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Drought Tolerance of Several Tomato Genotypes Under Greenhouse Conditions

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Abstract: Growth and production of agricultural crops are greatly affected by water shortage. Thus, yield enhancement under drought conditions is a major goal of plant breeding. Four commercial tomato cultivars (Imperial, Pakmore VF, Strain-B and Tnshet Star), a drought-tolerant breeding line (L 03306) and their hybrid combinations were selected in this study to evaluate drought tolerance and to develop initial material for a drought tolerance breeding program. Four-weeks-old seedlings were transplanted into soil under greenhouse conditions. Six irrigation treatments (T_1 = 20, T_2 = 40, T_3 = 60, T_4 = 80, T_5 (control) = 100 and T_6 = 120% of the estimated evapotranspiration, ET_c) were imposed during a 140-day growing period through a drip irrigation system. Vegetative growth, flowering and yield traits were measured while water use efficiency (WUE) was determined. All vegetative and fruit traits decreased significantly as deficit irrigation levels increased. For T_1 and T_2, yield was reduced by 46.7 and 33.5%, respectively, compared with T_5. WUE was increased significantly as the amount of irrigation water decreased. The relationship between production and water amount was a second-degree polynomial. Significant differences among genotypes were found for all traits, suggesting that they could be taken into account when selecting for drought tolerance. Pakmore VF and the breeding line L 03306 had good yield performance under different deficit irrigation treatments. These genotypes could be selected for in a breeding program as recurrent (female) and donor (male) parents, respectively.

Key words: *Lycopersicon esculentum* Mill. · Growth · Yield · Drought tolerance · Plant breeding

INTRODUCTION

Drought is one of the most important environmental stresses limiting crop productivity. Plant species adapt to this adverse condition through different ways. Some plants can (a) complete their life cycle under optimum conditions, (b) reduce water loss by reducing leaf size or reducing stomatal pores, (c) maintain growth even during water deficit by retaining water content, or (d) increase water use efficiency (WUE) of limited available water [1]. These mechanisms can be utilized as indicators in a breeding strategy to improve crop drought tolerance. In recent years, crop physiology and genomics have led to new insights in drought tolerance providing breeders with new knowledge and tools for plant improvement [2]. Genetic variability within a species is a valuable tool for screening and breeding for drought tolerance. In areas of water shortage and long drought spells, conventional deficit irrigation is a common practice to mitigate drastic reductions in yield [3]. Regulated deficit irrigation (RDI) is a deficit irrigation technique where crops are irrigated with less water and the minor stress that develops has minimal effects on yield [4]. Pulupol *et al.* [5] observed a significant reduction in dry mass yield for a glasshouse tomato cultivar using RDI, while Zegbe-Domínguez *et al.* [6] reported no reduction in yield for a field-grown processing cultivar. Although the effects on yield may be different, many of the results obtained have shown that RDI saves substantial amounts of irrigation water and increases WUE [7, 8].

Tomato (*Lycopersicon esculentum* Mill.) is one of the most widely grown vegetables in the world [9]. Most commercial tomato cultivars are drought sensitive at all stages of plant development, with seed germination and early seedling growth being the most sensitive stages [10]. Papadopoulos [11] reported that water consumption for tomatoes is estimated at 0.5 - 0.9 m^3 / m^2 greenhouse area / year. Other study conducted by Soria and Cuartero [12] revealed that plant water consumption of tomatoes ranged from 0.19 to 1.03 $plant^{-1}$ day^{-1} at different water salinities. The amount of water required daily for tomato in different growing systems varies from 0.89 to 2.31

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/plant/day [13, 14]. The pan evaporation method within a greenhouse was used to estimate water consumption use [15]. They also reported that increasing the irrigation rate up to 120% of pan evaporation increased crop yield and decreased total soluble solids. Drip irrigation applied with 75% of crop evapotranspiration (ET_c) was the optimum amount of irrigation for a humid tropical environment in order to maximize tomato yield [16]. New transplants need only about 0.05 /plant /day. At maturity on sunny days, however, plants may need up to 2.7 /plant/day. Generally, about 1.8 /plant/day is adequate for fully-grown tomato plants [17]. Crop water production function (CWPF) reflects the relationship between applied water and yield. Various production functions have been studied which relate production components and parameters to the volume of irrigation water applied. The form of the regression equations in most of these studies was polynomial with applied water or linear with ET_c [18, 19]. Substantial genetic variation in drought tolerance exists within cultivated tomato, as well as its related wild species *Lycopersicon pimpinellifolium* [20]. A primary task in breeding for stress tolerance is the identification and genetic characterization of useful germplasm.

The objectives of this study were: (a) to evaluate drought tolerance of four tomato cultivars, one breeding line and their 10 hybrid combinations and (b) to select starting materials for a drought tolerance breeding program.

MATERIALS AND METHODS

Experiment Set-Up: The study was carried out in a fiberglass greenhouse during the 2008 and 2009 seasons at the Dirab Agricultural Research and Experimental Station of the Faculty of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia (24° 39' N, 46° 44' E). Four commercial tomato cultivars (Imperial, Pakmore VF, Strain-B and Tnshet Star) and a drought-tolerant breeding line (L 03306) were used. The commercial cultivars were previously evaluated by the authors as high yielding and that could be grown over a wide range of environments [21] and the breeding line was provided by the Asian Vegetables Research and Development Center (AVRDC, Shanhua, Taiwan).

Development the Genetics Materials: In the first season, seeds of the five parental tomato genotypes were germinated in Jiffy 7 pots on August 30, 2008. Four-weeks-old seedlings were transplanted into 30-cm diameter pots containing a mixture of peat, sand and vermiculite (1:1:1). At the flowering stage, selfing and hybridization among the five genotypes were carried out in a diallel cross system in one direction. Sufficient seeds of all 10 possible hybrids and new seeds of the five selfed parents were obtained after 4 months from transplanting.

Evaluation the Genetics Materials: In the second season, irrigation treatments were started after 7 days from transplanting. Six irrigation treatments ($T_1 = 20$, $T_2 = 40$, $T_3 = 60$, $T_4 = 80$, $T_5 = 100$ (control) and $T_6 = 120\%$ of ET_c) were imposed through a drip irrigation system. Seeds of the genotypes were sown in seedling trays on February 20, 2009. Four-weeks-old seedlings were transplanted into soil in the fiberglass greenhouse. The soil was composed of 82% sand, 9% silt and 9% clay. Temperature and relative humidity averaged about 26 ± 0.5°C and 74 ± 2%, respectively during all growth stages. Fertilization and other cultural practices were applied as commonly recommended for commercial tomato production in a greenhouse [22].

Data Collection and Analysis: The experimental layout was a split-plot in a randomized complete block design with three replications. Irrigation treatments were randomly allocated to the main plots while genotypes were arranged in the sub-plots. The sub-plot area was 4 m^2 (2×2) and included 10 plants. Planting distance was 50 cm and 100 cm between plants and lines, respectively. The amount of irrigation water was estimated using ET_c for tomatoes which were calculated by the FAO Penman Monteith method [16]. It was measured in m^3 using a water gauge. The total period of the irrigation treatments was 140 days and the amount of water applied in each irrigation treatment was 250, 500, 750, 1000, 1250 and 1500 $m^3\ ha^{-1}$ for irrigation treatments T_1, T_2, T_3 T_4, T_5 (control) and T_6, respectively. Forty-five days after transplanting, a random sample of 4 plants from each sub-plot was chosen to measure vegetative growth traits: plant height, stem thickness and dry matter percentage. Number of flowers and fruits per cluster was counted throughout the flowering and fruiting periods on 4 plants and the percentage fruit set was determined by dividing the average number of fruits by the average number of flowers for each experimental unit. Total cumulative yield and average fruit weight (total weight of all harvested fruits per plot divided by their number) were determined. WUE was used to evaluate comparative benefits of the irrigation treatments. It was calculated by dividing the total yield (kg ha^{-1}) by seasonal irrigation water ($m^3\ ha^{-1}$) applied in different irrigation treatments (WUE = Y/I), as reported by Kirda *et al.* [7]. CWPF was used to illustrate the relationship between tomato production and applied irrigation water. It was calculated using the quadratic polynomial function of Helweg [23], in the form:

$$Y_a = b_0+b_1*X+b_2*X^2$$

Where: Y_a = crop production or yield (ton ha^{-1}) and X = applied irrigation water (m^3 ha^{-1}), b_0, b_1 and b_2 = fitting coefficients.

Statistical Analyses: Data were statistically analyzed using SAS statistical analysis system (version 8.1; SAS Institute, Cary, NC) software. Differences among means were tested using a revised L.S.D. test at the 0.05 level according to Steel and Torrie [24].

RESULTS AND DISCUSSION

Influence of Drought Stress on Growth Parameters: All growth traits were greatly reduced by successive decreases in the amount of irrigation water. However, the rate of response varied among studied traits (Table 1). Less irrigation water caused a significant reduction in plant height, stem diameter, leaf dry matter content and fruit set. When the applied water is reduced, it affects physiological processes and exposes plants to drought stress, which is reflected in low water absorption and transmission to different parts of the plant. Similar results were reported by Al-Damry [25], who studied the impact of irrigation regime on tomato growth and yield. He reported that tomato growth parameters and yield were higher at a high irrigation rate (6 L h^{-1}) and decreased significantly at a low irrigation rate (2 L h^{-1}). Lee and Shin [26] investigated an optimal irrigation management system for greenhouse tomato based on the bio-information of the plant. The micro variation in stem diameter reflected the plant water status and could be utilized as a criterion for timing irrigation.

Yield, as determined by average fruit weight and total yield / plant, was significantly affected and decreased with increasing drought stress (Table 1). Increasing irrigation levels from 20 to 100% of ET$_c$ significantly increased average fruit weight and total yield. However, no significant difference between 100 and 120% ET$_c$ was observed. Similar effects of drought stress on tomato fruit

Table 1: Influence of irrigation treatments on plant height, stem thickness, leaf dry weight %, fruit setting %, average fruit weight and total yield for the average of all tomato genotypes

Irrigation treatments*	Plant height (cm)	Stem diameter (mm)	Leaf dry matter content (%)	Fruit setting (%)	Average fruit weight(g)	Total yield (ton ha^{-1})
T_1	68.3 f	12.7 c	11.2 d	46.0 d	67.2 e	27.5 e
T_2	72.3 e	12.3 c	12.1 c	47.1 d	75.3 d	35.1 d
T_3	79.0 d	13.8 b	13.8 b	47.6 d	85.4 c	39.0 c
T_4	81.8 c	13.2 b	13.7 b	52.3 c	93.9 b	43.7 b
T_5	87.6 b	15.6 a	15.9 a	56.6 b	112.7 a	51.5 a
T_6	94.5 a	15.2 a	15.7 a	66.6 a	114.8 a	52.8 a

*T_1 = 20, T_2 = 40, T_3 = 60, T_4 = 80, T_5 = 100 (control) and T_6 = 120% of ET$_c$

Values followed by the same letter in a column do not differ significantly from each other using a revised LSD test at the 0.05 level

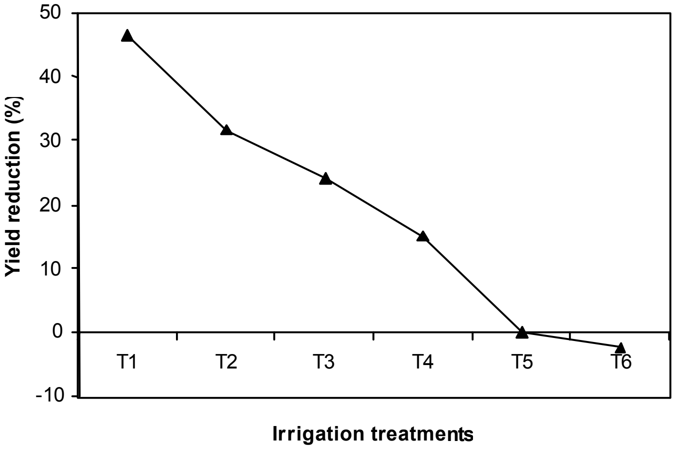

Fig. 1: Influence of irrigation treatments on yield reduction percentage for tomato genotypes

growth were reported by Sladjana *et al.* [27]. They mentioned that potential size of tomato fruit also depends on the rate of water accumulation since water may account for 95% of the total fresh weight.

Compared with the control treatment, a successive decrease in the amount of irrigation water reduced total yield by 46.7, 31.9, 24.3 and 15.1%, for T_1, T_2, T_3 and T_4 treatments, respectively (Fig. 1). No significant differences were found between 100% (T_5) and 120% (T_6) ET_c since the amount of irrigation water increased from 100 to 120% ET_c caused an insignificant increase in yield, i.e., by only 2.5%. These results are in agreement with those of Kirda *et al.* [7] and Harmanto *et al.* [16]. Kirda *et al.* [7] assessed comparative yield responses of greenhouse-grown tomato to full, deficit irrigation and partial root drying practices. They reported that marketable tomato yield was lowest under conventional deficit irrigation treatments (30 and 50% water deficit). Harmanto *et al.* [16] studied the effect of four different levels of drip irrigation, equivalent to 100, 75¸ 50 and 25% of crop evapotranspiration on tomato productivity under greenhouse conditions. They reported that the application of irrigation at a lower amount (water deficit) of the water requirement resulted in lower yield; however, increasing the irrigation water over a certain level (over-irrigation) did not increase the tomato yield above the maximum yield.

Water Use Efficiency: There was a great decrease in WUE from 35.2 to 110.3 kg/m^{-3} as irrigation level increased (Fig. 2). This decrease was attributed to the increase of applied water. Similar results were reported by Kirda *et al.* [7], Harmanto *et al.* [16] and Howell [28]. Kirda *et al.* [7] reported that the lowest WUE was recorded under full-irrigation treatments. Harmanto *et al.* [16] reported that over-irrigation resulted in lower water productivity

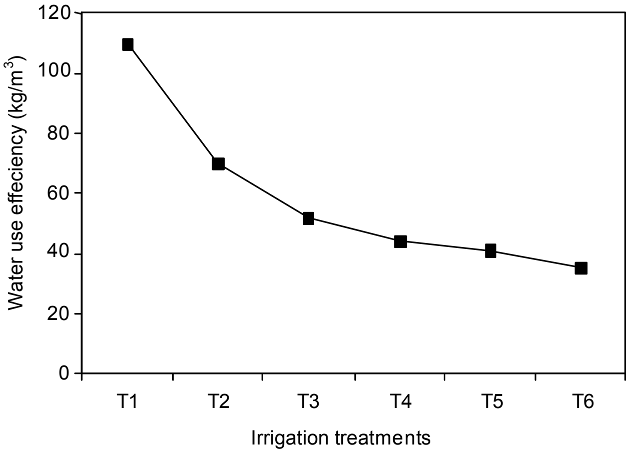

Fig. 2: Influence of irrigation treatments on water use efficiency for tomato genotypes

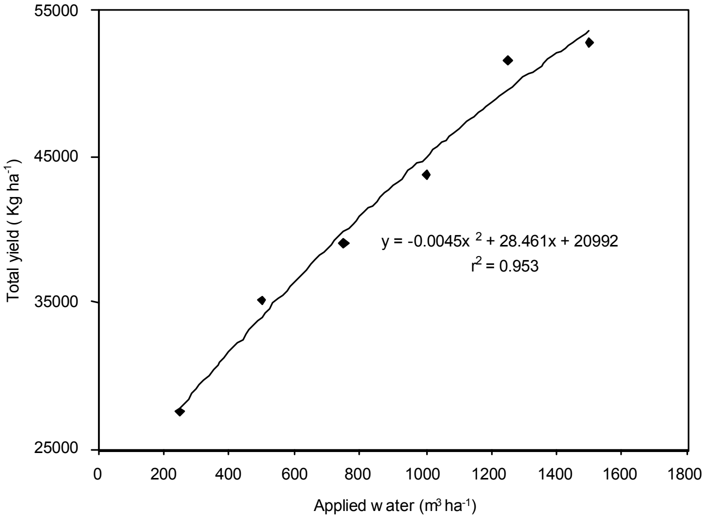

Fig. 3: Relationship between tomato production and applied irrigation water

(fresh fruit tomato yield divided by volume of irrigation water applied) while a lack of irrigation caused very low water productivity. The highest water productivity was reached with 75% of ET_c treatment. Howell [28] mentioned that WUE differed considerably among treatments and generally tended to increase with a decline in irrigation.

Crop Water Production Function: The mathematical function that illustrates the relationship between production and water volume was a second-degree polynomial with a highly significant determination factor (r^2) of 0.953 (Fig. 3). The curve shows a markedly upward trend which indicates the clear response of tomato production to the amount of irrigation water. Similar results were reported by Fabeiro *et al.* [18] on muskmelon (*Cucumis melo* L.). They reported that the mathematical function that best fits the relation between production and water amount was a second-degree polynomial.

Responses of Tomato Genotypes to Drought Stress: Except for stem diameter, tomato genotypes showed significant differences for all studied traits in response to drought treatments (Table 2). Plant height of Imperial was significantly higher (89.0 cm), lowest (70.5 cm) in hybrid Tnshet Star x L 03303 (P4×P5). The highest leaf dry matter content (14.4%) was in the hybrid Pakmore VF x Strain B (P2×P3) whereas the lowest value (13.5%) was observed in the cross Imperial x L 03303 (P1×P5). There were only slight, insignificant differences in fruit set among all genotypes, although the cultivar Tnshet Star had the highest value (64.0%) while the lowest value (45.0%) was observed in the cross Imperial x Strain B (P1×P3). Data of the first generation hybrids (Table 2) illustrates that most of the F_1's produced average values around their respective mid-parental values or deviated towards the values of the higher parents. These results suggested that inheritance of these traits involved additive and partial dominance for the high value over their alternative forms and that the additive gene effects contributed to the genetic variability more than the non-additive gene effects.

The cultivars Pakmore VF and Tnshet Star had significantly higher average fruit weight, while the hybrid Pakmore VF x L 03303 (P2 x P5) had the highest total yield. All F_1's produced an average fruit weight that deviated towards the smaller fruited parent, reflecting the dominance of small over large fruit weight. However, all F_1 hybrids showed significant higher total yield than their respective parents. Therefore, a pronounced degree of dominance and over-dominance was involved in the inheritance of these traits. Few reports on genotypic variation in commercial cultivars are available and they have been developed during a short period of drought stress, giving only partial information about osmotic adjustment [10]. Other studies, Alian *et al.* [29] and Romero-Aranda *et al.* [30] reported large variations among tomato genotypes in response to drought.

Interaction Effects Between Irrigation Treatments and Tomato Genotypes: The interactions between irrigation treatments and tomato genotypes had a significant influence on some traits. A successive decrease in the amount of irrigation water was associated with significant decreases in all traits. The lowest reduction in average

Table 2: Effect of tomato genotypes on plant height, stem thickness, leaf dry weight %, fruit setting %, average fruit weight and total yield

Genotypes	Plant height (cm)	Stem diameter (mm)	Leaf dry matter content (%)	Fruit setting (%)	Average fruit weight (g)	Total yield (ton ha^{-1})
Imperial (P1)	89.0 a	14.0 a	13.5 b-f	62.5 a	98.9 e	38.7 i
Pakmore VF (P2)	80.3 egh	14.7 a	13.7 abc	60.3 b	107.6 a	41.9 g
Strain B (P3)	81.0 e	14.3 a	13.9 abc	62.0 a	87.9. f	24.7 m
Tnshet Star (P4)	78.9 egh	14.1 a	13.8 abc	64.0 a	106.8 a	31.3 i
L 03306 (P5)	82.3 bcd	13.6 a	13.2 fg	62.0 a	77.2 k	20.9 n
P1 x P2	84.5 abc	13.5 a	14.0 bc	57.8 c	102.5 c	57.0 b
P1 x P3	80.6 de	13.9 a	13.8 a-e	45.0 e	80.5 j	41.9 g
P1 x P4	81.3 e	13.8 a	13.7 abc	52.8 c	101.3 d	47.4 e
P1 x P5	81.6 cde	14.3 a	13.5 c-g	60.0 b	81.1 i	55.5 c
P2 x P3	85.9 abc	14.0 a	14.4 a	50.0 cd	87.8 g	44.0 f
P2 x P4	86.1 ab	14.2 a	14.2 ab	50.0 cd	104.5 b	52.1 d
P2 x P5	82.3 bcd	13.7 a	13.5 a-f	52.0 c	91.5 f	58.0 a
P3 x P4	81.5 e	14.0 a	13.9 a-d	51.0 cd	87.7 g	36.1 j
P3 x P5	82.2 b-e	14.1 a	13.7 b-g	50.0 cd	71.8 l	33.8 k
P4 x P5	70.5 i	14.1 a	13.6 b-g	52.0 c	87.1 h	40.5 h

Values followed by the same letter in a column do not differ significantly from each other using a revised LSD test at the 0.05 level

Table 3: Average fruit weight (g) for tomato genotypes as affected by different irrigation treatments

	Irrigation treatments*					
Genotypes	T_1	T_2	T_3	T_4	T_5	T_6
Imperial (P1)	72.1	79.3	93.8	103.4	121.6	123.2
Pakmore VF (P2)	89.1	91.5	99.7	108.2	128.0	129.1
Strain B (P3)	65.8	79.8	86.3	92.0	100.5	103.5
Tnshet Star (P4)	72.9	81.8	102.4	111.6	135.4	136.4
L 03306 (P5)	76.2	77.3	76.8	77.4	78.5	77.0
P1 x P2	73.1	83.5	99.3	107.1	124.7	127.6
P1 x P3	56.6	61.1	69.1	81.8	106.4	104.5
P1 x P4	68.9	80.6	92.0	105.3	129.0	132.0
P1 x P5	64.5	68.9	78.1	84.3	95.2	95.7
P2 x P3	55.9	66.6	75.9	89.8	117.5	121.5
P2 x P4	70.6	80.1	95.1	107.7	134.7	138.6
P2 x P5	83.5	85.3	86.2	91.3	101.2	102.0
P3 x P4	54.2	61.6	75.3	89.6	120.1	125.4
P3 x P5	54.6	57.8	66.6	71.9	88.7	91.3
P4 x P5	60.4	75.3	84.4	88.3	106.5	107.8
L.S.D $_{0.05}$	4.3					

*T_1 = 20, T_2 = 40, T_3 = 60, T_4 = 80, T_5 = 100 (control) and T_6 = 120% of ET_C

Table 4: Total yield (ton ha^{-1}) for tomato genotypes as affected by different irrigation treatments.

	Irrigation treatments*					
Genotypes	T_1	T_2	T_3	T_4	T_5	T_6
Imperial (P1)	25.9	32.2	36.5	41.2	47.9	48.5
Pakmore VF (P2)	28.3	35.6	39.6	44.6	51.5	51.9
Strain B (P3)	13.8	18.7	20.8	25.1	33.9	36.1
Tnshet Star (P4)	20.2	26.0	29.2	32.0	39.4	41.2
L 03306 (P5)	19.0	20.2	20.9	21.6	22.1	21.5
P1 x P2	37.7	47.6	55.4	60.7	69.7	70.6
P1 x P3	25.0	32.6	37.1	44.5	54.8	57.3
P1 x P4	30.9	38.3	44.5	49.2	59.8	61.7
P1 x P5	39.4	51.8	54.0	58.9	64.1	64.6
P2 x P3	24.7	34.9	38.4	46.3	58.3	61.3
P2 x P4	34.3	43.1	49.0	54.1	65.1	67.0
P2 x P5	42.7	51.9	56.4	62.2	67.3	67.5
P3 x P4	21.0	27.7	31.7	37.8	47.7	50.6
P3 x P5	24.0	29.0	31.4	35.0	41.3	42.3
P4 x P5	26.4	36.4	39.7	42.0	49.0	49.4
L.S.D $_{0.05}$	2.340					

*T_1 = 20, T_2 = 40, T_3 = 60, T_4 = 80, T_5 = 100 (control) and T_6 = 120% of ET_C

fruit weight and total yield with a decrease in the amount of applied water was reflected in cultivar Pakmore VF, the breeding line L 03306 and their hybrid combinations (Tables 3 and 4). Based on the growth traits studied here, the drought tolerance of the different parental genotypes can be classified in descending order: L 03306 > Pakmore VF > Imperial > Tnshet Star > Strain B.

CONCLUSION

Drought tolerance of tomato plants has usually been expressed as the decrease in yield at a given level of water stress compared with the yield of non water-stressed plants. The performance of tomato genotypes under drought stress showed significant differences in all studied traits, suggesting that they could be taken into account when selecting for drought tolerance. The cultivar Pakmore VF, the breeding line L 03306 and their hybrid combination had good yield performance under different drought treatments. They could be utilized as suitable genetic materials and selected as donor parental material for a tomato drought tolerance breeding program.

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