield/plant was measured at each time of harvesting and then summed up to obtain the total marketable yield. The percentage of fruit set was calculated from the percentage ratio of the total number of flowers at the flowering period to the total number of fruits after harvesting.

In addition, 5 tomato fruits/plant were randomly selected 3 times to analyze fruit quality consisting of fruit firmness, total soluble solids (TSS), titratable acidity (TA), ascorbic acid, lycopene, β-carotene contents, and the color of fruit (L*, a*, and b* values). The fruit firmness was measured using a penetrometer with a press head with a diameter of 0.5 cm. The TSS was analyzed using a hand refractometer (PR-101 alpha, Atago, Thailand). The TA was analyzed based on 1 mL of tomato juice homogenized in 50 mL of distilled water. Then, the TA was obtained by titrating with 0.1 N NaOH. TA was calculated referring to the percentage of citric acid (AOAC, 2000). The ascorbic acid content was analyzed using an RQ-flex reflectometer (Merck, Germany) according to the method of Takebe and Yoneyama (1995). The lycopene and β-carotene contents in the tomato flesh were extracted using a mixed solution of hexane, acetone, and ethanol in a 2:1:1 ratio. Then, the lycopene and β-carotene contents were analyzed according to Anthon and Barrett (2007). Lastly, the color of the fruit peel was measured using a colorimeter. The results displayed in the CIELAB system (Pandurangaiah *et al*., 2020), which was the L* value, represented the lightness of the color, ranging from 0 (black) to 100 (white). The a* value represented the color's position between the red and green colors, redness (+) and greenness (-), whereas the b* value represented the color's position between the yellow and blue, yellowness (+) and blueness (-).

Statistical Analysis

Statistical data were analyzed using analysis of variance (ANOVA) of split-plot design in CRD. Mean differences of the main plot and sub-plot were compared using Student's t-test. Significant differences among means of the interaction between the main plot and sub-plot were separated using Duncan's Multiple Range Test at the 95% confidence level (P < 0.05).

RESULTS AND DISCUSSION

Temperature Inside the Greenhouse

The temperature inside greenhouses was recorded from January 2023, when tomato plants began flowering, to April 2023, which was the end of production. Daily temperature showed that from 1:00 to 3:00 PM, the temperature inside the greenhouse was highest (Figure 1). The highest temperatures inside 3 m and 4 m height greenhouses in January 2023 were 34.60 and 32.71°C, respectively (Figure 1A). In February 2023, the highest temperatures inside 3 m and 4 m height greenhouses were 39.37 and 38.93°C, respectively (Figure 1B). In March 2023, the highest temperatures inside 3 m and 4 m height greenhouses were 42.30 and 40.43°C, respectively (Figure 1C). In April 2023, the highest temperatures inside 3 m and 4 m height greenhouses were 44.34 and 41.53°C, respectively (Figure 1D). From the data, it was found that the highest temperature inside the 3 m height greenhouse each month was higher than the 4 m height greenhouse by 1–3°C (Figure 1). Compared to the 3 m height greenhouse, which was the recommended height for vegetable production (Sethi *et al*., 2009; Kumar, 2011), the increase in greenhouse height to 4 m reduced the inside temperature. This is because hot air has a lower density than cooler air, so hot air is easily raised to the upper level (NOAA, 2023). Hot air during the day in the 4 m height greenhouse might rise to a higher level than in the 3 m greenhouse, and then hot air is ventilated to the outside of the greenhouse.

Growth of Tomato

The result showed that stem height and stem diameter in every treatment increased every week during measurements (Figure 2). At 4 WAT, the average stem height ranged from 87.68 ± 14.84 cm to 101.14 ± 10.51 cm, while at 8 WAT, the average stem height ranged from 188.62 ± 6.92 cm to 224.03 ± 5.31 cm. Considering different heights of greenhouses and different tomato cultivars, it was found that at 4 WAT, the average stem diameter ranged from 0.85 ± 0.17 cm to 0.93 ± 0.03 cm, and at 8 WAT, the average stem diameter ranged from 1.23 ± 0.05 cm to 1.30 ± 0.07 cm. Despite this observation finding the increase of stem height and stem diameter over time, the height of greenhouse and tomato cultivars did not significantly change the stem height and stem diameter of tomato plants at P < 0.05. However, tomato plants grown in the 4 m height greenhouse tended to show longer stem height than those grown in the 3 m height (Figure 2A). In contrast, tomato plants grown in the 3 m and 4 m height greenhouse exhibited quite a similar stem diameter (Figure 2B). The 4 m height greenhouse showed a lower inside temperature than the 3 m height greenhouse. The optimal temperature contributed to better growth of tomatoes (Lee and Kader, 2000).

In addition, the number of flowers/inflorescence and the total number of inflorescence/plant were counted. The result showed that the number of flowers/inflorescence ranged from 14.20 ± 4.02 to 19.40 ± 2.60 and 19.60 ± 4.72 to 23.40 ± 9.29 flowers at 4 and 6 WAT, respectively (Figure 3A). In contrast, the total number of inflorescences/plant ranged from 17.2 ± 0.91 to 20.8 ± 1.37 inflorescences (Figure 3B).

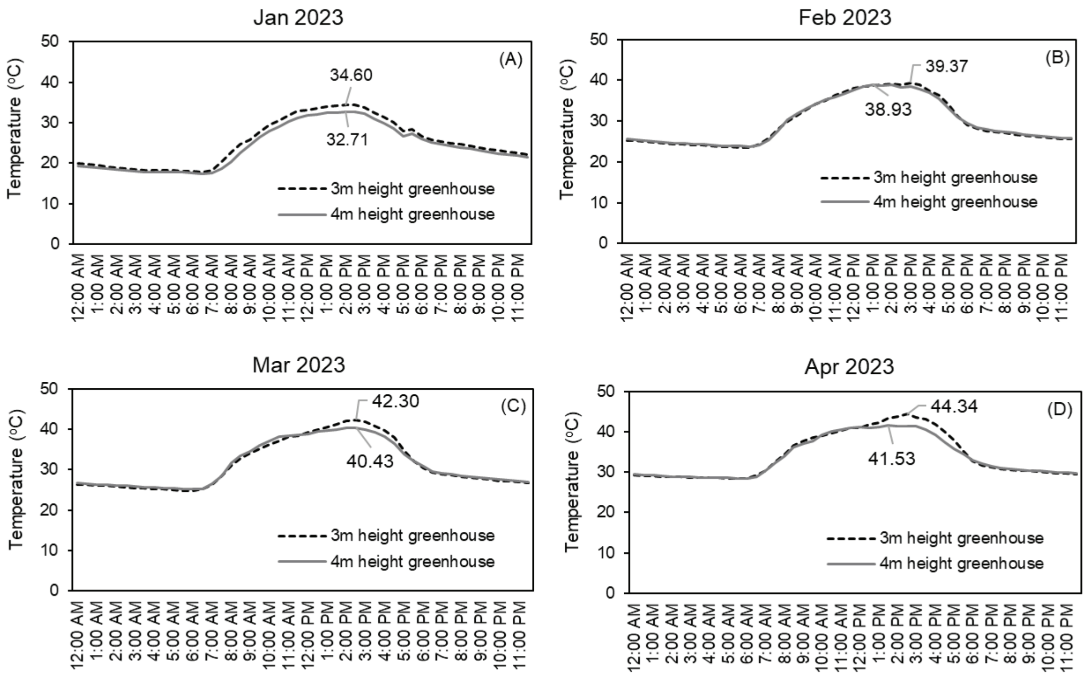

Figure 1 Diurnal temperature on January (A), February (B), March (C), and April (D) 2023 during cherry tomato cultivations in 3 m and 4 m height greenhouses

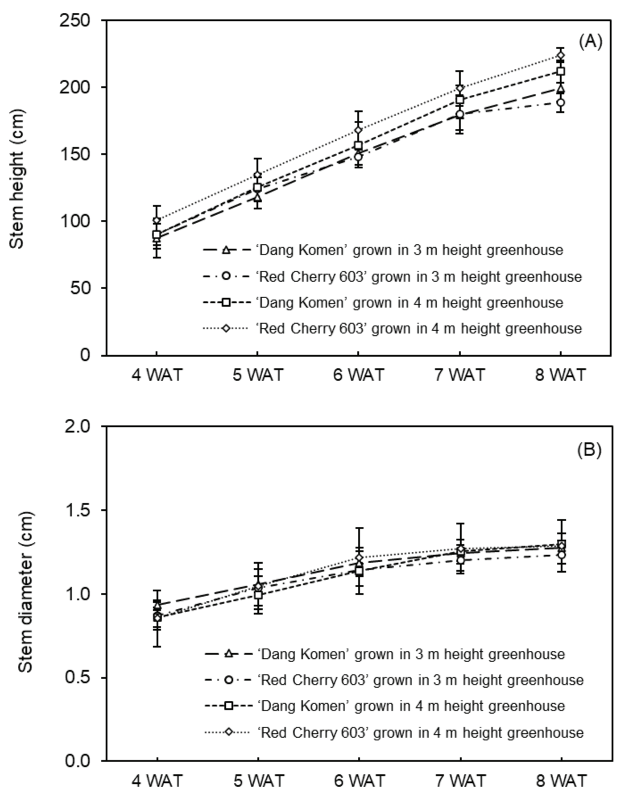

Figure 2 Changes of stem height (A) and stem diameter (B) of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses. Data were analyzed according to Duncan's Multiple Range Test at $P < 0.05$. Data are means ± standard deviation shown by vertical error bars. WAT = weeks after transplanting.

Considering the different heights of greenhouses and different cherry tomato cultivars, it was found that the height of the greenhouse and tomato cultivars did not significantly change flowers/inflorescence and inflorescences/plant of the tomato plant ($P > 0.05$). The number of flowers/inflorescence and the total number of inflorescences/plant can be used as indicators of the fruit set of tomatoes (Panthee and Gardner, 2011). It implied that tomato plants in all treatments might exhibit the same percentage of fruit set.

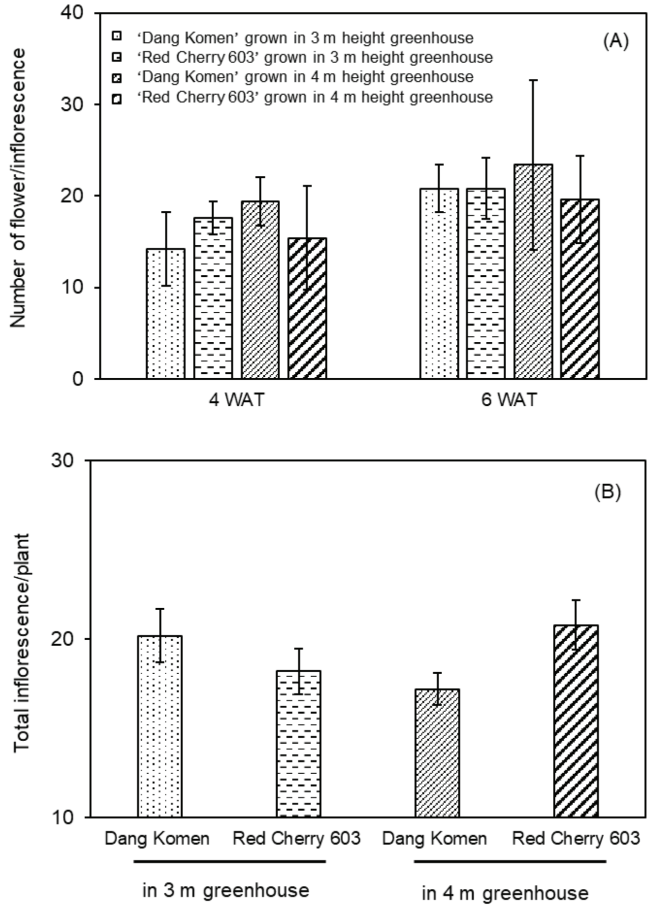

Figure 3 Changes of number of flowers/inflorescence (A) and total number of inflorescences/plant (B) of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses. Data were analyzed according to Duncan's Multiple Range Test at $P < 0.05$. Data are means ± standard deviation shown by vertical error bars. WAT = weeks after transplanting.

Physiological Changes of Cherry Tomato

The physiological changes, consisting of the maximum quantum efficiency of photosystem II, the net photosynthetic rate, and the leaf greenness index, were measured at the fruit setting stage. The results showed that tomatoes grown in the 3 m height greenhouse had the F_v/F_m at 0.67 ± 0.03, which was significantly lower ($P < 0.05$) than those grown in the 4 m height greenhouse, shown at 0.70 ± 0.02 (Table 1). When comparing the tomato 'Dang Komen' and 'Red Cherry 603' found that F_v/F_m of tomato 'Dang Komen' (0.67 ± 0.03) was significantly lower than 'Red Cherry 603' (0.70 ± 0.02) at $P < 0.05$ (Table 1). Typically, non-stress plants have an F_v/F_m value of about 0.83. When F_v/F_m value was lower than 0.79 indicated that plants were subjected to some environmental stress, leading to an exhibit of chlorophyll fluorescence (Björkman and Demmig, 1987). The low F_v/F_m indicated that excess energy did not contribute to photosynthesis in plants. Therefore, tomato 'Dang

Komen' plants grown in the 3 m height greenhouse showed the highest F_v/F_m value, implying that they had the highest chlorophyll fluorescence. However, considering the height of the greenhouse, it was found that the net photosynthetic rate and the leaf greenness index of tomato plants were not significantly different at P < 0.05 (Table 1). Comparing cherry tomato cultivars showed that tomato 'Dang Komen' had a higher photosynthetic rate (8.17 ± 1.07 μmol $CO_2/m^2/s$) than tomato 'Red Cherry 603' (6.87 ± 1.68 μmol $CO_2/m^2/s$) (Table 1). Nevertheless, there was no interaction between the height of the greenhouse and the cultivar of cherry tomatoes, indicating that cherry tomatoes in all treatments had a similar ability to fix carbon dioxide for yield production. In addition, tomato 'Dang Komen' showed a significantly lower leaf greenness index (47.44 ± 4.03 SPAD unit) than tomato 'Red Cherry 603' (51.87 ± 5.68 SPAD unit) at P < 0.05 (Table 1). After considering the interaction between the main plot and the sub-plot, it was found that tomato 'Red Cherry 603' grown in the 3 m height greenhouse showed a significantly higher leaf greenness index than others at P < 0.05 (Table 1). The leaf greenness index depends on plant species, plant cultivars, environment, and growing conditions (Ravier *et al*., 2017). It could represent growth issues or nutritional deficiencies in several plants (Tenga *et al*., 1989).

Table 1 The maximum quantum efficiency of photosystem II (F_v/F_m), the net photosynthetic rate, and leaf greenness index of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses during fruit set

Treatment	Maximum quantum efficiency of photosystem II	Net photosynthetic rate (μmol CO_2 /m²/s)	Leaf greenness index (SPAD unit)
Greenhouse			
3 m height greenhouse	0.67 ± 0.03^b	7.33 ± 1.25	51.01 ± 6.28
4 m height greenhouse	0.70 ± 0.02^a	7.70 ± 1.68	48.30 ± 3.98
P-value	0.007	0.545	0.131
Cultivar			
'Dang Komen'	0.67 ± 0.03^b	8.17 ± 1.07^a	47.44 ± 4.03^b
'Red Cherry 603'	0.70 ± 0.02^a	6.87 ± 1.68^b	51.87 ± 5.68^a
P-value	0.003	0.049	0.021
Greenhouse × Cultivar			
'Dang Komen' grown in 3 m height greenhouse	0.65 ± 0.03	7.73 ± 0.97	46.50 ± 4.34^b
'Red Cherry 603' grown in 3 m height greenhouse	0.69 ± 0.01	6.94 ± 1.49	55.52 ± 4.36^a
'Dang Komen' grown in 4 m height greenhouse	0.69 ± 0.01	8.62 ± 1.08	48.38 ± 3.93^b
'Red Cherry 603' grown in 4 m height greenhouse	0.71 ± 0.03	6.79 ± 1.76	48.22 ± 4.50^b
P-value	0.167	0.402	0.018

Note: Means within the same column followed by different superscript letters (a, b) are significantly different (P < 0.05). Values are presented as mean ± standard deviation.

Quantity and Quality of Cherry Tomatoes Production

After harvesting, ripe tomatoes in all treatments were collected to analyze tomato yield in both quantitative and qualitative aspects. The result showed that different heights of the greenhouse did not affect the percentage of fruit set, fruit fresh weight, and total marketable yield (Table 2). Considering the difference of cherry tomato cultivars, it was found that tomato 'Dang Komen' showed a significantly lower percentage of fruit set and total yield/plant than tomato 'Red Cherry 603' at $P < 0.05$ (Table 2). In addition, comparing both tomato cultivars grown in different height of greenhouses found that tomato 'Dang Komen' grown in both 3 m and 4 m height greenhouse tended to show lower percentage of fruit set (2.70 ± 0.33% and 3.71 ± 0.18%, respectively) than tomato 'Red Cherry 603' in both 3 m and 4 m height greenhouse (14.58 ± 1.69% and 15.65 ± 2.81%, respectively) (Table 2). In the same way, tomato 'Dang Komen' grown in both 3 m and 4 m height greenhouses had a lower marketable yield (72.11 ± 12.44 and 89.32 ± 13.50 g/plant, respectively) than tomato 'Red Cherry 603' (327.79 ± 71.22 and 317.39 ± 54.16 g/plant, respectively) (Table 2). Generally, the yield of tomatoes depended on cultivars and environmental conditions (Nederhoff, 1994). However, this study confirms that yield differences between tomato 'Dang Komen' and 'Red Cherry 603' were linked to inherent genetic traits more than environmental factors like greenhouse temperature.

In addition, this research was conducted at the beginning of the summer season in Thailand and showed the rise of ambient temperature over the time of cultivation. These environmental conditions might have contributed to the very low fruit yield observed in the cherry tomatoes, as tomato plants are sensitive to heat stress during flowering and fruit setting stages. High temperatures decreased the pollen viability (Razzaq *et al*., 2019). Therefore, selecting tomato cultivars that are resistant to heat stress could be a suitable option for conducting experiments during the summer season. Heat-tolerant cultivars might help mitigate the adverse effects of high temperatures and improve fruit yield under challenging environmental conditions (Ayenan *et al*., 2019). This study found that the cultivar of cherry tomatoes had more significant effects on tomato yield than the height of greenhouses. However, considering the effect of greenhouses together with cherry tomato cultivar, it found that tomatoes 'Dang Komen' grown in the 4 m height greenhouse had a higher yield than those tomatoes grown in the 3 m greenhouse, whereas tomatoes 'Red Cherry 603' grown in both types of greenhouses showed the same yield (Table 2). This might be because the temperature inside the 3 m height greenhouse was higher than the 4 m height greenhouse (Figure 1). Therefore, tomato 'Dang Komen' might be less tolerant to high temperatures than tomato 'Red Cherry 603', which is consistent with the lower F_v/F_m in tomato 'Dang Komen', indicating the high level of chlorophyll fluorescence shown by the high F_v/F_m (Table 1). In the same way, the percentage of fruit set of tomato 'Dang Komen' grown in both types of greenhouses was poor, whereas tomato 'Red Cherry 603' had the percentage of fruit set approximately 4.7 times higher than tomato 'Dang Komen' (Table 2). It might be one indicator that implied that tomato 'Dang Komen' plants were sensitive to high temperatures, such as in this experiment, cultivating tomatoes in the summer season. The percentage of fruit set correlated with the total yield of tomatoes (Table 2). Berry and Uddin (1988) reported that the fruit set of tomatoes grown in high temperatures was very low since their pollen and stigma were damaged from heat stress. Although greenhouse height did not influence tomato yield in this time study, the exploration of temperature inside the greenhouse might provide additional insights into optimizing growing conditions in the future.

Table 2 The quantitative yield of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses during fruit set

Treatment	Fruit weight/fruit (g)	Total yield/plant (g)	Fruit set/plant (%)
Greenhouse			
3 m height greenhouse	6.02 ± 0.97	199.95 ± 143.11	8.64 ± 6.36
4 m height greenhouse	6.38 ± 0.91	203.35 ± 125.83	9.67 ± 6.56
P-value	0.439	0.770	0.183
Cultivar			
'Dang Komen'	6.47 ± 0.99	80.72 ± 19.97[b]	3.20 ± 0.58[b]
'Red Cherry 603'	5.93 ± 0.84	322.59 ± 59.90[a]	15.12 ± 2.26[a]
P-value	0.244	< 0.001	< 0.001
Greenhouse × Cultivar			
'Dang Komen' grown in 3 m height greenhouse	6.36 ± 1.20	72.11 ± 12.44	2.70 ± 0.33
'Red Cherry 603' grown in 3 m height greenhouse	5.68 ± 0.62	327.79 ± 71.22	14.58 ± 1.69
'Dang Komen' grown in 4 m height greenhouse	6.58 ± 0.84	89.32 ± 13.50	3.71 ± 0.18
'Red Cherry 603' grown in 4 m height greenhouse	6.17 ± 1.03	317.39 ± 54.16	15.65 ± 2.81
P-value	0.769	0.420	0.970

Note: Means within the same column followed by different superscript letters (a, b) are significantly different (P < 0.05). Values are presented as mean ± standard deviation.

In addition, the fruit firmness, TSS, and TA were measured after harvest. Considering the different heights of greenhouses, it was found that the height of the greenhouse did not affect fruit firmness and TSS of tomatoes. However, tomato plants grown in the 3 m height greenhouse showed significantly lower TA (0.49 ± 0.07%) and higher TSS/TA (17.01 ± 2.17) than those grown in the 4 m height greenhouse (0.58 ± 0.12% and 14.83 ± 2.90, respectively) at P < 0.05 (Table 3). It might be because the 3 m height greenhouse had higher temperatures than the 4 m height greenhouse. The high temperature increased the percentage of ripe fruit in tomatoes and TSS in fruits (Mesa *et al*., 2022). There was a reason why tomato fruit grown in the 3 m height greenhouse had a lower TA than in the 4 m height greenhouse. However, temperatures above 36°C increase the TSS of tomatoes (Vijayakumar *et al*., 2021). In this experiment, tomatoes grown in the 3 m height greenhouse had significantly higher TSS/TA due to tomatoes grown in the 3 m height greenhouse reduced TA, which the results were consistent with the report of Mesa *et al*. (2022). Considering the different tomato cultivars found that tomato 'Red Cherry 603' showed significantly higher TSS and TA (8.58 ± 0.35% and 0.63 ± 0.07%) than tomato 'Dang Komen' (7.77 ± 0.47% and 0.45 ± 0.04%) at P < 0.05 (Table 3). On the other hand, tomato 'Red Cherry 603' exhibited significantly lower TSS/TA (13.91 ± 1.64) than tomato 'Dang Komen' (17.93 ± 2.02) at P < 0.05 (Table 3). The high TSS/TA values in tomatoes indicated that the tomatoes contained high sugar content. This ratio is considered an important indicator of tomato flavor quality (Xu *et al*., 2018). Therefore, the high TSS/TA ratio in the tomato 'Dang Komen' might refer to the tastier flavor than the tomato 'Red Cherry 603'.

Table 3 Fruit quality parameters of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses

Treatment	Firmness (N/cm²)	TSS (%)	TA (%)	TSS/TA
Greenhouse				
3 m height greenhouse	0.76 ± 0.08	8.14 ± 0.56	0.49 ± 0.07[b]	17.01 ± 2.17[a]
4 m height greenhouse	0.78 ± 0.57	8.22 ± 0.62	0.58 ± 0.12[a]	14.83 ± 2.90[b]
P-value	0.632	0.715	<0.001	0.005
Cultivar				
'Dang Komen'	0.77 ± 0.08	7.77 ± 0.47[b]	0.45 ± 0.04[b]	17.93 ± 2.02[a]
'Red Cherry 603'	0.77 ± 0.06	8.58 ± 0.35[a]	0.63 ± 0.07[a]	13.91 ± 1.64[b]
P-value	0.904	< 0.001	< 0.001	< 0.001
Greenhouse × Cultivar				
'Dang Komen' grown in 3 m height greenhouse	0.77 ± 0.08	7.75 ± 0.54	0.43 ± 0.03[c]	18.66 ± 1.87
'Red Cherry 603' grown in 3 m height greenhouse	0.76 ± 0.08	8.53 ± 0.18	0.56 ± 0.01[b]	15.37 ± 0.62
'Dang Komen' grown in 4 m height greenhouse	0.78 ± 0.08	7.80 ± 0.44	0.46 ± 0.47[c]	17.22 ± 2.12
'Red Cherry 603' grown in 4 m height greenhouse	0.78 ± 0.01	8.63 ± 0.49	0.69 ± 0.02[a]	12.46 ± 0.62
P-value	0.952	0.908	0.003	0.283

Note: Means within the same column followed by different superscript letters (a, b, c) are significantly different (P < 0.05). Values are presented as mean ± standard deviation.

The analysis of phytochemicals in tomatoes consisting of ascorbic acid, lycopene and β-carotene found that cherry tomatoes grown in the 3 m height greenhouse showed significantly higher ascorbic acid, lycopene, and β-carotene contents (333.75 ± 14.33, 11.03 ± 0.90, and 5.56 ± 0.54 mg/kg FW, respectively) than in the 4 m height greenhouse (249.38 ± 32.99, 10.13 ± 1.32, and 5.14 ± 0.58 mg/kg FW, respectively) at P < 0.05 (Table 4). It might be because the 3 m height greenhouse had higher temperatures than the 4 m height greenhouse. The high ascorbic acid, which is one of the antioxidants in tomatoes grown in the 3 m height greenhouse, might cause plants to produce ascorbic acid to defend against heat stress (Khan *et al*., 2011). Comparing cherry tomato cultivars found that tomato 'Dang Komen' had significantly lower ascorbic acid content (278.13 ± 52.77 mg/kg FW) but higher lycopene content (10.93 ± 1.01 mg/kg FW) than tomato 'Red Cherry 603' (305.00 ± 46.52 and 10.22 ± 1.30 mg/kg FW, respectively) at P < 0.05 (Table 4). In addition, the tomato 'Red Cherry 603' grown in the 4 m height greenhouse exhibited significantly lower lycopene and β-carotene contents than other treatments at P < 0.05 (Table 4). Lycopene and β-carotene are the main carotenoids in tomatoes, and their contents depend on tomato cultivar (Flores *et al*., 2017). The patterns of change in lycopene and β-carotene contents in each treatment were similar due to lycopene and β-carotene share the same biosynthetic pathway (Gonzali *et al*., 2009).

Lastly, the color of cherry tomatoes was evaluated. The result showed that cherry tomatoes grown in the 3 m height greenhouse had significantly higher a* and b* values (25.20 ± 2.61 and 23.86 ± 2.09) than those grown in the 4 m height greenhouse (22.58 ± 1.86 and 22.18 ± 1.83) at P < 0.05 (Table 5).

The positive values of a* and b* represented red and yellow, respectively (Pandurangaiah *et al*., 2020). Cherry tomatoes grown in the 3 m height greenhouse had high a* and b* were consistent with the high content of lycopene and β-carotene. Considering cherry tomato cultivar found that tomato 'Dang Komen' exhibited a higher L* (32.31 ± 1.69) but lower a* (22.79 ± 2.14) than tomato 'Red Cherry 603' (30.06 ± 0.81 and 24.98 ± 2.62, respectively) at P < 0.05 (Table 5). It might be because the peel colors of tomato alter from tomato cultivar (Flores *et al*., 2017).

Table 4 Ascorbic acid, lycopene, and β-carotene contents of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses

Treatment	Ascorbic acid (mg/kg FW)	Lycopene (mg/kg FW)	β-carotene (mg/kg FW)
Greenhouse			
3 m height greenhouse	333.75 ± 14.33^{a}	11.03 ± 0.90^{a}	5.56 ± 0.54^{a}
4 m height greenhouse	249.38 ± 32.99^{b}	10.13 ± 1.32^{b}	5.14 ± 0.58^{b}
P-value	< 0.001	0.016	0.030
Cultivar			
'Dang Komen'	278.13 ± 52.77^{b}	10.93 ± 1.01^{a}	5.42 ± 0.54
'Red Cherry 603'	305.00 ± 46.52^{a}	10.22 ± 1.30^{b}	5.27 ± 0.65
P-value	0.029	0.049	0.409
Greenhouse × Cultivar			
'Dang Komen' grown in 3 m height greenhouse	326.25 ± 10.31	10.62 ± 1.18^{a}	5.25 ± 0.64^{b}
'Red Cherry 603' grown in 3 m height greenhouse	341.25 ± 14.93	11.44 ± 0.08^{a}	5.88 ± 0.10^{a}
'Dang Komen' grown in 4 m height greenhouse	230.00 ± 14.72	11.24 ± 0.81^{a}	5.60 ± 0.41^{ab}
'Red Cherry 603' grown in 4 m height greenhouse	268.75 ± 36.37	9.02 ± 0.40^{b}	4.67 ± 0.23^{c}
P-value	0.293	< 0.001	< 0.001

Note: Means within the same column followed by different superscript letters (a, b, c) are significantly different (P < 0.05). Values are presented as mean ± standard deviation.

Table 5 L*, a*, and b* values of tomato 'Dang Komen' and 'Red Cherry 603' grown in 3 m and 4 m height greenhouses

Treatment	L*	a*	b*
Greenhouse			
3 m height greenhouse	31.48 ± 1.94	25.20 ± 2.61[a]	23.86 ± 2.09[a]
4 m height greenhouse	30.89 ± 1.54	22.58 ± 1.86[b]	22.18 ± 1.83[b]
P-value	0.307	0.004	0.047
Cultivar			
'Dang Komen'	32.31 ± 1.69[a]	22.79 ± 2.14[b]	23.53 ± 1.87
'Red Cherry 603'	30.06 ± 0.81[b]	24.98 ± 2.62[a]	22.51 ± 2.29
P-value	0.002	0.012	0.207
Greenhouse × Cultivar			
'Dang Komen' grown in 3 m height greenhouse	32.66 ± 2.01	23.65 ± 2.28	23.70 ± 2.06
'Red Cherry 603' grown in 3 m height greenhouse	30.30 ± 0.98	26.75 ± 2.03	24.02 ± 2.36
'Dang Komen' grown in 4 m height greenhouse	31.96 ± 1.44	21.94 ± 1.80	23.34 ± 1.87
'Red Cherry 603' grown in 4 m height greenhouse	29.82 ± 0.60	23.22 ± 1.87	21.00 ± 0.76
P-value	0.307	0.244	0.105

Note: Means within the same column followed by different superscript letters (a, b) are significantly different ($P < 0.05$). Values are presented as mean ± standard deviation.

CONCLUSIONS

The 4 m height greenhouse has an inside temperature lower than the 3 m height greenhouse by about 1–3°C. The different heights of the greenhouse did not affect the growth of cherry tomatoes, but growing in the 4 m height greenhouse showed a high quantum yield efficiency in cherry tomatoes. Comparing the height of the greenhouse and tomato cultivars, it was found that only tomato cultivars affected tomato marketable yield, as shown by the higher total yield/plant and the higher percentage of fruit set in tomato 'Red Cherry 603' than in tomato 'Dang Komen'.

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CONFLICTS 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.

REFERENCES

Alsamir, M., T. Mahmood, R. Trethowan and N. Ahmad. 2021. An overview of heat stress in tomato (*Solanum lycopersicum* L.). Saudi J. Biol. Sci. 28(3): 1654–1663. https://doi.org/10.1016/j.sjbs.2020.11.088.

Anthon, G. and D.M. Barrett. 2007. Standardization of a rapid spectrophotometric method for lycopene analysis. Acta Hortic. 758: 111–128. https://doi.org/10.17660/ActaHortic.2007.758.12.

AOAC (International Official Methods of Analysis). 2000. Acidity (Titratable) of Fruit Products. Official Method 942.15. Official Methods of Analysis of AOAC International. 17th Edition. AOAC International, Maryland, USA.

Atherton, J.G. and J. Rudich. 1986. The Tomato Crop: A Scientific Basis for Improvement. Chapman and Hall, London, UK.

Ayenan, M.A.T., A. Danquah, P. Hanson, C. Ampomah-Dwamena, F.A.K. Sodedji, I.K. Asante and E.Y. Danquah. 2019. Accelerating breeding for heat tolerance in tomato (*Solanum lycopersicum* L.): An integrated approach. Agronomy 9(11): 720. https://doi.org/10.3390/agronomy9110720.

Berry, S.Z. and M.R. Uddin. 1988. Effect of high temperature on fruit set in tomato cultivars and selected germplasm. HortScience 23(3): 606–608. https://doi.org/10.21273/HORTSCI.23.3.606.

Björkman, O. and B. Demmig. 1987. Photon yield of O_2 evolution and chlorophyll fluorescence characteristics at 77 K among vascular plants of diverse origins. Planta 170: 489–504. https://doi.org/10.1007/bf00402983.

Department of Agriculture. 2017. Announcement Requesting Registration of Cultivars. Department of Agriculture, Bangkok, Thailand.

Flores, P., E. Sánchez, J. Fenoll and P. Hellín. 2017. Genotypic variability of carotenoids in traditional tomato cultivars. Food Res. Int. 100: 510–516. https://doi.org/10.1016/j.foodres.2016.07.014.

Gemici, M., B. Türkyilmaz and K. Tan. 2006. Effect of 2,4-D and 4-CPA on yield and quality of the tomato, *Lycopersicon esculentum* Miller. JFS. 29: 24–32.

Gharezi, M., N. Joshi and E. Sadeghian. 2012. Effect of post harvest treatment on stored cherry tomatoes. J. Nutr. Food Sci. 2(8): 157. http://dx.doi.org/10.4172/2155-9600.1000157.

Gonzali, S., A. Mazzucato and P. Perata. 2009. Purple as a tomato: Towards high anthocyanin tomatoes. Trends Plant Sci. 14(5): 237–241. https://doi.org/10.1016/j.tplants.2009.02.001.

Hemming, S., F. de Zwart, A. Elings, I. Righini and A. Petropoulou. 2019. Remote control of greenhouse vegetable production with artificial intelligence—greenhouse climate, irrigation, and crop production. Sensors 19(8): 1807. https://doi.org/10.3390/s19081807.

Hirich, A. and R. Choukr-Allah. 2017. Water and energy use efficiency of greenhouse and net house under desert conditions of UAE: Agronomic and economic analysis, pp. 481–499. *In:* O. Abdalla, A. Kacimov, M. Chen, A. Al-Maktoumi, T. Al-Hosni and I. Clark, (Eds.), Water Resources in Arid Areas: The Way Forward. Springer, Cham, Switzerland.

Islam, M.Z., Y.T. Lee, M.A. Mele, I.L. Choi and H.M. Kang. 2019. Effect of fruit size on fruit quality, shelf life and microbial activity in cherry tomatoes. AIMS Agric. Food. 4(2): 340–348. https://doi.org/10.3934/agrfood.2019.2.340.

Khan, T.A., M. Mazid and F. Mohammad. 2011. Ascorbic acid: An enigmatic molecule to developmental and environmental stress in plant. Int. J. Appl. Biol. Pharm. Technol. 2(3): 468–483.

Kumar, B. 2011. Technical Standards for Naturally Ventilated, Fan & Pad Green House and Shade Net House. Ministry of Agriculture, Gurgaon, India.

Lee, S.K. and A.A. Kader. 2000. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol. Technol. 20(3): 207–220. https://doi.org/10.1016/S0925-5214(00)00133-2.

Maxwell, K. and G.N. Johnson. 2000. Chlorophyll fluorescence-a practical guide. J. Exp. Bot. 51(345): 659–668. https://doi.org/10.1093/jexbot/51.345.659.

Mesa, T., J. Polo, A. Arabia, V. Caselles and S. Munné-Bosch. 2022. Differential physiological response to heat and cold stress of tomato plants and its implication on fruit quality. J. Plant Physiol. 268: 153581. https://doi.org/10.1016/j.jplph.2021.153581.

NOAA (National Oceanic and Atmospheric Administration). 2023. Parcel theory. National Oceanic and Atmospheric Administration. Available Source: https://www.noaa.gov. July 29, 2024.

Nokkaew, C. 2023. New tomato variety: Virus resistance, farmer safety, and cost reduction. Available Source: https://www.bangkokbiznews.com/tech/868855. November 20, 2024.

Nederhoff, E.M. 1994. Effects of CO_2 Concentration on Photosynthesis, Transpiration and Production of Greenhouse Fruit Vegetable Crops. PhD Thesis, Wageningen University, Netherlands.

Pandurangaiah, S., A.T. Sadashiva, K.S. Shivashankar, R.D.V. Sudhakar and K.V. Ravishankar. 2020. Carotenoid content in cherry tomatoes correlated to the color space values L*, a*, b*: A non-destructive method of estimation. J. Hortic. Sci. 15(1): 27–34. https://doi.org/10.24154/jhs.v15i1.779.

Panthee, D.R. and R.G. Gardner. 2011. 'Mountain Majesty': A tomato spotted wilt virus-resistant fresh market hybrid tomato and its parents NC 714 and NC 1CS. HortScience 46(9): 1321–1323. https://doi.org/10.21273/HORTSCI.46.9.1321.

Pérez-Marín, J., H. Issa-Issa, J. Clemente-Villalba, J.M. García-Garví, F. Hernández, Á.A. Carbonell-Barrachina, Á. Calín-Sánchez and L. Noguera-Artiaga. 2021. Physicochemical, volatile, and sensory characterization of promising cherry tomato (*Solanum lycopersicum* L.) cultivars: Fresh market aptitudes of pear and round fruits. Agronomy 11(4): 618. https://doi.org/10.3390/agronomy11040618.

Ravier, C., M. Quemada and M.H. Jeuffroy. 2017. Use of a chlorophyll meter to assess nitrogen nutrition index during the growth cycle in winter wheat. Field Crops Res. 214: 73–82. https://doi.org/10.1016/j.fcr.2017.08.023.

Razzaq, M.K., S. Rauf, M. Khurshid, S. Iqbal, J.A. Bhat, A. Farzand, A. Riaz, G. Xing and J. Gai. 2019. Pollen viability an index of abiotic stresses tolerance and methods for the improved pollen viability. Pak. J. Agric. Res. 32(4): 609–624. https://dx.doi.org/10.17582/journal.pjar/2019/32.4.609.624.

Resh, H.M. 2012. Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower. CRC Press, Florida, USA.

Sato, S., M.M. Peet and J.F. Thomas. 2000. Physiological factors limit fruit set of tomato (*Lycopersicon esculentum* Mill.) under chronic, mild heat stress. Plant Cell Environ. 23(7): 719–726. https://doi.org/10.1046/j.1365-3040.2000.00589.x.

Scott, J.W., R.B. Volin, H.H. Bryan and S.M. Olson. 1986. Use of hybrids to develop heat tolerant tomato cultivars. Proc. Fla. State Hort. Soc. 99: 311–315.

Sethi, V.P., R.K. Dubey and A.S. Dhath. 2009. Design and evaluation of modified screen net house for off-season vegetable raising in composite climate. Energy Convers. Manag. 50(12): 3112–3128. https://doi.org/10.1016/j.enconman.2009.08.001.

Takebe, M. and T. Yoneyama. 1995. An analysis of nitrate and ascorbic acid in crop exudates using a simple reflection photometer system. JSSSPN. 66(2): 155–158. https://doi.org/10.20710/dojo.66.2_155.

Tenga, A.Z., B.A. Marie and D.P. Ormrod. 1989. Leaf greenness meter to assess ozone injury to tomato leaves. HortScience 24(3): 514. https://doi.org/10.21273/HORTSCI.24.3.514.

Van Ploeg, D. and E. Heuvelink. 2005. Influence of sub-optimal temperature on tomato growth and yield: A review. J. Hortic. Sci. Biotechnol. 80(6): 652–659. https://doi.org/10.1080/14620316.2005.11511994.

Vijayakumar, A., S. Shaji, R. Beena, S. Sarada, T.S. Rani, R. Stephen, R.V. Manju and M.M. Viji. 2021. High temperature induced changes in quality and yield parameters of tomato (*Solanum lycopersicum* L.) and similarity coefficients among genotypes using SSR markers. Heliyon 7(2): e05988. https://doi.org/10.1016/j.heliyon.2021.e05988.

Villareal, R.L. and S.H. Lai. 1979. Development of heat tolerant tomato varieties in the tropics, pp. 188–200. *In*: Proceedings of the International Symposium on Tropical Tomato. The World Vegetable Center, Taiwan.

Xu, S., X. Sun, H. Lu, H. Yang, Q. Ruan, H. Huang and M. Chen. 2018. Detecting and monitoring the flavor of tomato (*Solanum lycopersicum*) under the impact of postharvest handlings by physicochemical parameters and electronic nose. Sensors 18(6): 1847. https://doi.org/10.3390/s18061847.