Tolerance to high temperature in F₅ inbred lines of tomato

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ABSTRACT

High temperatures in the growing tomato have caused a reduction in fruit set and consequently productivity. This work aimed to evaluate F₅ lines of tomato to fruit set and high temperature tolerance in two culture environments. Two experiments were carried out, one in cultivation in greenhouse and the other in the field conditions, from February to June 2012. We evaluated 20 lines F₅ of tomato, originating from the segregation of hybrid SE 1055 F₅, developed for the hot and humid conditions, with resistance to Fusarium oxysporum f.sp. lycopersici race 2, the tomato mosaic virus (ToMV), the Verticilium dahliae and geminivirus (TYLCV) and the control cultivar Yoshimatsu and own hybrid SE 1055 F₅. The experiment was performed in a randomized blocks design with 22 treatments, four replications and plots with two plants. We evaluated the total number of fruits per plant (NTF/PL), mass of unmarketable fruits per plant (MFNC/PL), fruit set (PEG), mass of marketable fruits per plant (MFC/PL) and yield of marketable fruits (REND). In the greenhouse were recorded higher temperatures and lower luminosity than in field cultivation. Lines 08, 12 and 13 showed higher fruit set in a greenhouse, being more suitable for cultivation at high temperatures. In the field, the lines 06 and 08 showed that marketable fruit production did not differ from ‘Yoshimatsu’. Comparing the field experiment average with the average of greenhouse, a higher fruit set and a higher mass of marketable fruits per plant was achieved in field.

Keywords: Solanum lycopersicum, breeding, fruit set.

Tolerância a altas temperaturas em linhagens F₅ de tomateiro

As temperaturas elevadas nas áreas de cultivo de tomateiro têm causado redução no pegamento de frutos e consequentemente na produtividade. Este trabalho teve como objetivo avaliar linhagens F₅ de tomateiro quanto ao pegamento de frutos e tolerância a altas temperaturas em dois ambientes de cultivo. Foram conduzidos dois experimentos, um no cultivo em casa de vegetação e outro no campo, de fevereiro a junho de 2012. Foram avaliadas 20 linhagens F₅ de tomateiro, oriundas da segregação do híbrido SE 1055 F₅, desenvolvido para condições quentes e úmidas, com resistência a Fusarium oxysporum f.sp. lycopersici race 2, a mosaic virus (ToMV), a Verticilium dahliae e geminivirus (TYLCV) e o próprio híbrido SE 1055 F₅. O delineamento experimental adotado foi em blocos ao acaso, com 22 tratamentos, quatro repetições e parcela útil com duas plantas. Foram avaliados o número total de frutos por planta (NTF/PL), pegamento de frutos (PEG), massa de frutos não comerciais por planta (MFNC/PL), massa de frutos comerciais por planta (MFC/PL) e rendimento de frutos comerciais (REND). Em casa de vegetação foram registradas maiores temperaturas e menor luminosidade em relação ao cultivo no campo. As linhagens 08, 12 e 13 apresentaram maior pegamento de frutos em casa de vegetação, mostrando-se mais indicadas para o cultivo em temperaturas elevadas. No campo, as linhagens 06 e 08 se destacaram na produção de frutos comerciais, não diferindo da ‘Yoshimatsu’. Observaram-se em relação à média geral dos ambientes, maiores PEG e MFC/PL das linhagens quando estas foram conduzidas no cultivo em campo.

Keywords: Solanum lycopersicum, melhoramento genético, pegamento de frutos.

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Intergovernmental Panel on Climate Change (IPCC) announced that the global average temperature could rise 2.6°C by 2050 compared to 1990 and 5.8°C by 2100 (IPCC, 2012a). According to the IPCC (2012b) report this global average temperature rise can cause significant changes in the natural ecosystems, such as higher frequency of drought and increases in heavy rainfall. Many researchers have been studying this rise in the temperature and reported its effect as a serious threat to global agricultural production (Sato et al., 2006; Kamel et al., 2010).

In the latest years, all over the world, an increase in planting of various crops has been noticed, including tomato, in high temperature regions or environments, either in the field or greenhouse. The stress caused by high temperatures in these environments causes a reduction in the number of pollen grains in susceptible tomato genotypes, reducing fruit set (Firon et al., 2006).

The temperature considered optimal for the production of tomato ranges from 21 to 28°C during the day and from 15 to 20°C during the night. Considering that the night temperature is also considered a limiting factor to good fruit set in tomato (Filgueira, 2008).

Traits such as pollen grains viability, osmotic pressure, production of fruits per plant and fruit set are suggested by some authors (Abdul-Baki & Stommel, 1995; Hanson et al., 2002; Saeed et al., 2007) for evaluation and selection of heat tolerant genotypes. For this, the use of experiments in field and greenhouse still stands as the most appropriate
methodology to evaluate the tolerance to heat.

Considering that the increase of growing tomato in high temperature environments, the elucidation of these mechanisms of protection and the identification of the genes related to the tolerance have been presented as the best strategy for selection of heat tolerant genotypes (Bita et al., 2011).

Similarly, tomato accessions collected in sites presenting natural high temperatures conditions can constitute important sources of genetic variability for heat tolerance (Giordano et al., 2005).

The choice of commercial hybrids to form the base population which will be worked is justified for being already tested in various environments, resistance genes to important diseases of tomato and for showing great proportion of favorable loci previously set (Bison et al., 2003; Carvalho et al., 2004; Amorim & Souza, 2005; Ferreira et al., 2009).

Given the above, this work aims to identify and select F₁ inbred lines of tomato concerning the fruit set and tolerance to high temperatures in two growing environments: greenhouse and field.

**MATERIAL AND METHODS**

Two experiments were carried out, one in a greenhouse and the other in the field, conducted at Universidade Federal Rural de Pernambuco, Recife, Pernambuco state, Brazil, from February to June 2012. In figures 1, 2 and 3 are shown the climate characterization of the temperature, humidity and solar radiation, during the experiments, for both growing environments.

Randomized block design with four replications was used. Each plot consisted of two plants, spaced at 0.6 m in the row and 1.0 m between rows. In both experiments, 20 lines F₁ of tomato, originating from the segregation of hybrid SE 1055 F₀, and control treatment: cultivar Yoshimatsu, resistant to bacterial wilt and tolerant to high temperatures, and the hybrid SE 1055 F₀, itself.

The lines were obtained from F₂ plants, originating from hybrid SE 1055 F₀, developed for hot and humid conditions by East-West Seed Company. SSD method for the advancement of the segregating generations was used, being recorded 180 lines in the F₁ generation. Hybrid ‘SE 1055 F₁’ shows resistance to Fusarium oxysporum f. sp. lyceopersici race 2, to tomato mosaic virus (ToMV), Verticillium dahliae and geminivirus (TYLCV). In order to represent 180 lines, 20 of these lines were sampled, randomly, to represent the random model for the genotypes.

For the experiment in the greenhouse, the sowing was performed in polystyrene trays of 128 cells containing Plantmax® substrate. When the seedlings have developed four definitive leaves, they were transplanted to plastic pots with a capacity of 8.5 L, containing washed powdered coconut peels.

Forty days after sowing, another sowing was done, the same way of the first one, for the production of seedlings for the experiment in the field, where they were transplanted to bags of cultivation, called slabs, made of polyethylene, 15 cm in diameter and 2.0 m in length. The bags, filled with washed coconut powder, were distributed in six seedbeds covered with mulching, double face, black and white. Each seedbed received 18 bags of cultivation, divided into two rows of nine bags, each block consisting of three rows of slabs. In each bag, two holes were opened, spaced at 0.6 m one from the other, forming a plot, consisted of two plants.

Mineral nutrition and water requirements of plants, for both experiments, were supplied by nutrient solution, with concentrations of N, P, K, Ca, Mg, S, Cl of 187.5, 57.5, 354, 190, 50, 99 and 70.5 mg L⁻¹, respectively and micronutrients Fe, Mn, Zn, Cu, B and Mo, 3.375, 0.875, 0.175, 0.07, 0.417 and 0.075 mg L⁻¹, respectively. The irrigation system used was dripping, with a 2 L h⁻¹ emitter, three times a day. The irrigation time varied according to the crop water requirement, at different growth stages. These two methods of planting, in pots and slabs, are called hydroponics with substrate.

The plants were tutored, vertically, with plastic ribbon, stuck in wires stretched horizontally. As the plants developed, the sprouting of lateral branches was done until the first cluster.

Preventive insecticide applications were made for pest control: The whitefly (Bemisia argentifolii), white mite (Polyphagotarsonemus latus), greenbug (Myzus persicae), thrips (Frankliniella schultzei) and the tomato fruit small driller (Neoleucinodes elegantalis).

The evaluated traits were total number of fruits per plant (NTF/PL); fruit set (PEG), relationship between number of commercial fruits and total number of flowers in the first three floral clusters; mass of unmarketable fruits per plant (MFNC/PL); mass of commercial fruits per plant (MFC/PL) and yield of marketable fruits (REND), relationship between mass of marketable fruits and total mass of fruits. Eight harvests were performed, from April to June 2012, in the experiment conducted in the greenhouse. In the field experiment, six harvests were performed, from May to June 2012.

Six descriptors for tomato indicated by Ministry of Agriculture, Livestock and Food Supply were used for morphologic traits. Thus, ten fruits of each genotype were taken, obtained in the two first harvests, and the following descriptors were observed: (a) fruit shape (flattened, rounded, elliptical, rectangular, cylindrical, cordate and piriformis); (b) number of locules per fruit (fruits cut transversely to observation); (c) fruit color [using a scale ranging from 1 to 4 (1= green; 2= yellowish red; 3= orange red; 4= red and 5= intense red), visually determinated]; (d) green shoulder (presence or absence of the characteristics in the fruits); (e) pedicle abscission (visual assessment, considering the presence or absence in clusters) and (f) growth habit (considering the number of leaves until the first inflorescence, whether or not the branch ended in an inflorescence and the plant height).

The statistical analysis of the traits was performed by the program Genes, v.3.0 (Cruz, 2006). From the experimental data, the individual analysis of variance was conducted in each environment studied in order to verify if the average squares were
and if the two environments could be included in the joint analysis without restrictions. When the assumptions were met, the joint analysis was performed using the following model: \( Y_{ijk} = m + G_i + B/A_{jk} + A_j + G_{Ai} + E_{ijk} \), where \( Y_{ijk} \) = observation of the plot; \( m \) = overall mean; \( G_i \) = effect of the \( i \)th treatment; \( B/A_{jk} \) = effect of \( A_{jk} \)-th block; \( A_j \) = effect of the \( j \)th environment and \( E_{ijk} \) = experimental error. Then, the Scott Knott test (\( p<0.5 \)) was used, to compare the averages, and from the test, the performance of \( F_5 \) inbred lines in two environments and in each environment was analyzed.

**RESULTS AND DISCUSSION**

In Table 1 is shown the morphological characterization made from the tomato descriptors for type of growth, presence of green shoulder in the fruits, abscission of the pedicel, color of the fruit, fruit shape and number of locules, suitable for characterization and registration of cultivars by the Ministry of Agriculture, Livestock and Supply-MAPA (BRASIL, 2005).

For green shoulder, most lines and control treatments did not show this characteristic, with exception of lines 13 and 19 (Table 1). For fresh tomatoes, the appearance of the fruit is a determining factor in market value to the consumer, based, mainly, on color, shape and absence of undesirable morphological traits. The presence of green shoulder in the fruits is one of these undesirable traits which alters the color of ripe fruits, leaving them orange red or yellowish, depreciating the fruit.

In order to grow fresh tomato, indeterminate type cultivars, as well as, semi-determinated and determinated type can be used. In Table 1, lines of the three types of growth were verified, but a predominance of semi-determinated type was observed.

For number of locules, shape and color of the fruits, most lines fit the commercial standard with red fruits, rounded or elliptical, bi or trilocular (Table 1).

The average values of the maximum temperature during the whole period of the experiment in the greenhouse and in the field were 37.46 and 32.55°C, respectively (Figures 1 and 2). The ideal temperature for the vegetative development is around 18-28°C (Saeed et al., 2007), however, some tomato genotypes can tolerate high temperatures with a higher amplitude.

The average values of the minimum temperature, in the greenhouse and in the field, were 22.53 and 23.5°C during the whole period of the experiment. These values are far above the ideal for the crop, which is 15 to 18°C (Rudick et al., 1977). The radiation was not considered a limiting factor for the development of the plants in the field. However, in the greenhouse the average of daily solar radiation during the whole

**Table 1.** Characterization of \( F_5 \) lines for the main morphological descriptor according to the Ministry of Agriculture, Livestock and Supply (MAPA) [caracterização dos genótipos para as principais características morfológicas segundo o descritor do Ministério da Agricultura Pecuária e Abastecimento (MAPA)]. Recife, UFRPE, 2012.

| Genotype | Growth habit | Green shoulder | Pedicel abscission | Fruit color | Fruit shape | Locules (n°) |
|----------|--------------|----------------|-------------------|-------------|-------------|--------------|
| 01       | semi-determinated | -              | -                 | red         | round       | 3            |
| 02       | semi-determinated | -              | -                 | red         | cordiform   | 2            |
| 03       | semi-determinated | -              | -                 | red         | round       | 2            |
| 04       | determinated   | -              | -                 | red         | elliptical  | 2            |
| 05       | determinated   | -              | -                 | red         | elliptical  | 2            |
| 06       | semi-determinated | -              | -                 | red         | elliptical  | 2            |
| 07       | semi-determinated | -              | -                 | red         | round       | 2            |
| 08       | semi-determinated | -              | -                 | red         | round       | 2            |
| 09       | determinated   | -              | no                | red         | elliptical  | 2            |
| 10       | semi-determinated | -              | -                 | red         | round       | 2            |
| 11       | semi-determinated | -              | -                 | red         | elliptical  | 2            |
| 12       | semi-determinated | -              | -                 | red         | elliptical  | 2            |
| 13       | semi-determinated | yes            | -                 | orange red  | round       | 2            |
| 14       | semi-determinated | -              | -                 | red         | round       | 2            |
| 15       | indeterminated | -              | -                 | red         | round       | 2            |
| 16       | determinated   | -              | -                 | red         | elliptical  | 2            |
| 17       | semi-determinated | -              | -                 | red         | round       | 2            |
| 18       | determinated   | -              | -                 | red         | elliptical  | 2            |
| 19       | indeterminated | yes            | -                 | orange red  | round       | 2            |
| 20       | indeterminated | -              | no                | red         | elliptical  | 2            |
| SE 1055 F₁ | semi-determinated | -              | -                 | red         | round       | 2            |
| Yoshimatsu | indeterminated | -              | -                 | red         | flattened   | >3           |
Tolerance to high temperature in F$_1$ inbred lines of tomato

Table 2. Estimates of the average of total number of fruits per plant (NTF/PL), fruit set (PEG), mass of unmarketable fruits per plant (MNFC/PL), mass of marketable fruits per plant (MFC/PL) and yield of fruits (REND), evaluated in two environments [estimativas das médias para número total de frutos por planta (NTF/PL), pegamento de frutos (PEG), massa de frutos não comerciais por planta (MNFC/PL), massa de frutos comerciais por planta (MFC/PL) e rendimento de frutos (REND), avaliados em dois ambientes]. Recife, UFRPE, 2012.

| Genotypes | MFC/PL (kg) | NTF/PL | PEG (%) | MNFC/PL (kg) | REND (%) |
|------------|-------------|--------|---------|--------------|----------|
| Green house | Field | Green house | Field | Green house | Field | Green house | Field | Green house | Field |
| 01 | 1.50 Bb | 2.60 Ac | 121.63 Aa | 57.50 Ba | 39.25 Bc | 72.25 Aa | 0.73 Ab | 0.31 Ba | 66.25 Bc | 88.75 Aa |
| 02 | 1.34 Bb | 2.84 Ac | 60.50 Ac | 51.87 Aa | 30.25 Bc | 73.25 Aa | 0.36 Aa | 0.20 Aa | 69.25 Bc | 91.50 Aa |
| 03 | 1.33 Ab | 1.81 Ad | 122.50 Aa | 55.90 Ba | 42.75 Bc | 74.50 Aa | 0.79 Ab | 0.33 Ba | 62.25 Bc | 83.50 Aa |
| 04 | 1.81 Bb | 3.60 Ab | 98.66 Ab | 72.52 Aa | 48.75 Bb | 83.75 Aa | 0.71 Ab | 0.24 Ba | 71.50 Bc | 93.25 Aa |
| 05 | 1.01 Bb | 2.47 Ac | 66.12 Ac | 53.98 Aa | 38.50 Bc | 65.25 Aa | 0.69 Ab | 0.25 Ba | 59.00 Bc | 86.50 Aa |
| 06 | 2.61 Ba | 4.35 Aa | 118.62 Aa | 62.90 Ba | 57.75 Ab | 67.75 Aa | 1.18 Ac | 0.15 Ba | 68.00 Bc | 96.25 Aa |
| 07 | 2.30 Aa | 2.78 Ac | 73.98 Ab | 44.87 Aa | 52.25 Bb | 82.50 Aa | 0.43 Aa | 0.19 Ba | 83.50 Aa | 92.75 Aa |
| 08 | 3.38 Aa | 4.30 Aa | 77.80 Ab | 67.37 Aa | 76.62 Aa | 72.25 Aa | 0.33 Aa | 0.19 Aa | 90.00 Aa | 95.50 Aa |
| 09 | 2.36 Aa | 3.21 Ab | 88.25 Ab | 60.37 Bc | 41.75 Bc | 74.50 Aa | 1.06 Ac | 0.18 Ba | 67.00 Bc | 93.50 Aa |
| 10 | 1.85 Ab | 2.09 Ad | 102.87 Aa | 51.75 Ba | 58.75 Bb | 73.50 Aa | 0.94 Ac | 0.28 Ba | 64.75 Bc | 86.50 Aa |
| 11 | 2.41 Aa | 3.34 Ab | 111.88 Aa | 60.50 Ba | 36.25 Bc | 75.00 Aa | 0.70 Ab | 0.15 Ba | 74.50 Bb | 95.00 Aa |
| 12 | 3.00 Aa | 2.23 Ad | 128.37 Aa | 48.91 Ba | 80.25 Aa | 77.00 Aa | 0.58 Ab | 0.25 Ba | 82.75 Aa | 89.25 Aa |
| 13 | 3.06 Aa | 1.46 Bd | 57.75 Ac | 52.41 Aa | 80.75 Aa | 63.00 Aa | 0.36 Ba | 0.64 Ab | 88.75 Aa | 67.50 Bb |
| 14 | 1.79 Ab | 2.43 Ac | 125.50 Aa | 60.02 Ba | 47.50 Bb | 69.00 Aa | 1.06 Ac | 0.28 Ba | 62.00 Bc | 88.25 Aa |
| 15 | 2.38 Aa | 2.45 Ac | 73.81 Ab | 44.00 Ba | 52.00 Bb | 69.50 Aa | 0.39 Aa | 0.09 Ba | 85.50 Bc | 95.50 Aa |
| 16 | 2.36 Aa | 3.21 Ab | 88.25 Ab | 60.37 Bc | 53.75 Bb | 75.00 Aa | 1.06 Ac | 0.18 Ba | 41.50 Bc | 84.00 Aa |
| 17 | 1.35 Bb | 3.15 Ab | 121.62 Aa | 64.08 Ba | 49.00 Bb | 72.25 Aa | 1.25 Ad | 0.25 Ba | 48.00 Bc | 91.75 Aa |
| 18 | 1.65 Bb | 3.56 Ab | 93.71 Ab | 53.48 Ba | 43.00 Bc | 88.50 Aa | 0.60 Ab | 0.11 Ba | 70.75 Bc | 96.25 Aa |
| 19 | 1.15 Bb | 2.88 Ac | 52.87 Ac | 63.50 Aa | 27.00 Bc | 75.25 Aa | 0.36 Aa | 0.28 Aa | 74.50 Bb | 89.50 Aa |
| 20 | 0.93 Bb | 2.93 Ac | 52.87 Ac | 58.23 Aa | 46.75 Bb | 82.75 Aa | 0.45 Aa | 0.33 Aa | 67.50 Bc | 89.00 Aa |
| SE 1055 F$_1$ | 1.76 Bb | 2.91 Ac | 145.25 Aa | 68.98 Ba | 53.25 Bb | 80.00 Aa | 1.35 Ad | 0.23 Ba | 53.25 Bb | 80.00 Aa |
| Yoshimatsu | 2.12 Ba | 4.40 Aa | 104.37 Aa | 83.15 Aa | 41.00 Bc | 64.50 Aa | 0.85 Ab | 0.89 Ac | 70.50 Bc | 82.25 Aa |

Average 1.92 B 2.88 A 96.15 A 57.89 B 50.05 B 74.14 A 0.75 B 0.27 A 69.20 B 89.3 A

CV (%) 28.73 22.66 15.73 25.38 8.65

Average values followed by lowercase letters within column and capital letters within row do not differ by Scott-Knott test at 5% probability. CV (%) obtained from the joint variance analysis [médias seguidas pelas letras, minúsculas na coluna e maísculas na linha, não diferem entre si pelo teste de Scott-Knott em nível de 5% de probabilidade. CV (%) obtido na análise conjunta].

period of the experiment was 7.1 MJ m$^{-2}$ day$^{-1}$, lower the trophic limit 8.4 MJ m$^{-2}$ day$^{-1}$, suitable for the crop (FAO, 1990). This way, high temperature and low radiation are directly related to the development of the plants and to the lower fruit set in the greenhouse (Andriolo, 2000).

The joint analysis showed that no significant differences among genotypes were noticed, between environments and genotype x environment interaction by F test (p<0.01), for all traits evaluated, except for MFNC/PL and MFC/PL, which did not show any significance between the environments (Table 2).

For NTF/PL, MFNC/PL and MFC/PL, the coefficient of variation was above 20%, considered acceptable for these traits, as observed in other studies (Carvalho et al., 2003; Cargnelutti Filho et al., 2004). For PEG and REND, the coefficient of variation was 15.73 and 8.65%, respectively, which shows good experimental precision for evaluations.

The general average of the total number of fruits per plant (NTF/PL) was higher in the greenhouse, with 96.15 fruits, in relation to the field, which obtained 57.89 fruits (Table 2). Evaluating the performance of two hybrids of tomato Sunny and EF-50, grown in protected and non protected environments, Fontes et al. (1997) observed that the number of fruits produced was significantly influenced by genotypes and the growing environment. The hybrid Sunny produced 31.2 and 15.0 fruits per plant, in protected and non protected environment, respectively, while the hybrid EF-50 produced only 26.8 and 12.5 fruits per plant.

In tomato growth in greenhouse, according to Table 2, the lines 01, 03, 06, 10, 11, 12, 14 and 17 showed the highest values for NTF/PL, and they did not differ among themselves and in relation to control ‘Yoshimatsu’ and ‘SE 1055 F$_1$', by Scott Knott test at 5% probability. These results are much higher than the ones found by Eklund et al. (2005) that, evaluating the performance of five hybrids and
two cultivars in protected environment, observed that the best hybrid produced 35.75 fruits per plant.

Overall, the plants with high NTF/PL may not be the most productive, because many fruits in the same plant become small, reducing fruit quality and production. As observed, for lines 08 and 13, which showed values for NTF/PL much lower than the reported lines before and obtained the higher values for MFC/PL in the greenhouse. Except line 12, which showed high NTF/PL, not differing from lines 08 and 13 for MFC/PL.

In the field, lines and control treatments did not show significant differences among themselves for NTF/PL. Also in field conditions, Pena et al. (2012), studying the cultivar Yoshimatsu and four advanced generation progenies of tomato, observed lower NTF/PL than the values shown in this work.

The fruit set (PEG) refers to the percentage of flowers produced in each cluster which were pollinated, developed and formed fruit. In the field, PEG was higher than in the greenhouse (Table 2), notably, because of the best temperature conditions.

Considering the growth in the greenhouse, the lines 08, 12, 13 showed the higher values for PEG, 76.62, 80.25 and 80.75%, respectively, not differing among themselves and differing from the others by Scott Knott test at 5% probability, indicating the greater tolerance to high temperatures. These data are according to the values found by Kamel et al. (2010), who evaluated F$_2$ plants, resulting from the crossing between contrasting parents, observed up to 68.5% PEG, in high temperature conditions. However, Hanson et al. (2002) observed average of 30% of PEG, when evaluating PEG also for F$_2$ plants, resulting from the crossing between tolerant and susceptible parent.

Analyzing the number of flowers per cluster and the number of fruit set, Silva et al. (2000) verified that the average percentage of fruit set ranged from 2.5%, in the cultivar Santa Clara, which is not tolerant to high temperatures, to 40% in line CL5915, which is tolerant to high temperatures. This highlights the importance of the use of tolerant genotypes for the cultivation in high temperature.

For the mass of unmarketable fruits per plant (MFNC/PL), the direct effect of unfavorable environmental conditions on fruit set was verified. With the reduction in the number of viable pollen, the authors noticed lower fertilization and reduced number of seeds and deformed fruits, considered unmarketable.

The general average for MFNC/PL in the greenhouse was significantly higher than in the field (Table 2). This fact shows the negative influence of higher temperatures on fruit set.

As Table 2 shows, line 17 and hybrid SE 1055 F$_1$ showed higher values for MFNC/PL, not differing among themselves by Scott Knott test at 5% probability. As for the lines 02, 07, 08, 13, 15, 19 and 20, lower values for MFNC/PL were found and they also did not differ among themselves. These lines showed to be less affected by high temperatures.

In the field, only line 13 and cultivar Yoshimatsu showed higher MFNC/PL, differing statistically from the others. In relation to line 13, this line showed higher MFNC/PL in the field due to the presence of many small fruits. However, the cultivar Yoshimatsu showed many split and malformed fruits.

For mass of marketable fruits per plant (MFC/PL), the average growth in the field was higher than the average...
grown in the greenhouse, being 2.88 and 1.92 kg, respectively, highlighting the strong influence of high temperatures on this trait.

Lines 08, 12 and 13 showed the highest values for MFC/PL in the greenhouse, being these values above 3.0 kg of fruits per plant. These lines showed to be more productive (Table 2), although they did not differ from lines 06, 07, 09, 11, 15, and 16 and ‘Yoshimatsu’, which showed values ranging from 2.3 to 2.6 kg of fruits per plant. In the field, the most productive lines were 06 and 08 and cultivar Yoshimatsu.

Studies on commercial hybrids have shown productivity in the greenhouse with averages above 110 t ha⁻¹ (Gualberto et al., 2002; Caliman et al., 2005; Gualberto et al., 2007). In other studies, like this one, some commercial hybrids were evaluated in high temperature environments and these hybrids showed to be less productive, with averages ranging from 26.17 to 65.16 t ha⁻¹ (Eklund et al., 2005; Pereira et al., 2012).

High temperatures and low radiation observed in the greenhouse influenced MFC/PL of lines 04, 09, 11, 16, 17 and 18, which although showed more than 3.0 kg/plant in the field, in the greenhouse showed much lower production.

The general average for REND obtained in the greenhouse was significantly lower than the average obtained in the field experiment. Nevertheless, lines 07, 08, 12, 13 and 15 obtained yield over 80%, standing out from the others for this trait (Table 2). In the field, the lines and two control treatments did not differ among themselves, except for line 13.

Based on the results, the authors concluded that lines 08, 12 and 13 showed higher fruit set in the greenhouse, being more suitable for cultivation at high temperatures. In the field, lines 06 and 08 stood out in the production of marketable fruits, and they did not differ from cultivar Yoshimatsu.

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REFERENCES

ABDUL-BAKIAA; STOMMEL JR. 1995. Pollen viability and fruit set of tomato genotypes under optimum and high temperature regimes. HortScience 30: 115-117.

AMORIM EP; SOUZA JC. 2005. Híbridos de milho inter e intrapopulacionais obtidos a partir de populações S₀ de híbridos simples comerciais. Bragantia 64: 561-567.

ANDRILOJO JL. 2000. Fisiologia da produção de hortalícias em ambiente protegido. Horticultura Brasileira, 18: 26- 33. (suplemento).

BISON O; RAMALHO MAP; RAPOSO FV. 2003. Potencial de híbridos simples de milho para a extração de linhagens. Ciência e Agrotecnologia 27: 348-355.

BITACE; ZENONI S; VRIEZEN WH; MARIANI C; PEZZOTTI M; GERATS T. 2011. Temperature stress differentially modulates transcription in meiotic anthers of heat tolerant and heat sensitive tomato plants. BMC Genomics 12: 1-18.

BRASIL MAPA. 2005. Instruções para execução dos ensaios de distinguibilidade, homogeneidade e estabilidade de cultivares de tomate (Lycopersicon esculentum). Diário Oficial da União 1: 4-5.

CALIMAN FRB; SILVA DJH; FONTES PCR; STRINGHETA PC; MOREIRA GR; CARDOSO AA. 2005. Avaliação de genótipos de tomateiro cultivados em ambiente protegido e em campo nas condições edafoclimáticas de Viçosa. Horticultura Brasileira 23: 255-259.

CARENGLUTTI FILHO A; RADIN B; MATZENAUER R; STORCK L. 2004. Número de colheitas e comparação de genótipos de tomateiro cultivados em estufa de plástico. Pesquisa Agropecuária Brasileira 39: 953-959.

CARVALHO ADF; SOUZA JC; RAMALHO MAP. 2004. Capacidade de combinação de progêniés parcialmente endogâmicas obtidas de híbridos comerciais de milho. Revista Brasileira de Milho e Sorgo 3: 429-437.

CARVALHO JOM; LUZ JMQ; JULIATTI FC; MELO LC; TEODORO REF; LIMA LML. 2003. Desempenho de famílias e híbridos comerciais de tomateiro para processamento industrial com irrigação por gotejamento. Horticultura Brasileira 21: 525-533.

CRUZ CD. 2006. Programa Genes: versão Windows; aplicativo computacional em genética e estatística. Viçosa: Imprensa Universitária. 648p.

EKCLUD CRB; CAETANO LCS; SHIMOYA A; FERREIRA JM; GOMES JMR. 2005. Desempenho de genótipos de tomateiro sob cultivo protegido. Horticultura Brasileira 23: 1015-1017.

EKLUND CRB; CAETANO LCS; SHIMOYA A; FERREIRA JM; GOMES JMR. 2005. Desempenho de genótipos de tomateiro sob cultivo protegido. Horticultura Brasileira 23: 1015-1017.

Ekland CRB; Caetano LCS; Shimoya A; Ferreira JM; Gomes JMR. 2005. Desempenho de genótipos de tomateiro sob cultivo protegido. Horticultura Brasileira 23: 1015-1017.

FILGUEIRA FAR. 2008. Novo Manual de Olericultura: agrotecnologia moderna na produção e comercialização de hortaliças. Viçosa: UFV. 421p.

FIRON N; SHAKED R; PEET MM; PHARR DM; ZAMSKI E; ROSENFELD K; ALTSHAN L; PRESSMAN E. 2006. Pollen grains of heat tolerant tomato cultivars retain higher carbohydrate concentration under heat stress conditions. Scientia Horticultrae 109: 212-
217.

FONTES PCR; DIAS EN; ZANIN SR; FINGER FL. 1997. Produção de cultivares de tomate em estufa coberta com plástico. Revista Ceres 44: 152-160.

GIORDANO LB; BOITEUX LS; SILVA JBC; CARRIJO OA. 2005. Seleção de linhagens com tolerância ao calor em germoplasma de tomateiro coletado na região Norte do Brasil. Horticultura Brasileira 23: 105-107.

GUALBERTO R; BRAZ LT; BANZATTO DA. 2002. Produtividade, adaptabilidade e estabilidade fenotípica de genótipos de tomate sob diferentes condições de ambiente. Pesquisa Agropecuária Brasileira 37: 81-88.

GUALBERTO R; OLIVEIRA PRS; GUIMARÃES AM. 2007. Desempenho de cultivares de tomateiro para mesa em ambiente protegido. Horticultura Brasileira 25: 244-246.

HANSON PM; CHEN J; KUO G. 2002. Gene action and heritability of high-temperature fruit set in tomato line CL5915. HortScience 37: 172-175.

IPCC-Intergovernmental panel on climate change. 2012a. 26 de agosto. Climate change 2001: impacts, adaptation and vulnerability technical summary. Disponível em: http://www.ipcc.ch. Acessado em 25 de agosto de 2012.

IPCC-Intergovernmental panel on climate change. 2012b. 26 de agosto. Climate change 2007: Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Disponível em: http://www.ipcc.ch. Acessado em 25 de agosto de 2012.

KAMEL MA; SOLIMAN SS; MANDOUR AE; AHMED MSS. 2010. Genetic evaluation and molecular markers for heat tolerance in tomato (Lycopersicon esculentum). Journal of American Science 6: 364-374.

PENA MAA; NODA H; MACHADO FM; PAIVA MSS. 2012. Adaptabilidade e estabilidade de genótipos de tomateiro sob cultivo em solos de terra firme e várzea da Amazônia infestados por Ralstonia solanacearum. Bragança 69: 27-37.

PEREIRA MAB; AZEVEDO SM; FREITAS GA; SANTOS GR; NASCIMENTO ER. 2012. Adaptabilidade e estabilidade produtiva de genótipos de tomateiro em condições de temperatura elevada. Revista Ciência Agronômica 43: 330-337.

RUDICK J; ZAMSKI E; REGEV Y. 1977. Genotypic variation for sensitivity to high temperature in the tomato: pollination and fruit set. Botanical Gazette 138: 448-452.

SAEED A; HAYAT K; KHAN AA; JQBAL S. 2007. Heat tolerance studies in tomato (Lycopersicon esculentum). International Journal of Agriculture & Biology 9: 649-652.

SATO S; KAMIYAMA M; IWATA T; MAKITA N; FURUKAWA H; IKEDA I. 2006. Moderate increase of mean daily temperature adversely affects fruit set of Lycopersicon esculentum by disrupting specific physiological processes in male reproductive development. Annals of Botany 97: 731-738.

SILVA ACF; LEITE IC; BRAZ LT. 2000. Avaliação da viabilidade do pólen como possível indicativo de tolerância a altas temperaturas em genótipos de tomateiro. Revista Brasileira de Fisiologia Vegetal 12: 156-165.

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