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The Effects of High Temperature Regime on Cherry Tomato Plant Growth and Development When Cultivated in Different Growing Substrates Systems

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Abstract: In the southern regions of China, it is very hot and relative humidity is high during summer. Similar conditions also prevail inside the greenhouse. In this experiment, it was observed that when roof ventilations were closed at noon, the greenhouse temperature could rise as high as 50^{o}C. This resulted in serious plant injury and in certain cases, death of plants. The investigation is a comparative study of heat stress on cherry tomato (*Lycopersicon esculentum* Mill. var.*cerasiforme*) cultivated in different substrate systems during summer time. The study was undertaken in a glasshouse from June to September 2007 in Hangzhou (Zhejiang Province). Our objective was to assess the critical temperature at a precise growth stage, and thereafter propose an appropriate cultivation system which can mitigate the thermal stress during summer. Growth was markedly related to the growing medium; the effect of temperature was less noticeable at seedling stage. Highly significant differences in the leaf expansion with temperature were noticed, stressed tomato plants showed a significant decrease in leaf area. High temperatures critically affected the plant development especially during flowering stage.

Key words: cherry tomato, substrate systems, *Lycopersicon esculentum* Mill. var.*cerasiforme*

1. Introduction

In regions of south China, during summer it is very hot and relative humidity is very high. Various cooling systems are applied in order to reduce the high temperatures, and in certain instances, production

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may even be suspended during this period. Nowadays, tomatoes are available at the market everyday, but the price changes dramatically and the season consumption correlates to the market price. Plants are capable of responding rapidly to changes in environmental factors particularly temperature.

Temperature is one of the determining factors, for plant growth, and is one of the major environmental constraints affecting photosynthetic efficiency and limiting the yield of crop plants (Bose *et al*, 1999). In recent years, many studies have focused on temperature that can maximize production and minimize the growing period (Stanghellini, 1999, Abou-Hadid, 1999, Newton, 2000). Other studies have been concerned with the effects of temperature on nutrient uptake (Papadopoulos *et al*, 2000, Ymeri, 1999). Other reports were related to the impact of temperature on the quality of production, and yield (Limonse *et al*, 1999, Schwartz, 1999). Further studies by Ferris *et al* (1998), Massai et al (2000), Bunce (1999) were focused on the recovery process after an environmental stress along a precise period. Although most of the studies have been aimed at understanding the yield responses to extended periods of moderately high temperature, short periods of very high maximum temperature also occur frequently in many parts of the World. The responses of each of these thermal regimes may be substantially different and experimentation using very high temperatures must be conducted.

The aim of our research was to study the effects of high temperature regimes on cherry tomato plants cultivated in different cultivation systems at different growth stages.

The investigation is a comparative study of heat stress on cherry tomato cultivated in different substrate systems: soil, peat moss, peat/perlite (3/2), perlite and a NFT (Nutrient Film Technique) during summer time. The study was undertaken in a glasshouse from June to September 2007.

2. Materials and Methods

The experiment was carried out in Hangzhou, the Institute of Agriculture and Bioenvironmental Engineering (Zhejiang University-China). The main object was to evaluate the tomato plant's reaction to temperature stress during summer time. Thirty five days after sowing, the plants were about 6-10 cm in height. Tomato seedlings at 5 to 7 true leaves were transplanted in pots with appropriate growing medium: Soil, peat moss, peat/perlite (3/2), perlite. Another soilless culture was the Nutrient film Technique (recirculation system) with 10 plants in each room. The NFT timer was set at a 1:2 minutes interval. Plants were selected for uniformity prior to treatments as described below for all subsequent experiments.

Each treatment unit (pot) was replicated 4 times and each experimental unit had 4 plants. Thereafter the plants were moved to the three identical glasshouse rooms at different temperature regimes (as treatments): Room-1 for 25/20^{o}C (day/night temperature), Room-2 for 35/25^{o}C (The maximum temperature

was maintained for 6 hours) and Room-3 for > 35°C / >25°C. In room-3, when day temperature was about 40°C, it was only maintained for 2 hours maximum. Measurements, observations or analysis done were for the vegetative period and the flowering period.

All the parameters (temperature, relative humidity, dioxide carbon) necessary to compute gas exchange were continuously recorded at 10 minutes interval using a computerized climate control system. Plant height was measured every two-weeks. It was determined as the average of the 4 plants from each growing medium. Internodes length was also measured. Growth rate was assessed by measuring stem height periodically. Leaf area was determined using a portable area meter (Brand: Li-Cor, Model: Li-3000, Origin: USA). It was determined four times during the vegetative stage on five fully expanded leaves. The Ec and pH of the nutrient solution was measured using the Ec meter (Hanna Instruments, HI 9033 Multi-range conductivity meter) and the pH (Hanna Instruments, HI 9024 microcomputer, pH meter) meter respectively. The measurements were done at a four-day interval for the recirculation system from the three rooms and for the tank. The feeding solution was prepared and kept in the tank. The Ec and pH were kept at 6.9mS/cm and 6.2 respectively. The nutrient solution was stirred regularly and renewed after each ten-day period. The plants were watered daily at dawn and in the late afternoon.

The trail was a factorial completely randomized design. The data were analyzed statistically using the SAS system (1996), general linear model procedure. The means difference were analyzed using the DPS 2000.

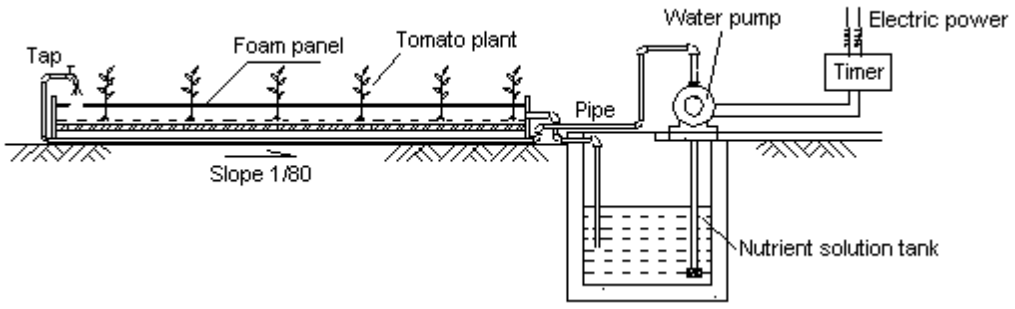

Fig. 1 Nutrient Film Technique design

3. Results and Discussion

Environmental Conditions

During day time, temperature, relative humidity and the CO_2 were recorded daily over a period of two weeks. In room-1, the daily temperature was in the range of 20.5°C to 27.2°C. The lowest temperatures were

observed in the early morning (20.5°C), there after temperature increased rapidly and was as higher as 25°C from 9 o'clock to 17 o'clock. In spite of the cooling system being applied, the temperature reached 27°C at midday (12-13 o'clock). Temperature was decreased gradually in the late afternoon. In room-2, temperature varied from a minimum of 23.7°C early in the morning to a maximum of 36.6°C around 12 o'clock (Δt=12.7°C). From 9:30 to 15 o'clock, temperature exceeded 35°C. It was gradually decreased to 26.8°C by the end of the day (19 o'clock). In room-3, the situation was analogous with the other rooms, with the minima temperatures in the early morning (24.3°C), and the maxima temperatures at midday (44.2°C), followed by an abrupt decrease in temperature down to 28.6°C. We recorded a temperature difference of about 20°C a day (Δt=19.9°C). Day (1998) pointed out that condensation was found to occur predominately in the early morning as the sun rose, leading to an increased transpiration rate and accompanied by an increase in greenhouse temperature.

Relative humidity (RH) was highest in the morning (85.08% in room-1, 78.02% in room-2, 75.68% in room-3), and it was lowest at midday (35.14% in room-1, 31.38% in room-2, 27.38% in room-3). There after, it was gradually increased in the late afternoon; but didn't reach the morning levels. These observations were similar in all the rooms. The daily difference RH was; in room-1: ΔRH=49.9%, in room-2: ΔRH=46.64% and in room-3: ΔRH=52.3%. Leonardi et al (2000) reported that high temperature in the greenhouse and low humidity outside can determine an increase of VPD (Vapor Pressure Deficit) in the greenhouse. The most obvious effect of very low humidity on open air crops is to induce leaf water stress when uptake of water through the root system is inadequate to cope with high transpiration rate. Takakura (1994) pointed out that higher humidity will promote stomata opening, if other factors are not constraining. Humidity affects the opening of stomata which are gates of carbon dioxide flow.

In contrast, the variation of the Carbon dioxide (CO_2) concentration was not as regular as RH and temperature. The concentration was in the range of 727 to 550 ppm (ΔCO_2=177 ppm) in room-1, 488 to 817 ppm (ΔCO_2=339 ppm) in room-2 and 508 to 700 ppm (ΔCO_2=198 ppm) in room-3. The concentration was decreased gradually from early morning until the early afternoon, after which there was a slight increase until evening. In the early morning, the concentration was 817 ppm, 727 ppm and 700 ppm respectively in room-2, room-1 and room-3. In the same, when the temperature reached 42-44°C, the relative humidity decreased by about 20%, and the CO_2 was less than 500ppm. It appears that as the temperature increases the relative humidity and the CO_2 decrease gradually. Gas exchange in the three rooms is dependent on the three physiological processes: photosynthesis, respiration and evapo- transpiration. Evapo-transpiration is more effective by daytime when the temperature is relatively high. Photosynthesis, under the right range of temperature, is markedly active by day when other conditions are fulfilled (light, CO_2, H_2O), with a relatively

elevated consumption of CO_2. From our study, the level of RH and CO_2 was very high in the early morning in all the rooms, and in spite of the decrease in temperature in the late afternoon, the morning levels of RH and CO_2 were not attained. Our results were in accordance with Rosenberg et al (1983), who reported that the daily pattern of air temperature describes a sine curve, with the minimum normally occurring in the early morning hours near sunrise and the maximum occurring sometimes after the peak of solar and net radiation has been reached. Mastalerz (1977) suggested that the respiration rate continues to increase with the rise of temperatures, whereas photosynthesis increases with temperature up to a certain threshold, a point at which radiant energy or the concentration of CO_2 probably becomes limiting.

At night, compared to the daily change, temperature didn't vary very much at night **(Fig-3).** It was slowly decreased from 29.4 to 25.8^oC (Δt=3.6^oC) in room-3, from 26.1 to 24^oC (Δt=1.9^oC) in room-2 and from 21.3 to 20^oC (Δt=1.3^oC) in room-1. In contrast, the relative humidity (RH) was increased faster in room-1 than in the other rooms. The variation was from 68.1 to 85.02% (ΔRH=16.92%) in room-1and was 64.9 to 78.2% (ΔRH=13.12%) and 61.07 to 75.68 (ΔRH=14.61%) in room-2 and room-3 respectively. The curve was almost similar for room-2 and room-3. CO_2 concentration was increased with time (at night); from 661 to 727ppm (ΔCO_2 =66 ppm) in room-1, 611 to 817 ppm (ΔCO_2 =206 ppm) in room-2 and 634 to 700(ΔCO_2 =66 ppm) ppm in room-3. However, the concentration was highest in room-2, followed by room-1 and lastly room3. Mastalerz (1977) reported that during the night, CO_2 accumulates as a result of plant respiration. At night, there is a loss of CO_2 from the soil to the atmosphere. The crop continues to respire but at a reduced rate because of lower temperatures.

Effects of Temperature on Other Environmental Factors

In our study, there was a negative linear relationship between temperature and RH, and also between temperature and CO_2 in all the rooms. However, that relationship was higher for RH than for CO_2. The regression coefficients for RH are (r^2) 0.8947, 0.9539 and 0.9729 for room- 1, room-2 and room-3 respectively. Conversely for CO_2, the regression coefficients are decreasingly smaller from room-1, to room-3. They are 0.786, 0.725 and 0.668 for room-1, room-2 and room-3 respectively. (Fig-2). In addition, it appears that in room-3, when the temperature abruptly exceeded 42^oC the consumption of CO_2 ceased earlier than in room-2, when temperature was maintained around 35^oC. We can assume that this is related to the photosynthetic activity which is limited by the temperature. This conforms to the findings of Ferris et al (1998) whereby stomata of well-watered plants tended to remain open over a wide range of temperatures, while an abrupt increase in temperature, caused the stomata to close. But, in our study we were not able to determine the precise temperature at which photosynthesis ceased. Pasterres et al, (1998) suggested that

maximum CO_2 assimilation was observed in the morning in control plants and in stressed plants, decreasing during the afternoon, but in stressed plants that decrease occurred faster than in control plants.

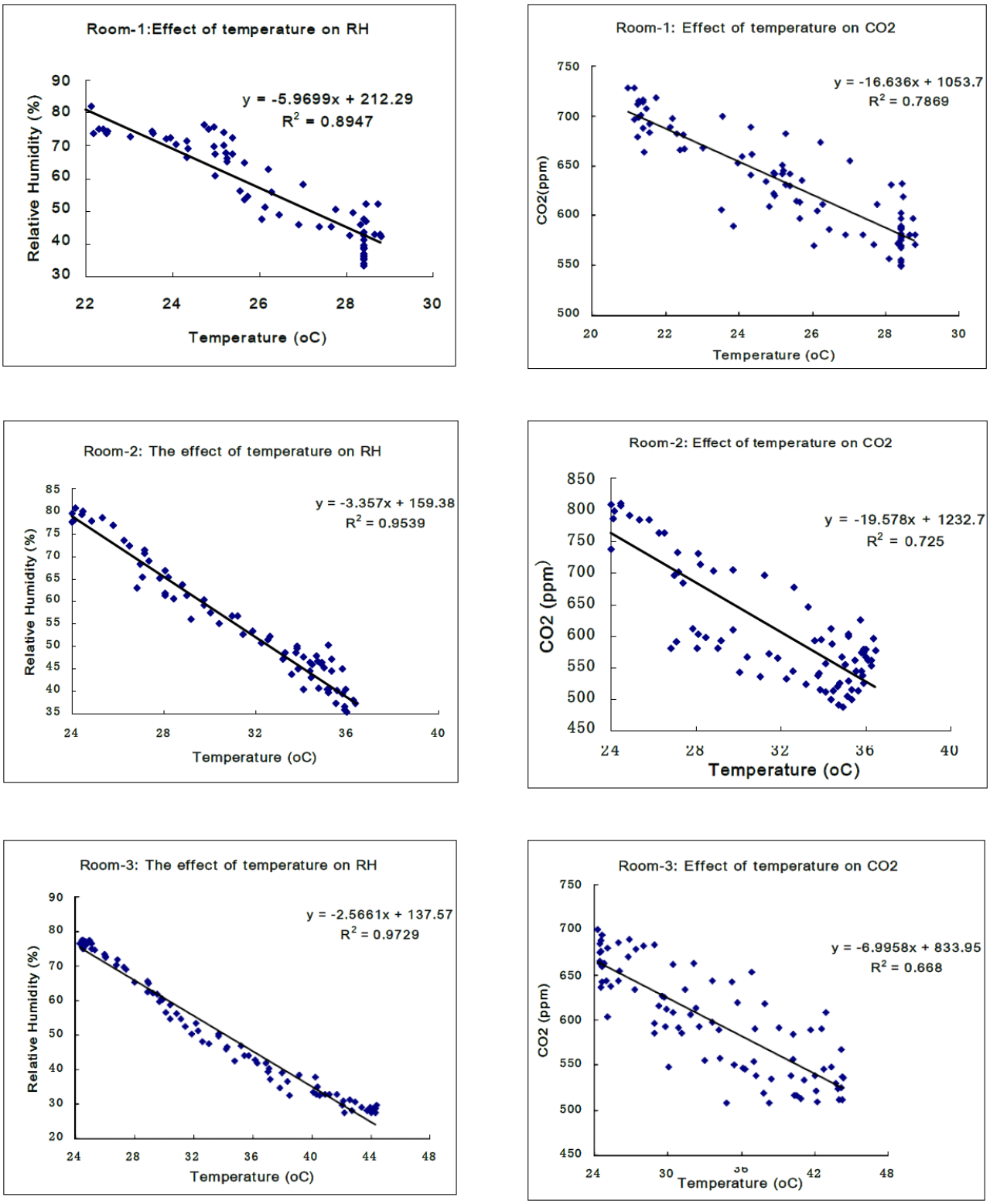

Fig. 2 Effects of temperature on other environmental factors

Harvinder et al (1999), reported that the changes in temperature regime from 30/25 to 40/25^{o}C affected the net photosynthesis rate, transpiration rate and intercellular CO_2 concentration.

Herppich-WB (1996) noted that during the course of a day the combination of increasing leaf water deficit, high temperature, high water vapour deficit of the air and high radiation load seriously disrupted carbon metabolism.

Effects of Temperature on Growth and Development

Growth is described here as the stem elongation, the number of branches per plant (internodes length), the number of leaves and their leaf area. As we are concerned with the first two development stages: the vegetative period and the flowering period, our attention focused on the time to flowering and flower expansion until first fruiting.

Stem Elongation

The length of the stem is the average plants' height for each growing medium in each room. From the DAS 34 to 48, there was no difference in stem elongation. Our results showed from DAS 62 that the stem elongation was slightly higher in room-2, where the daily average temperature was around 35^{o}C than in the other rooms, regardless of the growing medium **(Table. 1).** The same situation prevailed until the beginning of the flowering period. When appeared the first fruit (DAS99), in room-1, the plants were stronger and taller than those in the other rooms. In addition, the temperature regime of more than 35^{o}C negatively affected the stem length; stem length was the lowest in room-3 regardless of the growing medium. Our observations are analogous to those of Sorrentino et al (1997), in which temperature appeared to be the principal factor influencing growth and differentiation. From DAS 48, we found a highly significant effect caused both by temperature and growing media as well. The analysis of variance also showed that the interaction between temperature regime and growing media on stem elongation was significant from DAS 77. Moreover, Rahman-SML (1998) reported that high temperature regime significantly reduced yield, pollen germination percentage, shoot and root dry weight. However, we can not confirm the study of Ohta-K et al (1999) in which the growth of cherry tomatoes was not related to temperature or light intensity.

Table. 1 Stem elongation during tomato growth in different substrate systems under different temperature regimes.

DAS	Treatment	Soil	Peat	P/P	Perlite	NFT
34	R-1	7.25(0.95)a	7.75(1.5)a	7.75(0.95)a	8(1.41)a	8.25(0.95)a
34	R-2	8.25(0.5)a	7.75(1.5)a	7.75(0.95)a	7.5(1.29)a	7.75(0.95)a
34	R-3	7.5(1.9)a	7.5(1.29)a	7.5(1.29)a	7.25(2.06)a	7(1.41)a
48	R-1	37.7(4.03)a	26.5(6.8)a	31.5(6.9)b	22.75(2.3)a	28(3.9)b
48	R-2	41(9.05)a	29.5(7.7)a	45.5(5.8)a	24.7(4.9)a	34.5(4.5)a
48	R-3	27.7(6.8)b	20.7(4.11)a	27.7(6.1)b	21.7(1.5)a	26.7(0.9)b
62	R-1	68.5(9.9)b	43.7(12.1)b	56.2(8.8)ab	61.2(8.5)b	57.2(10.2)ab
62	R-2	79.2(9.2)a	49.2(11.8)a	60.7(5.3)a	66.5(4.1)a	59.5(7.9)a
62	R-3	62(10.4)c	40.2(8.6)b	49.2(11.3)b	52.7(7)c	55.2(8.9)b
77	R-1	104.5(14.9)a	72(15.2)ab	89.2(14.1)a	105.5(9.7)a	72.7(11.4)b
77	R-2	110.7(15.6)a	79(6.6)a	93(14.9)a	106.2(9.7)a	91.7(5.2)a
77	R-3	101.5(11)a	62.7(10.7)b	76(15.7)a	105.5(9.7)a	72.2(11.4)b
99	R-1	149.2(5.3)a	114(16.6)a	140(11.1)a	134.2(5.2)a	201.2(17.4)a
99	R-2	129(14.4)b	104(20)ab	137(14)ab	131(14.7)a	155.5(17.9)b
99	R-3	116.5(13)b	85.2(6.3)b	115(26.5)b	129(13.1)a	135(32.3)b

*Different letters: significantly different at p= 5% (DMRT)

*The values in parentheses represent the Standard deviation of the means.

*The unit is “cm”

Our observations could neither confirm the results of Incrocci-L (1999) which suggested that in tomato, stem elongation is controlled by light quality during the day, nor the report of Paez- A (2000) that plant height and leaf area increased in the shade and total biomass decreased under full sunlight. In our study, in room-1-the less heated stress-the plants’ height was higher than in the room-2 and room-3. These observations are similar to the findings of Grindal (2000), Langton (1999), who also reported that vegetative growth was affected by day /night temperature regimes.

Internode's Length

From the 34th to the 48th after sowing, the stem internodes were almost the same in all treatment **(Table. 2)**. From the 62nd day to the 99th day, the stem internodes were relatively shorter in room-1 than in room-2 and those in room-2 shorter than those in room-3. The difference in stem internodes seems to be connected to the daily temperature regimes. Plants subjected to a stronger thermal stress developed longer internodes. Our results confirm those of Takezaki et al (2000) who reported that shorter stem length at high temperature conditions was due to the small number of nodes. The number of nodes decreased and the average internodes' length increased when plants were grown at high temperature conditions. Langton-F. (1997) reported that day temperature had a large influence on internode's extension in tomato, but night temperature had relatively less effect; and observed that, the DIF (Day temperature/night temperature difference) is a significant factor in determining stem extension responses. The stem elongation pattern can be characterized by internodes number and internodes length, which varies with temperature (Junne-Jih et al, 1999). Our results also showed that the difference in internode's length was increasingly higher with the plant growth and the minimum stem elongation in room-3 with the highest daily temperature regime.

Weaich (1996) suggested that under diurnally varying temperature conditions, the major impact of high temperatures on shoot growth was due to a severe reduction in the first internode's growth rate, which was correlated with the day maximum temperature.

We noticed that the internode lengths are decreased progressively from the Nutrient Film Technique (NFT), soil, perlite, peat/perlite to peat respectively. The reasons for the decrease are still unknown. The report of Petrevska-Katarzyna et al (2001), Yang-SeungKoo et al (1999) and Logendra-LS (1999) suggested a close influence of the substrate system on the plants' growth and development.

Table. 2 Internodes length during tomato growth in different substrate systems under different temperature regimes

DAS	Treatment	Soil	Peat	P/P	Perlite	NFT
34	R-1	2.4(0.4)a	2.8(0.3)a	2.5(0.4)a	2.4(0.4)a	2.6(0.6)ab
34	R-2	2.8(0.7)a	2.6(0.4)a	2.2(0.1)a	2.5(0.3)a	2.8(0.5)a
34	R-3	2.5(0.3)a	2.8(0.5)a	2.5(0.3)	1.9(0.2)b	1.9(0.2)b
48	R-1	6.2(0.3)a	4.6(0.5)a	5.2(0.3)b	4.1(0.3)a	5.1(0.3)a
48	R-2	6.4(0.6)a	4.7(0.7)a	6(0.6)a	4.4(0.4)a	5.5(0.6)a
48	R-3	5.5(0.5)a	4.6(0.5)a	4.9(0.5)b	4.8(0.4)a	5(0.3)a
62	R-1	6.6(0.4)b	5.4(0.4)b	5.5(0.5)a	5.2(0.3)a	5.9(0.7)a
62	R-2	7.2(0.6)ab	5.7(1.4)b	5.8(0.9)a	5.8(0.3)a	6.1(0.3)a
62	R-3	8.1(0.5)a	6.9(0.9)a	6.2(0.2)a	5.9(0.2)a	6.3(0.1)a
77	R-1	8.5(0.1)b	7.1(0.5)a	7.6(1.2)a	8.1(0.6)b	6.6(0.1)b
77	R-2	9.8(1)a	7.9(1)a	7.8(0.8)a	9(0.7)ab	6.8(0.3)b
77	R-3	10.7(0.7)a	8.6(1.1)a	8.1(1.4)a	9.3(0.3)a	8.5(0.3)a
99	R-1	8.7(0.6)b	7.9(0.6)b	9.6(0.8)a	8.9(0.8)a	10.4(1.3)c
99	R-2	9(0.5)b	9.4(0.6)a	10.1(0.2)a	9.5(0.4)a	12.4(1.1)b
99	R-3	12.5(1.1)a	10.3(0.8)a	10.3(0.7)a	9.6(0.3)a	15.7(0.6)a

*Different letters: significantly different at p= 5% (DMRT)

*The values in parentheses represent the Standard deviation of the means.

*The unit is “cm”

Until DAS 62, we didn’t statistically notice any significant effect of the interaction between temperature and growing media on stem internodes’ length. Thereafter, from DAS 77, the effect of the interaction was found significant. We also noticed highly significant differences in stem internodes’ length caused independently both by temperature and by growing medium.

Prasad-M et al (2001) reported that the reasons for the influence of growing media on plant development are related to their media structure and physical properties to suit prevailing climatic conditions. In this study, the plants were watered adequately to insure that plants did not suffer any water stress. We conclude that the stem internodes growth is affected by the temperature regimes as well as by the growing media.

Leaf Expansion

The leaf expansion was considered as another criterion for vegetative growth. Determination of leaf area was based on the five fully expanded leaf from each pot, taken five times during the vegetative period (34, 41, 48, 55 and 62 DAS).

In room-1, where the temperature regime is about 25/20^{o}C (day/night temperature), the leaves were more expanded than in room-2 and room-3. In room-3 (>35/>25^{o}C), the plants had the smallest leaf area.

Our results **(Table. 3)** confirm those of Torrecillas et al (1994) who found that stressed tomato plants showed a significant decrease in leaf area, without reduction in leaf dry weight. In contrast, Stanghellini et al (1998), didn't find any significant difference between climate treatments, neither with respect to the leaf expansion, nor to the leaf area. In our study, in spite of different temperature regimes, there was slight difference in average leaf area in room-2 and room-3. A general linear model analysis (ANOVA) was used to test whether temperature, growing media, or their interaction affected the leaf area. In our study, the interaction of temperature and growing medium on leaf area had no significant effect. However, highly significant differences in the leaf expansion with temperature were noticed. These differences were independently caused by growing media and by temperature regimes. A significant difference caused by temperature regime was also detected by Duncan's Multiple Range Test.

Table. 3 The effect of temperature regime on leaf area (cm^2)**.**

Treatment	Growing media				
	Soil	Peat	Peat/Perlite	Perlite	NFT
Room-1	21.40(6.99)a	10.72(3.51)a	13.25(5.48)a	19.77(3.08)a	25.8.58(8.58)a
Room-2	11.26(0.45)b	5.83(1.36)b	6.935(1.37)b	9.19(1.50)b	10.98(2.27)b
Room-3	9.28(1.87)b	4.30(0.72)b	6.85(1.23)b	7.78(1.10)b	8.34(1.90)b

Table. 4 The effect of growing media on leaf area. (cm^2)

Growing media	Treatment		
	Room-1	Room-2	Room-3
Soil	21.40(6.99)a	11.26(0.45)a	9.2891.87)a
Peat	10.729(3.51)c	5.83(1.36)c	4.30(0.72)c
Peat/Perlite	13.25(5.48)bc	6.93(1.37)bc	6.85(1.23)b
Perlite	19.77(3.08)ab	9.19(1.50)ab	7.78(1.10)ab
NFT	25.46(8.58)a	10.98(2.27)a	8.34(1.90)ab

*Different letters: significantly different at p= 5% (DMRT)

*The values in parentheses represent the Standard deviation of the means.

*The unit for leaf area is "cm^2"

Temperature Regime and Reproductive Growth Stage

In this study, we focused on the period from the first flower to the first fruiting for each room and for each growing media.

The first flower appeared on DAS 68 in room-1, followed by room-2 after DAS 73 and lastly after DAS 78 in room-3. The relatively short delay in first flowering between the rooms may be related to the heat stress which is higher from room-1 to room-3 respectively. Heat stress adversely affects the vegetative and reproductive growth processes of tomato plants. (Aref et al, 1995). According to Saucer (1998), it has been observed that when temperature only affects the length of time at which the plant reached flowering, the plants respond with changes in their development rate depending on changes in air temperature.

From our observations**,** the emergence of the first flower was noticed in pot-soil, (used as a substrate system) in all the rooms. It was followed by peat/perlite, perlite, peat and NFT respectively.

As the flowering period started, the flower expansion and number of flowers per plant increased rapidly in all the rooms. In room-1, after two weeks, all the plants in soil and peat perlite had a minimum of five expanded flowers. That situation was similar in room-3 after three weeks. We noticed that in room-3, the full completion of flowering was delayed compared to the other rooms.

We can conclude that, the heat stress applied did not seriously affect either flower initiation or flower multiplication; however, the flowering period was more adversely affected than flower initiation and multiplication.

In room 3, the wilting of the leaves was followed by the loss of the flowers. Even after watering, though the leaves recovered, the flowers did not. This situation was similar in room- 2 and in room-1, though with less significance. In tomato, growth chamber and greenhouse studies suggest that high temperature is most deleterious at the time the flowers are first visible and the sensitive stage continues for 10-15 days (Willits et al, 1998). Lohar (1998) suggested that a tomato heat sensitive cultivar produced only flowers which aborted at 38/270C day/night temperature. Generally the higher the temperature, the higher is the percentage of abortion (Kinet et al., 1985).

In this study, after 40 days from first flower emergence (DAS 104), in room-1, a limited number of fruits appeared; in room-2, there were only 2 fruits from the plants in soil as a substrate system. No fruits were obtained from room-3. Our observations showed a drastic effect of heat stress on fruit set. The level of affection was related to the temperature regime applied.

Possible reasons for poor fruit set in tomatoes at high temperatures include: direct effects on pollen and other reproductive tissues, low level of carbohydrates, and hormonal imbalances (Kinet et al, 1997). Borbora et al, (1997) reported that low pollen production and viability and style exsertion are the major causes for low pollination and fruit set at high temperature. Deleterious effect of high temperature on the processes related to fruit set are not restricted to pollen germination and tube growth, ovule viability is also sensitive to high temperature (Song et al, 1999).

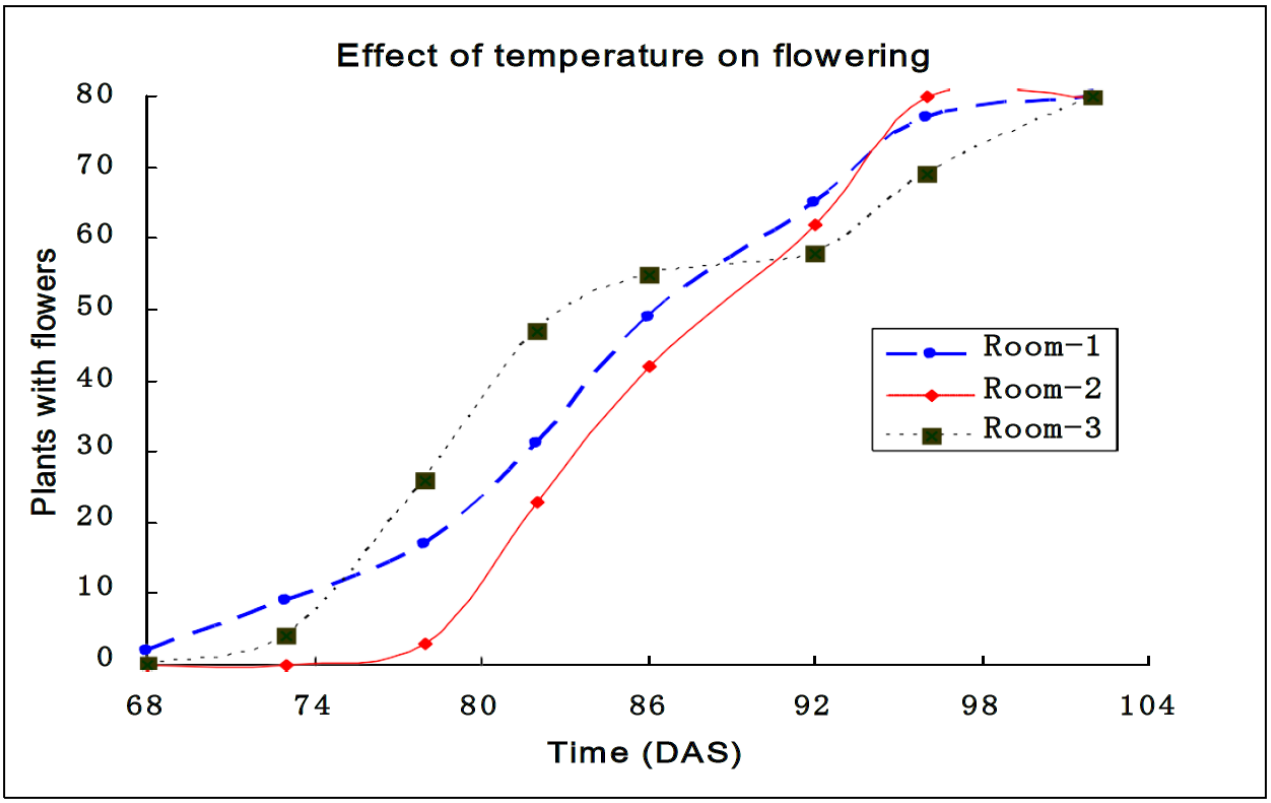

Fig. 3 Effects of temperature regime on flowering

The night temperature is important for fruit set (Borbora et al, 1997). Although tomato can grow under a wide range of climates, fruit-set is interrupted above 29/20°C day/night temperatures (Lohar, 1998). Willits et al, (1998) reported also that the high night temperatures during fruit set can limit tomato production in greenhouses in warm climates. In our study, the average night temperatures were varied from 20 to 22°C in room-1, from 24 to 26°C in room-2 and from 25 to 29.5°C in room-3, therefore, the night temperature was not favorable for fruit set in all of the rooms.

4. Conclusions

There was a negative linear relationship between temperature and relative humidity, and also between temperature and CO_2 in all the rooms. It is therefore very difficult to assess the effects of high temperatures on plants if it is considered independently.

Growth, expressed in terms of stem elongation and internode's length was markedly related to the growing medium; the effect of temperature was less noticeable at seedling stage. Stem elongation and internode's length decreased progressively from NFT, soil, perlite, and peat/perlite to peat respectively.

Highly significant differences in the leaf expansion with temperature were noticed, stressed tomato plants showed a significant decrease in leaf area. However, leaf expansion was independently affected by growing medium and temperature regime applied.

High temperatures critically affected the plant development especially during flowering stage. The fruit set was seriously compromised, and high numbers of aborted flowers were observed at temperatures higher than 35/25^{o}C (day/night temperatures). However, flower initiation and multiplication were less affected. Growers should be cautious to ensure that the flowering periods do not coincide with the hottest months of the year.

References

[1]. Abou-Hadid A.F. The use of weather data for crop production and protection. Acta Horticulturae 486 (1999), 169-172.

[2]. Aref A. Pollen viability and fruit set of tomato genotypes under optimum and high temperature regimes. Hortscience 30(1) (1995), 115-117.

[3]. Bose A., Tiwari Bs. Manas K. Chattopadhyay & Gosh B. Thermal stress induces differential degradation of Rubisco in heat-sensitive and heat tolerant rice. Physiologia plantarum 105 (1999), 89-94.

[4]. Borbora D.P., Talukdar P. & Shadeque A. Sensitivity of tomato (Lycopersicon esculentum) cultivars to high temperature pollination and fruit-set under plastic rain shelter. Indian Journal of agricultural Sciences 67(8) (1997), 312-313.

[5]. Bunce J. A. Leaf and root control of stomatal closure during drying in soybean. Physiologia plantarum 106 (1999), 190-195.

[6]. Ferris R., T. R. Wheeler, P. Hadley and& R. H. Ellis. Recovery of photosynthesis after environmental stress in soybean grown under elevated CO2. Crop Science 38 (1998), 948-955.

[7]. Harvinder T., Abdul K.; Fukamachi H.; Tsukaguchi, Komori T. S.&Hidaka. Photosynthetic response to high temperature under different levels of irradiance in Mango. Japanese Journal of Tropical Agriculture, 45:2 (2001), 77-83.

[8]. Herppich, W.B &Morphol M. F. Field investigations of photosynthetic activity, gas exchange and water potential at different leaf ages in Welwitschia mirabilis during a severe drought. Flora- Jena. 191: 1 (1996), 59-66.

[9]. Incrocci-L and Lercari-B. Growth responses of tomato plants under CuSO4 light filter: a comparison between wild type and aurea mutant. Advances-in-Horticultural-Science. 13: 4 (1999),143-146

[10]. Junne-Jih C., Yung-Wei S., and Tzay-Fa S.Use of cold water for irrigation reduces stem elongation of plug-grown tomato and cabbage seedlings. Hortscience 34(5) (1999), 853-854.

[11]. Kinet, J.M., Peet M.M. Tomato. In: Wien,HC (Ed.), The Physiology of vegetable crops. Commonwealth Agricultural Bureau (CAB) International. Wallingford, UK, (1997) pp.207-258.

[12]. Kine J.M., Sachs, R.M., G., The physiology of flowering. The development of flowers. (1985) Vol.III, CRC Press, Boca Raton, Fl.

[13]. Langton F.A. and Cockshull-K.E. Is stem extension determined by DIF or by absolute day and night temperatures, Scientia-Horticultura. 69: 3-4 (1997), 229-237.

[14]. Leonardi C., Baille A., Guichard S. High vapour pressure deficit influences growth, transpiration and quality of tomato fruits. Scientia horticulturae 84 (2000), 285-296.

[15]. Limonse L., Stanghellini C, W.Th.M. van Meurs. Combined effect of climate and concentration of the nutrient solution on a greenhouse tomato cropII: Yield quality and quantity. Acta Horticulturae 486 (1999), 231-237.

[16]. Lohar D.P., Peat W.E. Floral characteristics of heat-tolerant and heat sensitive tomato (Lycopersicon esculentum Mill) cultivars at high temperature. Scientia horticulturae 73 (1998), 53-60.

[17]. Logendra-L.S., Janes H.W. Hydroponic tomato production: growing media requirements. Acta-Horticulturae. 481 (1999), 483-485.

[18]. Massai R. and Remorini D. Sap flow in peach trees during water stress and recovery in two environmental conditions. Acta Horticulturae 537 (2000), 351-358.

[19]. Newton P., Sahraoui R, Economakis C. The influence of air temperature on truss weight of tomatoes. Acta Horticulturae 507 (1999), 43-46.

[20]. Ohta-K. Differences in the occurrence of blossom-end rot in cherry and large fruit tomatoes. Journal-of-Society-of-High-Technology-in-Agriculture 11: 1 (1999), 22-25.

[21]. Paez-A., Paz-V. & Lopez-J.C. Growth and physiological responses of tomato plants Effect of shading. Revista-de-la-Facultad-de-Agronomia,-Universidad-del-Zulia. 17: 2, (2000), 173-184.

[22]. Papadopoulos A.P., Hao X., Dorais M., Ehret D.L., Turcotte G., Gosselin A. Improving tomato fruit quality by raising the Ec on NFT nutrient solutions and Calcium spraying: Effects on growth, photosynthesis, yield and quality. Acta Horticulturae 511 (2000), 213-221.

[23]. Petrevska-K. &Lumbrikus H. The influence of the substrate on the growth and development of glasshouse tomatoes (Lycopersicon esculentum Mill.). Contemporary Agriculture 50 (1-2) (2001), 89-92.

[24]. Prasad M, Maher MJ The use of composted green waste (CGW) as a growing medium component. Acta-Horticulturae No. 549 (2001), 107-113.

[25]. Rahman S. M. L., Nawata E.&Sakuratani, T. Effects of temperature and water stress on growth, yield and physiological characteristics of heat tolerant tomato. Japanese-Journal-of- tropical agriculture 42:1, (1998) 46-53.

[26]. Sauser BJ, Giacomelli DGA, Janes DHW Modeling the effects of air temperature perturbations for control of tomato plant development. Acta Horti,culturae 456, (1998), 231-237.

[27]. Schwarz D, Kläring HP, Cierpinski W. Control of concentration of nutrient solution in soilless growing systems, depending on greenhouse climate advantages and limitations. Acta Horticulturae 507, (1999), 133-139.

[28]. Sorrentino G., Cerio L. Alvino, A. &Dubey, J.P.Effect of shading and air temperature on leaf photosynthesis, fluorescence and growth in lily plants. Scientia horticulturae 69 (1997), 259- 273.

[29]. Stanghellini C, W.Th.M. van Meurs, L. Simonse, J. van Gaalen . Combined effect of climate and concentration of the nutrient solution on a greenhouse tomato crop I: Vegetative growth. Acta Horticulturae 486 (1999), 221-225.

[30]. Takakura T. Temperature, Humidity, and Ventilatio-interelatioships. Procedings from the Greenhouse Systems International conference. New Brunswick, New Jersey. July 20-22,1994. Copyright 1994 by Northeast Regional Agricultural Engineering Service. Ithaca, NY 14853-5701.

[31]. TakedaT., Takahashi K. Seasonal changes of macro element absorption in solution cultured roses [Rosa]. Journal-of-the-Japanese-Society-for-Horticultural-Science (Japan). v. 67(1) (1998) p. 116-122.

[32]. Takezaki A. The effects of temperature treatments on stem length of Eustoma grandiflorum. Acta-Horticulturae. No. 515 (2000), 151-157

[33]. Torrecillas A. & Juan J. Water relation of two tomato species under water stress and recovery. Plant Science 105 (1995) 169-176.

[34]. Weaich K., Bristow Keith L. and Cass A.,Modeling preemergent maize shoot growth in high temperature stress conditions. Agronomy-journal (USA) v. 88 (3) (1996). p. 398-403.

[35]. Willits D.H. and Peet M.M. The effect of night temperature on greenhouse grown tomato yields in warm climates. Agricultural and forest meteorology 92 (1998) 191-202.

[36]. Yang-Seung K. Effect of culture media on rooting and root growth of lateral shoots of cutting in cherry tomato. Journal-of-the-Korean-Society-for-Horticultural-Science. 40: 3, (1999) 294-296.