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Effect of High Temperature and Heat Shock on Tomato (*Lycopersicon esculentum* Mill.) Genotypes under Controlled Conditions

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Abstract

Tomato (*Lycopersicon esculentum* MILL.) is usually produced during the winter period in Sudan. In summer due to high temperatures, monthly average temperatures are between 31 to 35°C, a shortage of tomatoes is common. General environmental changes, especially global warming, may have an adverse effect on crop production in Sudan.
The objective of this study is (i) to investigate the effect of heat stress on vegetative and productive development of heat sensitive and tolerant tomato genotypes, (ii) to compare the growth and development of different genotypes under defined heat stress conditions (intensity and duration) as well as (iii) to investigate if there are any positive effects of heat shock treatments to increase heat tolerance of tomatoes.
Different experiments were carried out under simulated temperature conditions in plant growth chambers at the Humboldt University of Berlin as well as under field conditions at the University of Khartoum, Sudan. Here only results obtained from experiments under controlled condition are presented. Plant height, leaf area, fresh and dry weight of leaves, stem and roots, number of clusters, number of flowers as well as the number of pollen grains per microscopic field were recorded.
The reproductive processes in tomato were more sensitive to high temperatures than the vegetative ones. The number of pollen grains produced by the heat tolerant genotypes, were higher than the numbers produced by the heat sensitive genotypes.
However, under field condition around Khartoum, Sudan other factors such as low relative humidity, insect and virus diseases as well as soil physical properties have also to be considered. Optimization of microclimate could be very important to ensure a good performance of new tolerant varieties cultivated in summer periods in Sudan.

Keywords: Heat stress, heat shock, pollen grains, summer period, Sudan, tolerant genotypes, tomato.

Introduction

Tomato is one of the most popular and widely consumed vegetables grown worldwide. Popularity of the crop stems from its acceptable flavour, nutritive value (high in vitamin C and A), the short life cycle, and the high productivity. In the Sudan tomato ranks second to onion among vegetable crops based on cultivated area. It is grown throughout the country

where irrigation water and arable land are available and is mainly grown by small holders who employ relatively poor crop management practices.
In the arid tropical region of the Sudan the high summer and the low relative humidity limits the production of tomato to the cooler period of the year. To extend the season of production it is necessary to know the nature of growth, flowering and fruiting of the plant in relation to climatic conditions (Abdalla and Verkerk, 1968). Heat stress (HS) is one of the most important constraints on crop production and adversely affects the vegetative and reproductive processes of tomato and ultimately reduces yield and fruit quality (Abdul-Baki, 1991). Moreover, a number of explanations have been offered for the poor reproductive performance of tomatoes at high temperatures. These include reduced or abnormal pollen production, abnormal development of the female reproductive tissues, hormonal imbalances, low levels of carbohydrates, and lack of pollination (Abdalla and Verkerk, 1968; Peet et al., 1997). Dinar and Rudich (1985) reported that in tomato plants, high temperatures affect several physiological and biochemical processes dealing finally with yield reduction. Possible biochemical and/or physiological processes affected by temperature are photosynthetic enzyme activity, membrane integrity, photophosphorylation, and electron transport in chloroplast, stomatal conductance to CO_2 diffusion and photoassimilate translocation.

Plants respond to HS by changing their metabolic pathways. Under HS, synthesis of most proteins is repressed and some proteins, which are called heat shock proteins (HSPs), start to be synthesised (Vierling, 1991). Heat shock can be used as control of some plant diseases as alternative for chemical control of vegetable seeds diseases (Jahn et al., 2000), as well as for post harvest, to improve the quality of vegetables (Loaiza-Velarde and Saltveit, 2001 and 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. Also, Lin et al. (1984) reported that soybean seedlings exposed to 40 °C for 2 h produced HSPs and tolerate temperature of 45 °C, but plants transferred directly from 28 to 45 °C did not produce HSPs. Chen et al. (1982) mentioned that tomato plants grown in temperature regimes below 30 °C their leaf tissues were killed in about 15 min at 50 °C, while tomatoes 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 heat shock treatments on tomatoes plants would be of benefit for tomato production under high temperature conditions.

The objectives of this study are (i) to investigate the effect of HS on vegetative and productive development of different tomato genotypes under defined conditions (intensity and duration) as well as (ii) to investigate if there are any positive effects of heat shock treatments to increase heat tolerance of tomatoes.

Materials and Methods

Two heat tolerant cultivars and one less heat tolerant cultivar were selected for this study (Table 1). They were sown in flat trays filled with a standard peat mixture substrate for germination (C200) from Stender AG, Germany. Substrate contains 0.5 g/l NPK fertiliser and had an electrical conductivity of 0.25 and pH 5.0-6.0 ($CaCl_2$). 15 days after sowing (DAS), the seedlings were transplanted into 9 cm containers filled with standard peat mixture substrate (B700) from the same company. Substrate contains 1g/l NPK fertiliser and had an electrical conductivity of 0.53 and pH 5.8 ($CaCl_2$).

Table 1: Tomato cultivars used in this experiment

Cultivars	Heat susceptibility	Company
UC 82-B	Less heat tolerant	Peto seed company, USA
Drd85 F_1	Heat tolerant	De Ruiter Seeds, the Netherland
Kervic F_1	Heat tolerant	De Ruiter Seeds, the Netherland

The transplants were grown in the greenhouse of the Department of Vegetable Crops, Institute for Horticultural Sciences, Faculty of Agriculture and Horticulture, Humboldt-Universität zu Berlin (Latitude 52° 30` N, Longitude 13° 25` E). Tomato plants were watered daily. Twice a week 40 ml of 0.2% soluble liquid fertiliser (12N-4P-6K) were applied to each pot. Tomato transplants were transplanted at 30 DAS into 14 cm diameter pots filled with same substrate. 35 DAS the transplants were subjected to heat shock 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 heat shock treatment). Afterwards the plants were divided into two sets, one set was transferred in one plant growth chamber under normal temperature (NT), 26/20 °C (day/night) for 13/11 h (light/dark). Another set was transferred in a second plant growth chamber under HS condition, 37/27 °C (day/night) temperatures, 13/11 h (light/dark). On the day a 550 µE m^{-2} s^{-1} irradiance from a combination of fluorescent and incandescent lights were provided for each set. Completely randomised design was followed for trial. Experiment was conducted twice: with Kervic F_1, Drd85 F_1 and UC 82-B in first experiment and with UC 82-B and Drd85 F_1 in a second one. Here only the results of the first experiment were presented.

The following parameters were recorded:
Plant height (cm) from substrate surface to the vegetative point, leaf area (cm^2) with an electronic leaf area, type Li-3100 (Licor, NE-USA), number of flowers per plant, leaf fresh and dry weight (g $plant^{-1}$) as well as stem fresh and dry weight (g $plant^{-1}$).
Number of pollen grains per field was determined as follows: flowers samples at anthesis were taken from the first four inflorescence twice a week for each cultivar. Each flower at the stage of anthesis was collected into a 2 ml microtube and homogenised after adding 200 µl of germinating solution according to Aloni et al. (2001). Drops of the solution with the released pollen grains were mounted on hemocytometer slide and counted with a light microscope 70x per field according to Peet and Bartholemew (1996) and Sato et al. (2000).

Data analysis
Collected data were analysed using the statistical software SPSS version 9.0. One-way analysis of variance (ANOVA) was used to determine differences among treatments. Mean separation was done by Tukey test. In tables and figures, means with same letters indicate no significant differences between treatments.

Results

There were systematic and consistent differences between the plants that subjected and not subjected to heat shock treatment at both temperature regimes. The results of the present study indicated that there was no positive effect of heat shock treatment on tomato plants under both temperatures regimes.
Plant height was generally reduced for the plants that subjected to heat shock treatment compared to that not subjected to heat shock treatment. At both temperature regimes, there were significant differences among the cultivars when subjected or no subjected to heat shock treatment. Kervic F_1 and Drd85 F_1 had the highest and UC 82-B the lower plant height.

Similar results were obtained for stem-fresh and dry weight (Table 2). Among the cultivars, Kervic F_1 and Drd85 F_1 had the larger stem fresh weight at both temperature regimes.

Generally, larger leaf-fresh and dry weight were found by plants that not subjected to heat shock treatment compared to that subjected to heat shock treatment at both temperature regimes (Table 2). Similar results were found for leaf area. Plants not subjected to heat shock treatment had tendency higher leaf area compared to that subjected to heat shock treatment at both temperatures regimes. Among cultivars there were no significant differences when plants subjected to heat shock treatment at both temperature regimes (Fig. 1).

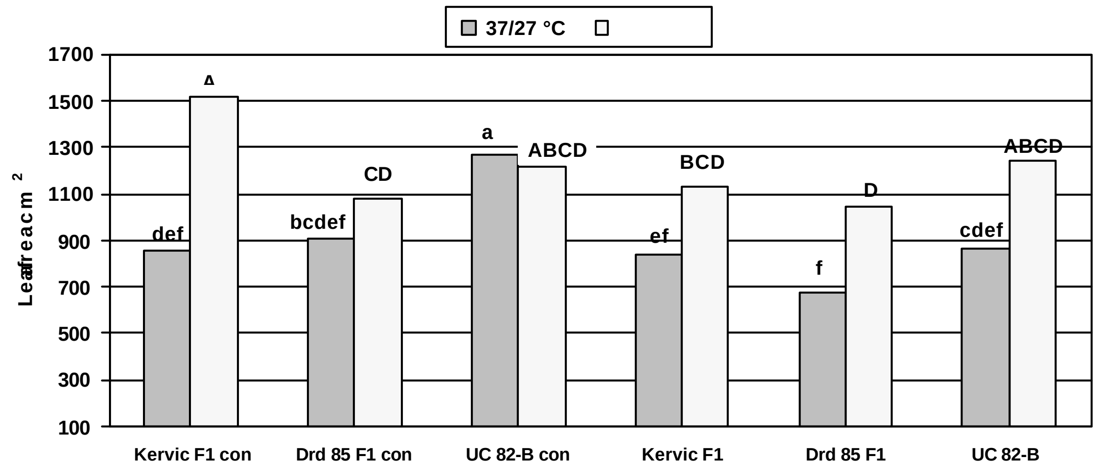

Fig. 1: Effect of heat shock and heat stress on leaf area (cm^2).
Differences between bars labeled by the same letter are not significant (P<0.05).
(con. = control, without heat shock treatment)

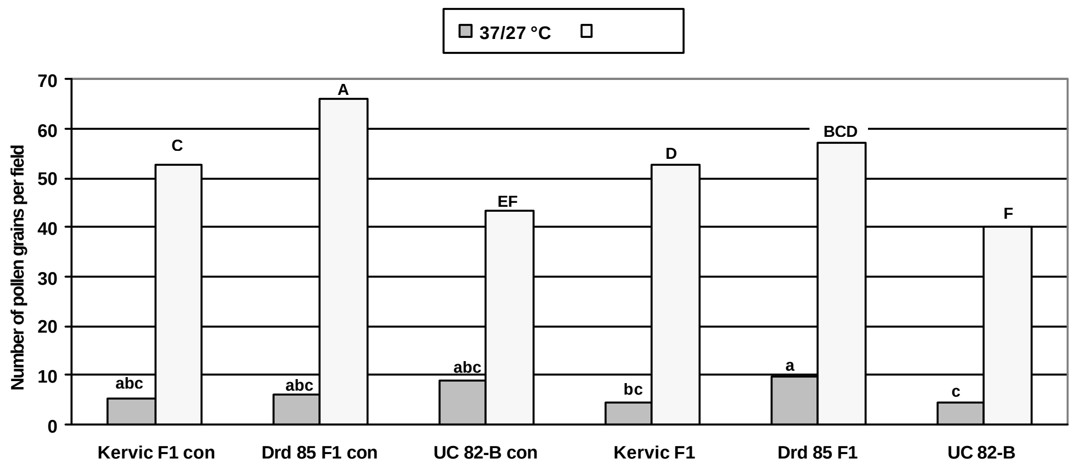

Fig. 2: Effect of heat shock and heat stress on number of pollen grains per microscopic field.
Differences between bars labeled by the same letter are not significant (P< 0.05)
(con. = control, without heat shock treatment)

Fig. 2 shows the number of pollen grains per microscopic field. Number of pollen grains produced and released by the plants under NT conditions were always higher than those produced and released under HS conditions. Among the cultivars at HS conditions there were no significant differences when the plants were not subjected to heat shock treatment. Drd85 F_1 had the highest numbers of pollen grains when the plants were subjected to heat shock treatment. At NT there were significant differences when not subjected to heat shock treatment, while UC 82-B have with approx. 39 pollen grains per microscopic field the lower one.

Discussion

High temperature condition strongly affected the vegetative and reproductive organs and tissues of tomato plants for all cultivars. For the most of vegetative parameters the most affected cultivar was UC 82-B. Kervic F1 and Drd85 F1 were more tolerant to high temperatures than UC 82-B.

This confirms earlier findings of Abdalla and Verkerk (1968), Abdul-Baki (1991), Peet et al. (1997) and El Ahamdi and Stevens (1979) and, that revealed the adverse effect of HS on the vegetative and reproductive development in tomato plants.

The effect of HS was more pronounced in the reproductive as in vegetative development (compare the result of Fig. 2 with the results of Fig. 1 and Table 2). Kuo et al. (1986) suggest as mechanism proline accumulation in tomato leaf tissue at high temperature. Proline thus causes the depletion of proline in the reproductive tissue, thereby seriously reducing pollen formation or viability.
In our study pollen production was reduced in all cultivars at HS conditions. However, Kervic F1 and Drd85 F1 seem to be tolerant to HS conditions and produced a higher number of pollen grains than the less heat tolerant one, UC 82-B.

Yarwood (1961) and Lin et al. (1984) reported positive effects of heat shock treatments on the plants that later on expose for a short period of time to higher temperature. Heat shock treatment in the present study have no positive effect on the vegetative 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. This is in agreement with Abdul-baki (1991) who observed and suggested that heat shock proteins have a little to do with reproductive stage. Also the plants in our experiments were well irrigated. Kimpel and Key (1985) reported that HSPs in soybean might accumulate under hot field conditions for drought plants 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 physical properties have also to be considered. Optimization of microclimate could be very important to ensure a good performance of new tolerant varieties cultivated in summer periods in Sudan.

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Table 2: Effect of heat shock and heat stress on some plant parameters.

Parameters	Plant height (cm)		Stem fresh weight (g $plant^{-1}$)		Stem dry weight (g $plant^{-1}$)		Leaf fresh weight (g $plant^{-1}$)		Leaf dry weight (g $plant^{-1}$)	
Treatments	**37/27 °C**	**26/20 °C**	**37/27 °C**	**26/20 °C**	**37/27 °C**	**26/20 °C**	**37/27 °C**	**26/20 °C**	**37/27 °C**	**26/20 °C**
Kervic F_1 con.	69.3 a*	65.7 b	31.93 abc	36.18 a	4.31 abc	4.79 a	58.92 bcdef	62.64 a	10.18a	8.40 a
Drd 85 F_1 con.	64.7 ab	78.0 a	35.05 a	31.10 abc	5.15 a	4.53 a	58.59 cdef	50.29 ef	9.94a	7.70 ab
UC 82-B con.	49.7 cd	37.7 cd	24.09 de	24.09 de	3.66 cd	2.33 cd	83.27 a	51.96 bcdef	10.86a	7.38 ab
Kervic F_1	66.7 a	66.0 ab	30.24 bc	25.99 cd	4.26 abcd	3.20 bcd	57.79 def	50.50 def	9.92a	5.85 b
Drd 85 F_1	57.7 bc	77.7 ab	27.68 cd	30.49 bc	3.92 bcd	4.04 ab	42.33 f	46.89 f	8.09b	7.00 ab
UC 82-B	42.0 d	36.3 d	20.40 e	20.40 e	3.27 d	2.28 d	55.05 ef	51.50 cdef	10.12a	7.36 ab

*Means with same letters in the columns are not significantly different ($P<0.05$).
(con. = control, without heat shock)