Comparative Studies on Growth and Development of Heat-Tolerant and Non Heat-Tolerant Tomato Plants Grown at Different Root-Zone Temperatures

George Oduro Nkansah and Tadashi Ito

Faculty of Horticulture, Chiba University, Matsudo, Chiba 271

Summary

Comparative studies on growth and development of young heat-tolerant tomato (*Lycopersicon esculentum* Mill. cv. Shuki) and non heat-tolerant one (cv. Sataan) grown under four root-zone temperatures (RZT) were carried out. Growth rates were measured at RZT of 15°, 20°, 25°, and 30°C. Plants in study 1, were grown for 10 days (21 to 31 days after sowing) and in study 2, 21 days (21 to 42 days after sowing). Optimum growth in both cultivars occurred at 30°C in plants grown for 10 days and at 25°~30°C in plants grown for 21 days. Cultivar 'Shuki' had greater shoot fresh and dry weight, greater root dry weight and greater leaf area than 'Sataan' at all RZT. Cultivar 'Shuki' had greater NAR compared to 'Sataan' at all RZT. Significant and positive correlations existed among growth parameters at all RZT in both cultivars. Biomass or carbohydrate production between the two cultivars at the end of 21 days was significantly different at RZT of 20°C and 25°C. The results indicate that the heat-tolerant cultivar, 'Shuki', is a better biomass or carbohydrate producer than the non heat-tolerant cultivar, 'Sataan'.

Introduction

The effect of root-zone temperature on growth of non heat-tolerant tomato cultivars has been studied extensively. The optimum root-zone temperature for seedling growth of tomato is between 27°~32°C when the air temperature is between 17°~25°C (Hurewitz and Janes, 1983). Yelle et al. (1987) reported maximal root growth at 25°C and Cooper (1974) found that shoot growth of tomato plants was highest at 30°C when the air temperatures were 23°/16°C±1°C day/night. Abdelhafeez et al. (1971) and Orchard (1980) found that soil warming increased total leaf area.

In heat-tolerant tomatoes, the effect of root temperature on growth is not well documented. This may be attributed to the fact that, heat-tolerant tomatoes, which can be defined as cultivars which have the ability to set fruits at night temperatures not lower than 21°C (Abdalla and Verkerk, 1968), are limited to a few districts of the tropics.

This study was therefore conducted to evaluate

differences in growth (leaf area, shoot fresh and dry weight, relative growth rate and net assimilation rate) of young heat-tolerant and non heat-tolerant tomato cultivars and also to test how to change biomass or carbohydrate production (total plant dry weight regressed on net assimilation rate) between the two cultivars grown at four root-zone temperatures.

Materials and Methods

Two studies were conducted. Growth measurements were made in 4 root-zone temperature treatments in both studies. For both studies, 'Shuki', a heat-tolerant and 'Sataan', a non heat-tolerant tomato plants were grown in a glasshouse. The air temperatures were 35° to 39°C (day) and 20° to 22°C (night) measured with thermocouples shielded and aspirated at plant height in the center of the glasshouse.

Seeds were sown on July 30, 1991 in study 1 and August 8, 1991 in study 2. In both studies, three-week-old plants were placed in 9-liter pots containing complete nutrient solution (EC, 2.5 mS · cm⁻¹). The pots were bathed in 4 water tanks maintained at temperatures of 15°, 20°, 25° and

30° ± 0.5°C using heating coils and chillers. Each water tank was prepared to have ten pots of five 'Shuki' and five 'Sataan', independently. Each of the five plants per cultivar was considered as a replicate.

Plants were harvested 10 days later (day 31) in study 1 and 21 days later (day 42) in study 2. The following parameters were measured: 1) leaf area (using a leaf area meter—type AAM-7, Hayashi Denki Co. Ltd.) and 2) fresh and dry weight of leaves, stems and roots.

At the start of each trial, 5 plants were sampled arbitrarily to give initial values for net assimilation rate (NAR) calculations. In the first trial, mean total dry weight and leaf area were 0.31 g and 71.6 cm² per plant for 'Shuki' and 0.21 g and 40.9 cm² per plant for 'Sataan', respectively. In the 2nd trial, mean total dry weight and leaf area were 0.20 g and 71.0 cm² per plant for 'Shuki' and 0.10 g and 41.0 cm² for 'Sataan', respectively.

NAR was calculated using the following equation: $NAR = (W_f - W_i) / (A_f - A_i) \times \ln(A_f / A_i) / (t_2 - t_1)$ (Radford, 1967; Evans, 1972) where, W_f is the total plant dry weight at the end of the measurement period, W_i is the total plant dry weight of initial measurement, A_f is final leaf area, A_i is initial leaf area, and $t_2 - t_1$ is the time between measurements. Relative growth weight (RGR) was calculated from the equation: $RGR = \log(W_f / W_i) / (t_2 - t_1)$; (Evans, 1972). Specific leaf area (SLA) was measured as

the ratio of leaf area to leaf dry weight (LA/LDW), leaf weight ratio (LWR), as the ratio of leaf dry weight to total plant dry weight (LDW/TPDW), and leaf area ratio (LAR), as the ratio of leaf area to total plant dry weight (LA/TPDW).

Data were represented by analysis of variance and by simple regression analysis. Biomass or carbohydrate production between cultivars were determined for homogeneity of regression coefficients in accordance with the procedure adopted by Gomez and Gomez (1984).

Results and Discussion

Shoot fresh and dry weight, root dry weight and leaf area.

In study 1 (plants grown for 10 days after treatment) and study 2 (plants grown for 21 days after treatment), root-zone temperature and cultivar exerted independent influence on tomato growth for the primary response variables (shoot fresh weight, shoot dry weight, root dry weight and leaf area) (Tables 1 and 2). That is, RZT × Cultivar interactions was not significant with the exception of RZT × Cultivar for leaf area in plants grown for 21 days (Table 2).

Table 1 indicates that, shoot fresh and dry weight in plants grown for 10 days were highest at RZT of 30°C. It also shows that, 'Shuki' had greater shoot and dry weight than 'Sataan'. Shoot

Table 1. Comparison of plant growth between heat-tolerant (cv. Shuki) and non heat-tolerant (cv. Sataan) tomato cultivars grown for 10 days at different root-zone temperatures (RZT).

Cultivar	RZT (°C)	Shoot fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Shoot/root ratio	Leaf area (dm ²)
Shuki	15	30.7(218) ^y	2.7(277)	0.66(245)	4.1	5.8(246)
	20	42.0(152)	4.0(196)	0.74(203)	5.7	8.4(203)
	25	52.5(184)	4.5(215)	0.77(149)	6.0	8.6(149)
	30	53.1(147)	4.6(165)	0.87(150)	5.9	9.9(150)
Sataan	15	14.1	1.0	0.27	4.1	2.4
	20	27.6	2.0	0.37	5.6	4.2
	25	28.6	2.1	0.47	4.4	5.8
	30	36.2	2.8	0.57	4.9	6.6
Significance ^z						
Cultivar		**	**	**	NS	**
RZT		*	*	*	NS	**
Cultivar × RZT		NS	NS	NS	NS	NS

^z *, **, and NS indicate significance at P=0.05, 0.01 and nonsignificance at 0.05 respectively.

^y Figures in parentheses indicate the percentage of values for 'Shuki' to those obtained for 'Sataan' at each temperature.

Table 2. Comparison of plant growth between heat-tolerant (cv. Shuki) and non heat-tolerant (cv. Sataan) tomato cultivars grown for 21 days at different root-zone temperatures (RZT).

Cultivar	RZT (°C)	Shoot fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Shoot/root ratio	Leaf area (dm ²)
Shuki	15	80.2 (218) ^y	7.6 (250)	1.14 (194)	7.2	20.2 (194)
	20	162.1 (186)	13.2 (220)	1.59 (217)	8.5	29.5 (217)
	25	205.6 (188)	14.3 (203)	1.77 (174)	8.2	34.1 (174)
	30	176.0 (181)	13.0 (194)	1.45 (160)	9.6	33.4 (161)
Sataan	15	36.8	3.0	0.57	5.4	10.4
	20	87.0	6.0	0.71	8.3	13.6
	25	109.6	7.0	0.73	9.7	19.6
	30	97.1	6.7	0.70	9.5	20.8
Significance ^z						
Cultivar		**	**	*	NS	**
RZT		*	*	NS	NS	**
Cultivar × RZT		NS	NS	NS	NS	**

^z *, **, and NS indicate significance at P=0.05, 0.01 and nonsignificance at 0.05 respectively.

^y Figures in parentheses indicate the percentage of values for 'Shuki' to those obtained for 'Sataan' at each temperature.

fresh weight of 'Shuki' was 118, 52, 84 and 47 % greater than that of 'Sataan' at 15°, 20°, 25° and 30°C, respectively. Shoot dry weight of 'Shuki' was 177, 96, 115 and 65 % greater than that of 'Sataan' at 15°, 20°, 25°, and 30°C, respectively.

In Table 2, maximum shoot and dry weight were recorded at RZT of 25°C for both cultivars when grown for 21 days. Cultivar, 'Shuki' had significantly greater shoot fresh and dry weight than 'Sataan'. Shoot fresh weight of 'Shuki' was 118, 86, 88 and 81 % greater than that of 'Sataan' at 15°, 20°, 25°, and 30°C, respectively. Shoot dry weight of 'Shuki' was 150, 120, 103 and 94% greater than that of 'Sataan' at 15°, 20°, 25°, and 30°C, respectively. The greater increase in shoot dry weight of 'Shuki', may have resulted from larger leaf area and higher net assimilation rates or its ability to produce more carbohydrates than the non heat-tolerant cultivars 'Sataan'.

Root dry weight of 'Shuki' was significantly greater than that of 'Sataan' grown for 10 days (Table 1). The former was 145, 103, 49 and 50 % greater than the latter at 15°, 20°, 25° and 30°C RZT respectively. Cultivar 'Shuki' recorded significantly greater root dry weight than 'Sataan' at the end of 21 days as well as 10 days (Table 2). Root dry weight of 'Shuki' was 94, 117, 74 and 60 % greater than that of 'Sataan' at 15°, 20°, 25° and 30°C RZT, respectively. RZT had significant effect on root dry weight in plants grown for 10

days but no significant effect in plants grown for 21 days.

Root-zone temperature had no effect on the ratio of shoot to root dry weight and no differences were observed between cultivars (Tables 1 and 2). Shoot growth was affected more than root growth by RZT. Shoot dry weight was lower at 15°C compared to 30°C in both cultivars.

Leaf area response to RZT was similar to that of shoot fresh and dry weight in plants grown for 10 or 21 days. Treatment at 30°C resulted in maximum leaf growth in plants grown for 10 days (Table 1), while in plants grown for 21 days, the best leaf growth was at RZT of 25°~30°C (Table 2). These results indicated that low RZT caused a considerable decrease in leaf area. The rate of increase in leaf growth was significantly greater in 'Shuki' than that in 'Sataan'. Root-zone temperature enhanced leaf growth of 'Shuki' by 146, 103, 49 and 50 % as compared with that in 'Sataan' for 10 days of 15°, 20°, 25° and 30°C, respectively (Table 1). In plants grown for 21 days, leaf area of 'Shuki' was 94, 117, 74 and 61 % greater than that of 'Sataan' at 15°, 20°, 25° and 30°C, respectively (Table 2).

Growth analysis

In order to explain differences in growth and development between the heat-tolerant and non heat-tolerant cultivars, growth analysis was car-

ried out for the secondary response variables such as RGR, NAR, LAR, SLA and LWR. The results indicated that root-zone temperature and cultivar also exerted independent influence since there was no interaction between RZT and Cultivar in both studies (Tables 3 and 4).

Relative growth rate can be separated into NAR and LAR. The mean RGR at the end of 10 days in cultivars was not significant (Table 3), but highly

significant at the end of 21 days in cultivars or RZT (Table 4). Root-zone temperature had the largest influence on RGR at the end of 10 days (Table 3). This effect may have been caused by an acclimation period and/or a higher RZT suitable for young tomato plants. In Table 4, the plateau/decline of RGR at 30°C at the end of 21 days in both cultivars may indicate that RZT of 25° ~ 30°C was optimum for tomato plants. The

Table 3. Plant growth analysis of heat-tolerant (cv. Shuki) and non heat-tolerant (cv. Sataan) tomato cultivars grown for 10 days at different root-zone temperatures.

Cultivar	RZT (°C)	RGR ($\text{g} \cdot \text{g}^{-1} \cdot \text{day}^{-1}$)	NAR ($\text{g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$)	LAR ($\text{cm}^2 \cdot \text{g}^{-1}$)	SLA ($\text{cm}^2 \cdot \text{g}^{-1}$)	LWR ($\text{g} \cdot \text{g}^{-1}$)
Shuki	15	0.25	12.9	172.5	258.8	0.56
	20	0.26	14.3	179.6	340.5	0.57
	25	0.28	15.7	164.0	335.4	0.51
	30	0.29	14.9	181.6	331.5	0.54
Sataan	15	0.19	10.0	188.6	277.6	0.69
	20	0.25	14.0	179.4	294.0	0.60
	25	0.25	11.5	202.1	395.9	0.62
	30	0.28	14.0	215.4	351.0	0.59
Significance ^z						
Cultivar		NS	NS	NS	NS	NS
RZT		NS	NS	NS	NS	NS
Cultivar $\times$ RZT		NS	NS	NS	NS	NS

^z NS : Nonsignificance at $P=0.05$.

^y RGR=Relative growth rate.
NAR=Net assimilation rate.
SLA=Specific leaf area.
LAR=Leaf area ratio.
LWR=Leaf weight ratio.

Table 4. Plant growth analysis of heat-tolerant (cv. Shuki) and non heat-tolerant (cv. Sataan) tomato cultivars grown for 21 days at different root-zone temperatures.

Cultivar	RZT (°C)	RGR ($\text{g} \cdot \text{g}^{-1} \cdot \text{day}^{-1}$)	NAR ($\text{g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$)	LAR ($\text{cm}^2 \cdot \text{g}^{-1}$)	SLA ($\text{cm}^2 \cdot \text{g}^{-1}$)	LWR ($\text{g} \cdot \text{g}^{-1}$)
Shuki	15	0.18	6.67	240.0	361.7	0.67
	20	0.21	8.88	205.3	313.1	0.66
	25	0.21	8.70	221.2	355.2	0.64
	30	0.21	8.35	221.0	352.5	0.63
Sataan	15	0.17	5.30	294.8	500.3	0.60
	20	0.20	8.22	210.2	350.9	0.60
	25	0.21	7.42	264.3	448.3	0.60
	30	0.20	6.70	309.4	509.5	0.61
Significance ^z						
Cultivar		*	**	NS	*	*
RZT		**	*	NS	NS	NS
Cultivar $\times$ RZT		NS	NS	NS	NS	NS

^z *, **, and NS indicate significance at $P=0.05$, 0.01 and nonsignificance at 0.05 respectively.

higher growth rates of 'Shuki', at this stage may have resulted from more light interception due to larger leaf area and higher photosynthetic activity. The results may also indicate that heat-tolerant cultivars have higher growth rates than non heat-tolerant ones.

Net assimilation rate or photosynthetic efficiency is defined as the rate of increase in total dry matter per unit leaf surface. Results in Table 3 suggest that RZT of 25°C was optimum for NAR of 'Shuki' and 20°C for 'Sataan' at the end of 10 days, although no significant differences were observed between cultivars. Root-zone temperature had no effect on NAR in plants grown for 10 days. Table 4 shows that, significant differences in NAR were observed between cultivars at all RZT; heat-tolerant cultivars have higher NAR than non heat-tolerant cultivars when grown at a temperature range of 20° to 30°C. Our results also indicate that, NAR of young vegetative plants (10 days) were higher than that of older ones (21 days). These results agree with those obtained by Ito (1972) and Acock et al. (1990) who reported that, as plants grew, the leaves began to shade each other from light source which decreased the intensity to which leaves were exposed. This change has the effect of lowering the value of NAR for older plants and it may explain why the younger plants were more responsive to RZT (Tables 1 and 2). The photosynthetic efficiency of leaf area of plants grown for 10 days may not have been limited by light compared to that of plants grown for 21 days. Plants grown for 10 days had smaller leaf area than those grown for 21 days.

The capacity of plants to accumulate dry matter depends to a large extent on the size of the leaf surface in relation to the overall size of the plant. Leaf area ratio may be used in assessing effects of environmental conditions on the relative size of the assimilatory part. The leaf area ratio is the product of the ratio $SLA \times LWR$. LAR in both studies, was nonsignificant between cultivars at all RZT and was numerically greater in 'Sataan', compared to that of 'Shuki' (Tables 3 and 4). SLA was significantly different between 'Shuki' and 'Sataan' during 10 days (Table 3). The results indicate that the heat-tolerant cultivar had thicker leaves as compared to that of the non heat-tolerant one. No significant difference was observed in plants grown for 21 days. Dry matter partitioning to the

leaves (LWR) was not affected by RZT and differences between cultivars were not observed in plants grown for 10 days (Table 3) but differences between cultivars were found in plants grown for 21 days (Table 4). Greater dry matter was partitioned to the leaves of 'Shuki', compared to 'Sataan'. Greater assimilate partitioning may contribute to improvement of crop productivity by increasing total carbohydrate production or by favouring assimilate transfer to the harvestable portion of the crop.

Correlations and regressions

Pairwise correlation coefficients calculated for the different growth parameters were positive and significant at all RZT (data not shown). To determine which cultivar was a better carbohydrate producer at all RZT, total plant dry weight was regressed on NAR in plants grown for 10 or 21 days. Regression coefficients between the two cultivars were significantly different at RZT of 20°C and 25°C in plants grown for 21 days (Table 5).

Table 5. Regression coefficients of total plant dry weight on net assimilation rate (NAR) for heat-tolerant (cv. Shuki) and non heat-tolerant (cv. Sataan) tomatoes grown for 10 and 21 days at different root-zone temperatures.

Cultivar	RZT °C	Plant dry weight regressed on NAR in plants grown for	
		10 days	21 days
Shuki	15	0.28	1.35
Sataan		0.21	1.07
Significance ^z		NS	NS
Shuki	20	0.16	1.67
Sataan		0.19	0.89
Significance		NS	*
Shuki	25	0.08	1.72
Sataan		0.21	0.79
Significance		NS	**
Shuki	30	0.10	1.53
Sataan		0.24	1.13
Significance		NS	NS

^z *, **, and NS : Significant at P=0.05, 0.01 and non-significant at 0.05 respectively using t-test of homogeneity for regressions df=6.

These results indicate that, 'Shuki', grown at 20°C or 25°C is a better carbohydrate producer than 'Sataan'.

Our results indicate that, the heat-tolerant cultivar is a better producer than the non heat-tolerant cultivar when exposed to high temperatures. This ability to produce more carbohydrates may be an important prerequisite for selection of tomato cultivar types for cultivation in the tropics and areas with summer conditions. The ability of heat-tolerant tomato cultivars to produce more carbohydrates may be related to their ability to produce high fruit yield compared to non heat-tolerant cultivars.

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耐暑性ならびに非耐暑性トマト品種の初期生育に及ぼす根圏温度の影響

George Oduro Nkansah・伊東 正

千葉大学園芸学部 271 千葉県松戸市

摘 要

トマトの耐暑性品種「朱喜」、ならびに非耐暑性品種「サターン」を、異なる根圏温度下で栽培し、その生育を調査した。根圏の温度は、15°, 20°, 25°, 30°Cの4水準に設定した。実験1の処理期間は10日間（播種後21～31日）とし、実験2では21日間（播種後21～42日）とした。その結果、両品種とも実験1では30°Cで、実験2では25°, 30°Cで生育が旺盛であった。「朱喜」は「サターン」に比べ、すべての根圏温度で地上部の生体重、乾物重、根の乾物重、葉面積が大

きかった。また、「朱喜」はすべての温度で「サターン」に比べてNARが高かった。生育に関する調査項目間にはいずれの品種も、すべての根圏温度で統計的な有意差が認められた。実験2における総乾物重、炭水化物含有量には20°, 25°Cの根圏温度で有意差があった。

以上の結果より、耐暑性品種「朱喜」は、いずれの根圏温度においても、通常の耐暑性しか持たない「サターン」に比べて、乾物および炭水化物の生産効率が優れるものと推察した。