Journal of Applied Botany and Food Quality 81, 26 - 28 (2007)

[1]Department of Horticulture, University of Khartoum, Sudan
[2]Institute for Horticultural Sciences, Humboldt University of Berlin, Germany

Influence of heat shock pretreatment on growth and development of tomatoes under controlled heat stress conditions*

A.H.A. Abdelmageed[1], N. Gruda[2]

(Received January 25, 2007)

Summary

The effect of a previous heat shock (HS) on growth and development of different tomato (*Lycopersicon esculentum* Mill.) cultivars under defined heat stress (HSt) conditions were investigated. Plants were grown under two day/night temperature regimes (26/20 ºC and 37/27 ºC, respectively) in growth chambers at the Department of Vegetable Crops, Institute for Horticultural Sciences, Faculty of Agriculture and Horticulture, Humboldt University of Berlin. The experiments were conducted twice and were set up in a randomized design with five replicates. The reproductive processes in tomato were more sensitive to high temperatures than the vegetative ones. The number of pollen grains, number of fruits and fruit fresh masses produced by the heat tolerant cultivars were higher than those of the heat sensitive cultivars. However, HS pretreatments had no positive effects on tomato growth and development.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is usually produced during winter in Sudan. It is grown throughout the country where irrigation water and arable land are available and is mainly grown by small holders who use relatively poor crop management practices.

Heat stress (HSt) is one of the most important constraints on crop production that adversely affects the vegetative and reproductive processes of tomato and ultimately reduces yield and fruit quality (ABDUL-BAKI, 1991; GRUDA, 2005).

Plants respond to HSt by changing their metabolic pathways to acclimatize to high temperature. Under HSt, synthesis of many proteins is repressed and some of them, which are called heat shock proteins (HSPs), start to be synthesized (VIERLING, 1991). HSPs synthesis is induced by a rapid rise in temperature of approximately 10 °C or more above the optimal growth temperature (NOVER and SCHARF, 1997). The authors reported that HSPs plays a major role in mitigating the deleterious effects of heat-induced protein denaturation. Moreover, physiological responses of plants to HSt, such as the damage of structure and the disorder of physiological metabolism, have been documented (VIERLING, 1991; BLUM et al., 2001).

Although the damage and death of cells are caused by extreme HSt, many plants can survive in otherwise lethal high-temperature regimes if they are first subjected to a pretreatment at non-lethal high temperatures (VIERLING, 1991).

Exposure of plants to elevated temperatures for short term, heat shock (HS), results in a complex set of gene expressions selective translation of mRNA-encoding HS proteins, thereby enhancing thermotolerance and improving cellular survival to subsequent HSt (NOVER et al., 1989; GONG et al., 2001).

Heat shock can be used as alternative to chemical control of vegetable seeds diseases and in the post harvest to improve the quality of vegetables (LOAIZA-VELARDE and SALTVEIT, 2001; LOAIZA-VELARDE et al., 1997). Moreover, YARWOOD (1961) demonstrated that leaves subjected to high temperatures (50 °C) for short periods (15-30 s) tolerated high temperatures (55 °C) longer than untreated leaves. In addition, LIN et al. (1984) reported that soybean seedlings exposed to 40 °C for 2 h produced HSPs and tolerate temperature of 45 °C. However, plants transferred directly from 28 to 45 °C did not produce HSPs. CHEN et al. (1982) mentioned that tomato leaf tissues of plants grown in temperature regimes below 30 °C were killed in about 15 min at 50 °C, while tomato plants increased significant tolerance when exposed to temperatures above 30 °C for 24 h.

The results of the above researchers led to the assumption that HS treatments on tomato plants would be of benefit for tomato production under high temperature conditions. Thus, this study was carried out to investigate whether or not any positive effects of HS on the vegetative growth and productive development in tomato plants cultivated under high temperature occur in order to mitigate the effect of HSt conditions. On this basis, the production of tomatoes in arid tropic areas should be possible even during the summer.

Materials and methods

Two heat tolerant and one heat sensitive cultivars of different origin were selected for this study, namely: 'Drd85 F_1', 'Kervic F_1' and 'UC 82-B', respectively. The plants were grown in the greenhouse of the Department of Vegetable Crops, Institute for Horticultural Sciences, Faculty of Agriculture and Horticulture, Humboldt University of Berlin (Latitude 52° 30` N, Longitude 13° 25` E). For more details concerning the plant cultivation, see ABDELMAGEED et al. (2003).

35 days after sowing the transplants were subjected to HS treatments by immersing the shoot system in a hot-water bath at 50 °C for 30 s. Another set from each cultivar was left as control (without HS treatment). Thereafter, the plants were divided into two sets. One set was transferred in one plant growth chamber under normal temperature (NT), 26/20 °C for 13/11 h (day/night). Another set was transferred in a second plant growth chamber under HSt conditions, 37/27 °C for 13/11 h (day/night). During the day, 550 µmol $m^{-2} s^{-1}$ irradiance from a combination of fluorescent and incandescent lights were provided for each set, on the top of the plants. Temperature and relative humidity were continuously recorded using hygrothermographs (Belfort Instrument, Baltimore, MD).

The experiments were conducted twice and were set up in a randomized design with five replicates. Plants were rotated within the plant growth chamber every week to avoid any potential positional effects.

The following parameters were recorded: leaf area (cm^2), measured with an electronic leaf area meter, type LI-COR Model 3100 (Lincoln, NE-USA), fresh and dry mass (g $plant^{-1}$) of different plant parts, number of fruits and fruit fresh mass (g $plant^{-1}$). Number of pollen grains per flower was recorded according to SATO et al. (2000) and

* The results of this paper were partly presented at the International Conference on Tropical and Subtropical Agricultural Research for Development, „Deutscher Tropentag, 2003", October 8-10, Göttingen.

ALONI et al. (2001). Leaf area ratio (*LAR*), specific leaf area (*SLA*), and leaf weight ratio (*LWR*) were calculated according to RADFORD (1967).

Statistical analysis

Collected data were analysed using the statistical software SPSS version 10.0. One-way analysis of variance (ANOVA) was used to determine the significance of variation among the different treatments. Mean separation was done by Duncan's multiple range test. A combined analysis of variance was performed. The same conclusions were drawn from each experiment and the data are presented as mean values of 10 replicates across the two experiments.

Results

Systematic and consistent differences between the plants subjected or not subjected to HS pretreatment at both temperature regimes were noticed. However, no positive effects of HS pretreatment on tomato plants under both temperatures regimes were shown.

Leaf area was generally reduced for the plants that were subjected to HS pretreatment compared to that not pretreated (Tab. 1). Similar results were found for leaf fresh and dry mass as well as stem fresh and dry mass (data not shown). At both temperature regimes, there were significant differences among the cultivars when subjected or not subjected to HS pretreatment. 'Kervic F_1' and 'Drd85 F_1' showed the better results in all plant parameters measured. Moreover, there was no significant difference in *LAR*, *SLA and LWR* (data not shown) among the different cultivars when the plants were subjected or not to HS pretreatment at both temperature regimes except for the cultivar 'UC 82-B' (Tab. 1).

Numbers of pollen grains produced and released by the plants under NT regime were higher than that produced and released under HSt conditions. However, among the cultivars at HSt conditions there were no significant differences when the plants were not subjected to HS pretreatment. 'Kervic F_1' had the highest number of pollen grains when the plants were subjected to HS pretreatment. At NT there were significant differences among the cultivars when not subjected to HS pretreatment, while 'UC 82-B' produced the lowest number of pollen grains per flower. The number of fruits per plant, and fruits fresh mass per plant showed the same trend as described above for the number of pollen grains (Tab. 1).

Discussion

High temperatures affected the vegetative and reproductive organs and tissues of tomato plants for all investigated cultivars. 'Kervic F_1' and 'Drd85 F_1' were more tolerant to high temperatures than 'UC 82-B'. This confirms earlier findings of ABDUL-BAKI (1991) and PEET et al. (1997) who reported the adverse effect of HSt on the vegetative and reproductive development in tomato plants.

The effect of HSt on reproductive development was more pronounced than on vegetative growth. Reduction in pollen production is an example of this in all cultivars at HSt conditions. KUO et al. (1986) suggested as mechanism that proline accumulation in tomato leaf tissue at high temperature leads to the depletion in the reproductive tissue, thereby seriously reducing pollen formation or viability.

In agreement with the results of SATO et al. (2000) the number of fruits per plant and fruits fresh mass in tomatoes were also reduced at high temperature regimes (Tab. 1). Flower abortion and delay of growth of newly formed fruits acted as a feedback control mechanism to prevent too generative growth of tomatoes due to a high sink-source ratio, influenced by high air temperature (DE KONING, 1989; GRUDA, 2005).

YARWOOD (1961) and Lin et al. (1984) reported positive effects of heat shock treatments on the plants that later on exposed for a short period to higher temperature. Heat shock response has been extensively studied in different plants (VIERLING, 1991). It has been known that plants induced thermotolerance and can survive under a normally lethal high temperature if they are preconditioned by mild heat shock treatment (HONG and VIERLING, 2000).

Although heat shock response has been extensively studied in plants, most of the studies have focused on the response at the whole plant level. However, the heat shock affects the development of each plant organ differently. HONG and VIERLING (2000) reported that seedling development during the very early stage shows stronger thermotolerance than the late stage.

Heat shock treatment in the present study had no positive effect on the vegetative growth and reproductive development and the hope that heat shock treatment would be beneficial for tomato plants, particularly for the reproductive development at high temperatures, was not fulfilled. On the other hand, this is in agreement with the results of ABDUL-BAKI (1991), who suggested that heat shock proteins have little to do with fruit set. Frova et al. (1991) reported that relative to the heat shock response in vegetative tissues, the response in pollen is weak, the subset of HSPs made are present in low amounts and mature pollen seems incapable of synthesizing HSPs under high

Tab. 1: Influence of heat shock pretreatment on some plant and physiological parameters of tomatoes grown under controlled conditions

Parameters	Leaf area (cm^2)		*LAR* ($cm^2\ g^{-1}$)		*SLA* ($cm^2\ g^{-1}$)		Number of pollen grains flower^{-1}		Number of fruits plant^{-1}		Fruit fresh mass (g plant^{-1})	
Treatment/Temp. (°C)	37/27	26/20	37/27	26/20	37/27	26/20	37/27	26/20	37/27	26/20	37/27	26/20
Kervic F_1 (cont.)	851.3 bc	1516.6 a	66.6 c	101.4 a	100.6 c	149.3 a	57.0 a	75.0 a	2.0 ab	7.0 a	14.5 a	46.3 a
Kervic F_1	838.9 bc	1126.6 b	92.7 b	79.1 bc	143.5 b	113.8 b	69.0 a	72.0 ab	2.5 a	7.5 a	17.8 a	50.0 a
Drd85 F_1 (cont.)	910.1 b	1077.5 b	74.5 c	72.3 c	118.3 c	108.7 b	61.0 a	68.0 b	1.8 ab	6.0 a	10.7 b	40.5 ab
Drd85 F_1	678.1 c	1046.9 b	63.1 c	86.3 abc	98.9 c	129.9 ab	60.0 a	74.0 ab	2.3 a	6.5 a	11.5 ab	37.5 ab
UC82-B (cont.)	1266.2 a	1212.8 b	130.4 a	83.5 bc	171.7 a	111.7 b	37.0 c	57.0 c	0.0 b	6.5 a	0.0 b	22.0 c
UC 82-B	862.8 bc	1238.9 b	90.7 b	92.4 ab	118.5 c	122.3 b	48.0 b	60.0 c	0.0 b	6.0 a	0.0 b	30.7 bc
Mean	901.2	1203.2	86.4	85.9	125.3	122.6	55.3	67.7	1.4	6.58	9.08	37.8
S.E.	35.68	31.17	5.03	2.75	5.95	4.04	2.05	1.38	0.21	0.18	1.36	1.87

cont. = control (without heat shock pretreatment), *LAR* = Leaf area ratio, *SLA* = specific leaf area. Means followed by the same letter(s) within each column are not significantly different at $P \leq 0.05$, according to Duncan multiple range test.
n = 10 plants

temperature conditions.

In addition, the plants in the present study were well irrigated. KIMPEL and KEY (1985) reported that HSPs in soybean might accumulate under hot field conditions for plants subjected to drought but not for irrigated plants.

Under field conditions in Sudan other factors, such as low relative humidity, insect and virus diseases as well as soil properties have to be considered as well. Optimization of microclimate could be very important to ensure a good performance of new tolerant varieties cultivated during the summer in Sudan.

Acknowledgments

The German Academic Exchange Services (DAAD) is acknowledged for providing a scholarship for the first author.

References

ABDELMAGEED, A.H.A., GRUDA, N., GEYER, B., 2003: Effect of high temperature and heat shock on tomato (*Lycopersicon esculentum* Mill.) genotypes under controlled conditions. International Conference on Tropical and Subtropical Agricultural Research for Development, „Deutscher Tropentag", October 8-10, Göttingen. www.tropentag.de.

ABDUL-BAKI, A.A., 1991: Tolerance of tomato cultivars and selected germplasm to heat stress. J. Amer. Soc. Hort. Sci. 116, 1113-1116.

ALONI, B., PEET, M.M., PHARR, M., KARNI, L., 2001: The effect of high temperature and high atmospheric CO_2 on carbohydrate changes in bell pepper (*Capsicum annum*) pollen in relation to its germination. Physiol. Plantarum 112, 505-212.

BLUM, A., KLUEVA, N., NGUYEN, H.T., 2001: Wheat cellular thermotolerance is related to yield under heat stress. Euphytica 117, 117-123.

CHEN, H-H., SHEN, Z-Y., LI, P.H., 1982: Adaptability of crop plants to high temperature stress. Crop Sci. 22, 719-725.

DE KONING, A.N.M., 1989: The effect of temperature, fruit load and salinity on development rate of tomato fruit. Acta Hort. 248, 329-336.

FROVA, C., TARAMINO, G., OTTAVIANO, E., 1991: Sporophytic and gametophytic heat shock protein synthesis in Sorghum bicolor. Plant Sci. 73, 35-44.

GONG, M., CHEN, B., LI, Z.G., GUO, L.H., 2001: Heat-shock-induced cross adaptation to heat, chilling, drought and salt stress in maize seedlings and involvement of H_2O_2. J. Plant Physiol. 158, 1125-1130.

GRUDA, N., 2005: Impact of environmental factors on product quality of greenhouse vegetables for fresh consumption. Crit. Rev. Plant Sci. 24, 227-247.

HONG, S.-W., VIERLING, E., 2000: Mutants of Arabidopsis thaliana defective in the acquisition of tolerance to high temperature stress. Proc. Nat. Acad. Sci. USA 97, 4392- 4397.

KIMPEL, J.A., KEY, J.L., 1985: Presence of heat shock mRNA as in field grown soybeans. Plant Physiol. 79, 672-678.

KUO, C.G., CHEN, H.M., MA, L.H., 1986: Effect of high temperature on proline temperature content in tomato floral buds and leaves. J. Amer. Soc. Hort. Sci. 111, 746-750.

LIN, C., ROBERT, J.K., KEY, J.L., 1984: Acquisition of thermotolerance in soybean seedlings. Synthesis and accumulation of heat shock proteins and their cellular localization. Plant Physiol. 79, 672-678.

LOAIZA-VELARDE, J.G., SALTVEIT, M.E., 2001: Heat shocks applied either before or after wounding reduce browning of lettuce leaf tissue. J. Amer. Soc. Hort. Sci. 126, 227-234.

LOAIZA-VELARDE, J.G., THOMAS-BARBERA, F.A., SALTVEIT, M.E., 1997: Effect of intensity and duration of heat-shock treatments on wound induced-phenolic metabolism in iceberg lettuce. J. Amer. Soc. Hort. Sci. 122, 873-877.

NOVER, L., SCHARF, K.D., 1997: Heat stress proteins and transcription factors. Cell. Molec. Life Sci. 53, 80-103.

NOVER, L., SCHARF, K.D, NEUMANN, D., 1989: Cytoplasmic heat shock granules are formed from precursor particles and are associated with a specific set of mRNAs. Molec. Cell. Biol. 9, 1298-1308.

PEET, M.M., WILLITS, D.H., GARDNER, R., 1997: Response of ovule development and post-pollen production processes in male sterile tomatoes in chronic, sub-acute high temperature stress. J. Exp. Bot. 48, 101-111.

RADFORD, P.J., 1967: Growth analysis formulae- their use and abuse. Crop Sci. 7, 171-175.

SATO, S., PEET, M.M., THOMAS, J.F., 2000: Physiological factors limit fruit set of tomato (*Lycopersicon esculentum* Mill.) under chronic, mild heat stress. Plant Cell Environ. 23, 719-726.

VIERLING, E., 1991: The roles of heat shock proteins in plants. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42, 579-620.

YARWOOD, C.E., 1961: Acquired tolerance of leaves to heat. Science 134, 941-942.

Address of the authors:

Dr. Adil H.A. Abdelmageed, Department of Horticulture, Faculty of Agriculture, University of Khartoum, 13314 Shambat, P.O. Box 32, Khartoum North, Sudan. Email: aadilhassan@hotmail.com

Dr. habil. N. Gruda, Institute for Horticultural Sciences, Faculty of Agriculture and Horticulture, Humboldt University of Berlin, D-14163 Berlin, Germany. Email: nazim.gruda@rz.hu-berlin.de