Agraarteadus
2 • XXXIII • 2022 389–395

Journal of Agricultural Science
2 • XXXIII • 2022 389–395

EFFECT OF WATER DEFICIT ON THE GROWTH AND YIELD OF DIFFERENT GENOTYPES OF TOMATO IN SEMI-ARID CLIMATE CONDITIONS

Aziz Mahdi Abd Al-Shammari, Ghassan Jaafar Hamdi

Department of Horticulture and Landscape Gardening, College of Agriculture, University of Diyala, 32001, Baqubah, Iraq

Saabunud:
Received: 23.05.2022

Aktsepteeritud:
Accepted: 28.07.2022

Avaldatud veebis:
Published online: 28.07.2022

Vastutav autor:
Corresponding author: Ghassan Jaafar Hamdi

E-mail: ghassanhamdi38@gmail.com

ORCID:
0000-0002-6144-4313 (AMAA-S)
0000-0001-9312-8238 (GJH)

Keywords: *Solanum lycopersicum*, breeding, cultivar, water stress, yield.

DOI: 10.15159/jas.22.29

ABSTRACT. In areas where the supply of water for irrigation is limited, tomato production is often subject to drought stress. This study was conducted at the Department of Horticulture and Landscape Gardening, University of Diyala, Baqubah, Iraq in 2021 wherein 22 genotypes ('S.G', 'San II', 'M.O', 'Red Pear', 'F.R', 'Marb', 15 F1 hybrids were obtained from 6×6 half diallel cross and 'Bobcat' control hybrid) were cultivated under full irrigation [covering 100% of crop evapotranspiration demands (ETc)] and water deficit (50% of ETc) conditions. The results showed that cv. 1×6 produced the longest plants (119.01 cm) and the least time to flowering (10.23 days). Most branches (31.98) were produced by cv. 5×6. Both cvs. 1×6 and 5×6 produced the most leaf area (1 991 and 1 977 cm^2 respectively) and most yield per plant (6.75 and 6.84 kg respectively). The 100% ETc irrigation treatment produced the longest plants (91.21 cm), the greatest number of branches (28.12), the most leaf area (1 673 cm^2), and the highest plant yield (4.61 kg). The 50% ETc irrigation treatment produced the least time to flowering (13.7 days). Irrigation level lowering to 50% ETc achieved good results for the water use efficiency (WUE) use with predicted $R^2 = 1.00$. Therefore, the results of this study recommend using the interaction of (both cvs. 1×6 and 5×6 irrigated with the 50% ETc treatment) to save water on irrigation and produce a high yield of tomatoes.

Introduction

Water is the most important component of agricultural output (Du *et al.*, 2015). As a result, lowering water usage for agriculture is a top priority in any country's development of sustainable agriculture (Lu *et al.*, 2021). The utilization of contemporary irrigation systems and plant breeding for water stress resistance are currently required to ensure global food security. As a result, it is critical to address this main challenge (*i.e.* excessive irrigation) to boost agricultural productivity. In this context, increasing crop water use efficiency (WUE) and stress tolerance become a challenge to fulfilling global food demand while consuming the least amount of agricultural water (Liu *et al.*, 2021).

Plants with higher WUE have lower leaf transpiration rates, which leads to higher leaf temperature, which results in decreased photosynthetic rates, plant growth, and yield (Medrano *et al.*, 2015; Fullana-Pericàs *et al.*, 2022). As a result, there is a pressing need to assess the performance of a large number of crop genotypes in the field to identify those that have higher WUE and drought tolerance while still producing and preserving acceptable commercial fruit quality (Mickelbart *et al.*, 2015).

Tomatoes (*Solanum lycopersicum* L.) are one of the most widely grown vegetables in the world, with output nearly doubling in the previous two decades, from 1 000 million to 1 900 million tons (FAOSTAT, 2021). Although, the tomato crop is widely dispersed and suited to a wide variety of conditions (Cuartero, Fernández-Muoz, 1999), it is mostly grown in temperate locations, especially in the Mediterranean basin. Tomatoes are a high-water-demanding crop in the open field, requiring more than 3 L per plant every day at maturity (Wu *et al.*, 2021). Considering the projected climate change scenario, it is critical to investigate tomato genotypic diversity to identify the most stress-resistant genotypes, which may then be used to increase WUE by reducing fruit output and quality under adverse circumstances. Given its global importance and status as the model species for fleshy fruit corps, the tomato crop is a well-known target for development

(Giovannoni, 2006, Klee, Giovannoni, 2011, The Tomato Genome Consortium, 2012). Due to millennia of selection under Mediterranean summer conditions, most drought-resistant genotypes in tomatoes have been identified among local landraces in the Mediterranean basin (Bota *et al.*, 2014; Patanè *et al.*, 2016). Several long shelf-life (LSL) landraces exhibit better drought tolerance than current genotypes, and several of their adaptation processes for increasing WUE have previously been documented (Conesa *et al.*, 2020). The LSL phenotype, which is characterised by extended fruit post-harvest conservation, is found in several West-Mediterranean landraces, including the 'de Ramellet' tomato from the Balearic Islands (Bota *et al.*, 2014, Conesa *et al.*, 2014), the 'de Penjar' tomato from the Eastern Iberian Peninsula (Casals *et al.*, 2012), and some Italian (Sacco extended review of LSL landraces distribution and traits can be found in Conesa *et al.*, 2020).

In this study, the physiologic and agronomic performance of 22 tomato genotypes under well-watered and deficit irrigation conditions was assessed.

Materials and Methods

Plant material

In this study, 22 tomato genotypes were evaluated at the College of Agriculture, University of Diyala, Iraq in 2021. Seeds were germinated under greenhouse conditions in plastic trays filled with peat-based substrate. To ensure seed germination and avoid the spread of fungal and virus diseases, seeds were treated according to the procedure described in Hamdi (2022). The dataset for air temperature, humidity, and solar radiation for the length of the experiment for which it was received from the meteorological station at the University of Diyala is included in Figure 1.

The genotypes were further evaluated in field conditions on the silty loam soils. The soil was classified as silty loam texture. The soil sample was taken from a depth of 3–10 cm and physiochemical properties were done before planting as shown in Table 1. The soil texture was determined according to Day (1965) and the soil content elements were measured according to (Jackson, 1958; Black, 1965).

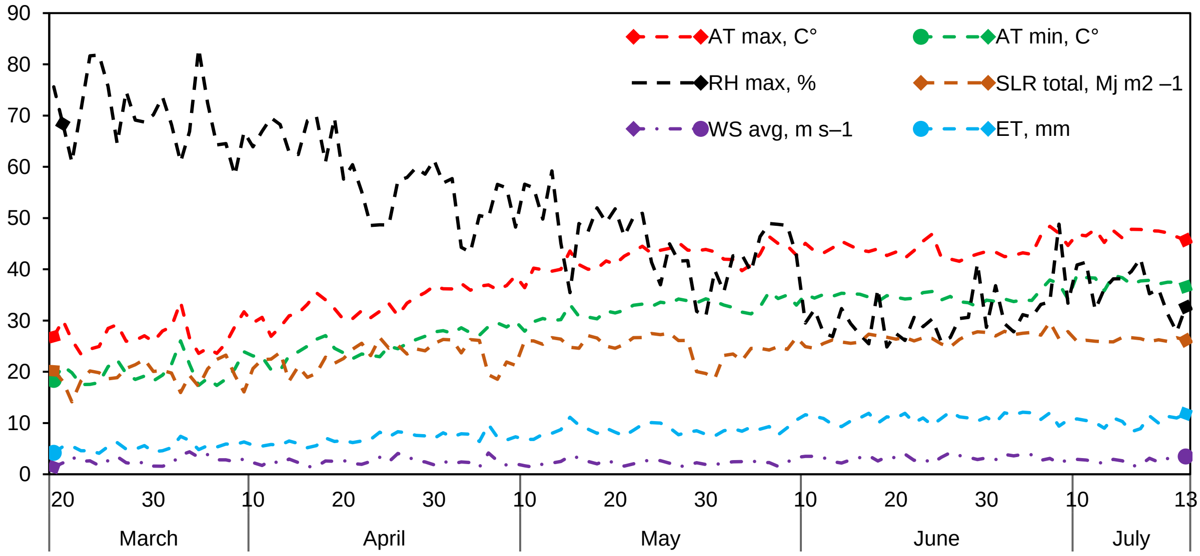

Figure 1. Maximum and minimum daily air temperature (AT), humidity (RH), solar radiation (SLR), wind speed (WS), plus evapotranspiration (ET) at Baqubah city. Monthly precipitation data was sourced from an onsite weather station at the University of Diyala

Table 1. Some chemical and physical soil properties of the field before planting

Parameters		Value	Unit
pH (1:1)		4.07	
Electrical conductivity (1:1)		7.55	dS
Organic matter		6.90	g kg^{-1}
$CaCO_3$		260.10	g kg^{-1}
Available nutrients	N	54.01	mg kg^{-1}
	P	8.04	mg kg^{-1}
	K	81.79	mg kg^{-1}
Soil separates	Sand	301.25	g kg^{-1}
	Silt	493.55	g kg^{-1}
	Clay	205.20	g kg^{-1}
Bulk density		1.35	mg $m^{3\,-1}$
Field capacity		25	%

Irrigation treatments

Two treatments were established, the first was irrigation at 100% of daily crop evapotranspiration (ETc) (Table 2) and the second, was irrigation at 50% of ETc. Weekly reference evapotranspiration was calculated according to FAO-56 (Allen *et al.*, 2008) using data obtained by two nearby weather stations. ETc was obtained as the product of the reference evapotranspiration (ETo) and the crop coefficient (Kc) at each growth stage (Allen *et al.*, 2008). Six plants were randomly selected from each plot to determine: plant height (cm), number of branches, total leaf area (cm^2), time to 50 flowering (day), and yield per plant (kg). WUE (kg $m^{3\,-1}$) was calculated as total yield (kg ha^{-1}) obtained per unit volume of seasonal evapotranspiration (m^3 ha^{-1}) (Wang *et al.*, 2007).

Table 2. Growth coefficient (Kc) and daily crop evapotranspiration (ETc) in mm day^{-1}, crop evapotranspiration (ETcd) in mm decade^{-1}.

Month	Decade	Stage	Kc coefficient	ETc mm day^{-1}	ETcd mm dec^{-1}
March	1	Initial	0.60	2.17	2.2
	2		0.60	2.46	24.6
	3		0.60	2.67	29.4
April	1	Develop	0.61	2.90	29.0
	2		0.76	3.87	38.7
	3		0.95	5.65	56.5
May	1	Mid	1.14	7.75	77.5
	2		1.19	9.10	91.0
	3		1.19	9.97	109.6
June	1	Mid	1.19	10.92	109.2
	2	Late	1.17	11.57	115.7
	3		1.01	10.24	102.4
July	1	Late	0.88	9.14	45.7

Statistical analysis

Data were subjected to analysis of variance using SAS JMP 9.1 (SAS Institute, Cary, NC). Means were separated with the Tukey-Kramer HSD test to determine the significant differences between means and the confidence level was 0.05.

Results and Discussion

Genotypes impact some measured traits of tomato

Table 3 shows the effect of genotypes and water deficit on the growth and yield of tomatoes. The cv. 1×6 produced the longest plants (119.01 cm) and the least time to flowering (10.23 days) while the cv. 'M.O' had the shortest plants (68.35 cm) and longest time to flowering (19.37 days). The cv. 5×6 produced the greatest number of branches (31.88) compared with other genotypes. Both cvs.1×6 and 5×6 produced the most leaf area (1 991 and 1 977 cm^2 respectively) and yield plant (6.75 and 6.84 kg respectively) compared with other genotypes. The reason for this can be attributed to genetic differences between genotypes (Al-Mfargy *et al.,* 2015; Abood *et al.,* 2019; Dariva *et al.,* 2021; Fayezizadeh *et al.,* 2021; Zhao *et al.,* 2021). Cultivar genotype may affect a plant's ability to absorb nutrients and/or the efficiency to transport them to the target organs, inducing, as a consequence, the plant growth positive response to irrigation application (Al-Mfargy, 2017; Giuliani *et al.,* 2018; Lu *et al.,* 2019; Aldubai *et al.,* 2022)

Water deficit impact on some measured traits of tomato

Table 3 shows the 100% ETc irrigation treatment produced the longest plants (91.21 cm), the greatest number of branches (28.12) most leaf area (1 673 cm^2) and most plant yield (4.61 kg) compared with other irrigation levels. The 50% ETc irrigation treatment produced and least time to flowering (13.76 days) compared with other irrigation levels. Full irrigation at 100% ETc provided a consistent supply of water to the entire root area of plants thereby water deficit conditions were minimized (Al-Shammari *et al.,* 2018; Giuliani *et al.*, 2019). Most morphological, physiological and biochemical processes associated with plant development might have compromised during water deficit and can result in poor photosynthesis, respiration and nutrient metabolism (Wu *et al.,* 2021). This reduction in the growth and yield of tomatoes might be due to an interruption in the photosynthesis process during the water deficit period (Sallume *et al.*, 2020).

Table 3. Effects of genotypes and irrigation levels on the plant height, number of branches, total leaf area, time to flowering and yield plant of tomato

Factors Genotypes	Plant height, cm	No. branches per plant	Total leaf area, cm^2	Time to flowering, day	Yield plant, kg
'S.G' (1)	97.59^{D}	22.82^{JK}	$1\,419^{L}$	17.80^{D}	3.58^{GH}
'San II' (2)	73.33^{P}	22.15^{LM}	$1\,327^{NO}$	18.29^{B}	3.18^{I}
'M.O' (3)	68.35^{R}	20.66^{O}	$1\,269^{P}$	19.37^{A}	2.43^{J}
'Red Pear' (4)	74.04^{NO}	21.56^{N}	$1\,414^{L}$	18.29^{B}	3.42^{H}
'F.R' (5)	87.03^{K}	23.73^{HI}	$1\,471^{JK}$	17.89^{D}	3.56^{GH}
'Marb' (6)	92.24^{G}	24.20^{GH}	$1\,567^{I}$	16.57^{EF}	3.94^{F}
1×2	76.54^{M}	22.17^{LM}	$1\,386^{M}$	17.81^{D}	3.50^{GH}
1×3	70.85^{Q}	22.44^{KL}	$1\,337^{N}$	17.89^{D}	3.46^{H}
1×4	81.76^{L}	23.34^{H}	$1\,482^{J}$	16.45^{F}	5.02^{C}
1×5	113.77^{B}	25.48^{EF}	$1\,816^{D}$	14.67^{H}	5.43^{B}
1×6	119.01^{A}	29.15^{B}	$1\,991^{A}$	10.23^{N}	6.75^{A}
2×3	70.11^{Q}	22.18^{LM}	$1\,310^{O}$	18.14^{C}	3.18^{I}
2×4	74.47^{N}	22.90^{JK}	$1\,469^{JK}$	16.63^{E}	3.68^{G}
2×5	89.74^{I}	25.26^{F}	$1\,568^{I}$	14.80^{H}	4.08^{EF}
2×6	96.38^{E}	28.35^{C}	$1\,783^{E}$	12.89^{K}	4.98^{C}
3×4	73.72^{OP}	21.56^{MN}	$1\,454^{K}$	18.05^{C}	3.43^{H}
3×5	91.15^{H}	24.47^{G}	$1\,610^{H}$	13.60^{I}	4.19^{E}
3×6	93.41^{F}	25.87^{DE}	$1\,836^{C}$	12.69^{L}	4.69^{D}
4×5	88.59^{J}	23.26^{IJ}	$1\,709^{F}$	13.19^{J}	4.98^{C}
4×6	91.85^{G}	26.36^{D}	$1\,935^{B}$	12.69^{L}	5.52^{B}
5×6	107.60^{C}	31.88^{A}	$1\,977^{A}$	11.67^{M}	6.84^{A}
'Bobcat'	82.34^{L}	22.45^{KL}	$1\,685^{G}$	15.26^{G}	4.11^{EF}
Irrigation levels ETc					
50	82.78^{B}	20.33^{B}	$1\,492^{B}$	13.76^{B}	3.93^{B}
100	91.21^{A}	28.12^{A}	$1\,673^{A}$	17.58^{A}	4.61^{A}

Data in interaction analyzed with Least Squares Means and means separated with Tukey *post-hoc* test.

Values in groups in columns followed by the different capital letters are significant at the level of P <0.05.

Impact of genotypes and water deficit interaction on some measured traits of tomato

Table 4 shows the genotype and irrigation-level interaction affected some measured traits of tomatoes. The cv. 1×6 irrigated with the 100% ETc treatment produced the tallest plants (123.17 cm), and most leaf area (2 154 cm^2). The same cv. irrigated with the 50% ETc treatment produced the least time to flowering (8.81 days), compared with other treatments. The cv. 5×6 irrigated with the 100% ETc treatment produced the greatest number of branches (36.28) compared with other treatments. Both cvs.1×6 and 5×6 irrigated with the 100% ETc treatment produced the most plant yield (7.02 and 7.18 kg respectively) compared with other treatments.

Table 4. Interaction effect of genotypes and irrigation levels on the plant height, number of branches, total leaf area, time to flowering and yield plant of tomato

Factors		Plant height, cm	No. of branches	Total leaf area, cm^2	Time to flowering, day	Yield plant, kg
Genotypes	Irrigation levels ETc, %					
'S.G' (1)	50	92.79^{L}	18.98^{TU}	$1\,351^{VW}$	15.88^{N}	3.14^{P-T}
	100	102.39^{G}	26.66^{JK}	$1\,487^{P}$	19.72^{F}	4.02^{IJK}
'San II' (2)	50	69.17^{X}	18.31^{VW}	$1\,248^{Y}$	16.22^{KL}	2.94^{RST}
	100	77.48^{U}	25.99^{M}	$1\,407^{RST}$	20.37^{B}	3.43^{NOP}
'M.O' (3)	50	63.02^{Z}	16.81^{X}	$1\,205^{Z}$	17.45^{I}	1.86^{U}
	100	73.68^{V}	24.52^{O}	$1\,334^{W}$	21.29^{A}	3.01^{RST}
'Red Pear' (4)	50	69.69^{X}	17.72^{W}	$1\,372^{UV}$	16.39^{K}	3.00^{RST}
	100	87.39^{T}	25.41^{MN}	$1\,457^{Q}$	20.23^{BC}	3.84^{KL}
'F.R' (5)	50	82.67^{Q}	19.39^{ST}	$1\,397^{STU}$	15.97^{MN}	3.11^{QRST}
	100	91.39^{M}	28.08^{GH}	$1\,545^{MN}$	19.81^{EF}	4.01^{IJK}
'Marb' (6)	50	87.80^{O}	19.45^{ST}	$1\,518^{NO}$	14.65^{PQ}	3.68^{LMN}
	100	96.67^{HI}	28.95^{FG}	$1\,617^{K}$	18.49^{H}	4.20^{IJ}
1×2	50	72.90^{W}	18.33^{VW}	$1\,276^{X}$	15.89^{N}	2.99^{RST}
	100	80.17^{R}	26.01^{L}	$1\,497^{OP}$	19.73^{F}	4.02^{IJK}
1×3	50	67.21^{Y}	18.60^{UV}	$1\,263^{XY}$	15.97^{MN}	3.18^{PQR}
	100	74.48^{V}	26.28^{JK}	$1\,412^{RS}$	19.81^{EF}	3.74^{KLM}
1×4	50	78.12^{TU}	19.69^{S}	$1\,397^{STU}$	14.53^{QR}	4.98^{FG}
	100	85.39^{P}	27.99^{H}	$1\,567^{LM}$	18.37^{H}	5.06^{FG}
1×5	50	109.14^{E}	21.64^{Q}	$1\,695^{I}$	13.75^{T}	5.05^{FG}
	100	118.39^{B}	29.32^{E}	$1\,938^{D}$	15.59^{O}	5.81^{C}
1×6	50	114.85^{C}	25.31^{NO}	$1\,829^{F}$	8.81^{Z}	6.48^{B}
	100	123.17^{A}	32.99^{B}	$2\,154^{A}$	11.65^{V}	7.02^{A}
2×3	50	66.38^{Y}	18.34^{VW}	$1\,194^{Z}$	16.21^{KL}	2.84^{T}
	100	73.83^{V}	26.02^{L}	$1\,427^{R}$	20.07^{CD}	3.52^{MNO}
2×4	50	70.25^{X}	19.04^{TU}	$1\,384^{TU}$	14.31^{RS}	3.16^{P-S}
	100	78.68^{ST}	26.77^{JK}	$1\,555^{LM}$	18.95^{G}	4.20^{IJ}
2×5	50	84.80^{P}	21.41^{QR}	$1\,433^{QR}$	12.97^{U}	3.90^{JKL}
	100	94.68^{K}	29.11^{EF}	$1\,704^{HI}$	16.63^{J}	4.26^{HI}
2×6	50	92.23^{LM}	24.99^{O}	$1\,575^{L}$	10.97^{X}	4.97^{FG}
	100	92.23^{L}	31.71^{C}	$1\,992^{C}$	14.81^{P}	5.00^{FG}
3×4	50	69.02^{X}	17.87^{W}	$1\,412^{RS}$	16.13^{LM}	2.86^{ST}
	100	78.42^{T}	25.62^{M}	$1\,497^{OP}$	19.97^{DE}	4.00^{IJK}
3×5	50	87.11^{O}	20.62^{R}	$1\,494^{OP}$	11.65^{V}	3.84^{KL}
	100	95.18^{JK}	28.32^{GH}	$1\,725^{H}$	15.52^{O}	4.54^{H}
3×6	50	89.31^{N}	21.97^{PQ}	$1\,725^{H}$	11.27^{W}	4.15^{IJ}
	100	97.50^{H}	29.78^{DE}	$1\,947^{D}$	14.11^{S}	5.22^{EF}
4×5	50	84.67^{P}	19.41^{ST}	$1\,644^{JK}$	11.77^{V}	4.97^{FG}
	100	92.50^{L}	27.11^{IJ}	$1\,774^{G}$	14.61^{PQ}	4.99^{FG}
4×6	50	87.81^{O}	22.52^{P}	$1\,866^{E}$	10.77^{X}	5.50^{DE}
	100	95.88^{IJ}	30.21^{D}	$2\,003^{C}$	14.61^{PQ}	5.54^{CD}
5×6	50	102.85^{F}	27.49^{HI}	$1\,889^{E}$	9.75^{Y}	6.50^{B}
	100	112.36^{D}	36.28^{A}	$2\,065^{B}$	13.59^{T}	7.18^{A}
'Bobcat'	50	79.31^{RS}	19.32^{ST}	$1\,655^{J}$	11.57^{V}	3.33^{OPQ}
	100	85.37^{P}	25.58^{MN}	$1\,714^{HI}$	18.96^{G}	4.89^{G}

Data in interaction analyzed with Least Squares Means and means separated with Tukey *post-hoc* test.
Values in groups in columns followed by the different letters are significant at the level of $P < 0.05$.

Effect of the genotypes and irrigation levels on the WUE of tomato

Both genotypes and irrigation amount influenced WUE significantly as shown in (Fig. 2). Both 1×6 and 5×6 irrigated with the 50% level treatment produced the highest WUE (33.32 and 33.34 kg m$^{3\,-1}$ respectively) and the lowest amount of WUE (7.74 kg m$^{3\,-1}$) was obtained in 'M.O' cv. irrigated with the 100% level treatment.

In WUE (Fig. 3), linear regression indicated a strong relationship with irrigation level lowering. The WUE increased linearly when the 50% irrigation level was lowered. The relationships recorded for WUE show a predicted $R^2 = 1.00$ and a line regression equation ($Y = -0.1668*X + 28.54$) for both irrigation levels. The highest WUE obtained in water-stressed plants could be attributed to a lower volume of water provided (50% of total water volume) in comparison to control plants, as well as a minor yield drop (fully irrigated-unsprayed plants). It is generally understood that, in times of water scarcity or drought, slowing the rate of water loss saves soil water for a longer period, resulting in a better yield and, as a result, higher WUE (Abd Allah, 2019; Liu *et al.*, 2021; Fullana-Pericàs *et al.*, 2022; Wu *et al.*, 2022).

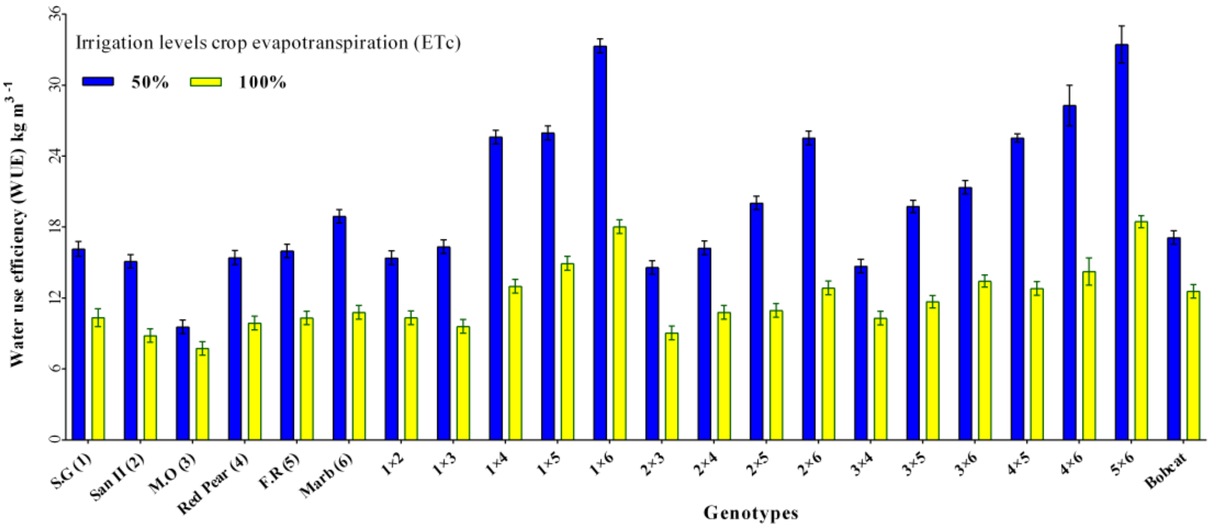

Figure 2. Effect of the genotypes × irrigation levels on water use efficiency of tomato plants yield

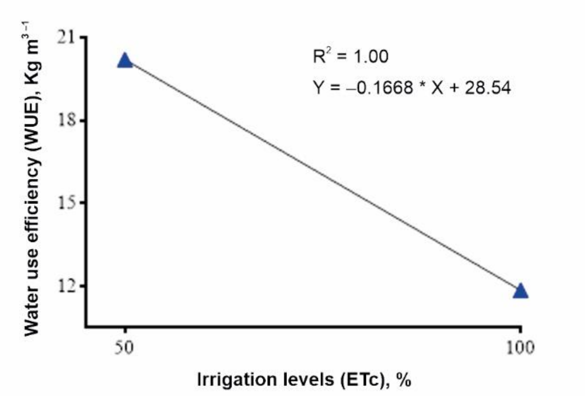

Figure 3. Effect of the irrigation amount analyzed with linear regression on water use efficiency for tomato plants yield.

Conclusion

The wide variation in all the genotypes might be due to their genetic makeup, which indirectly governs the morphology of the plant genetic differences between genotypes played a role in alleviating the negative impact of water deficit and improved vegetative growth and production of tomatoes plus water use efficiency. The plant height, number of branches, total leaf area and yield per plant in 100% ETc treated plants were the highest.

Funding statement

This research did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

GJH, AMA – designed the experimental setup;
GJH – analysed the data and results, and wrote the manuscript;
GJH – editing the manuscript.

References

Abd Allah, A. 2019. Impacts of Kaolin and Pinoline foliar application on growth, yield and water use efficiency of tomato (*Solanum lycopersicum* L.) grown under water deficit: A comparative study. – Journal of the Saudi Society of Agricultural Sciences, 18(3):256–268. DOI: 10.1016/j.jssas.2017.08.001

Abood, M.A., Al-Shammari, A.M.A., Hamdi, G.J. 2019. Foliar application of Tecamin flower® to alleviate water deficit on vegetative growth and yield of tomato. – International Journal of Vegetable Science, 25:394–399. DOI: 10.1080/19315260.2018.1535463

Aldubai, A.A., Alsadon, A.A., Al-Gaadi, K.A., Tola, E., Ibrahim. A.A. 2022. Utilizing spectral vegetation indices for yield assessment of tomato genotypes grown in arid conditions. – Saudi Journal of Biological Sciences, 29(4):2506–2513. DOI: 0.1016/j.sjbs.2021.12.030.

Allen R.G., Pereira L.S., Raes D., Smith M., and others. 1998. Crop Evapotranspiration-guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome.

Al-Mfargy, O.K.A. 2017. Effect of locations on production characters of tomato hybrid grown under greenhouse. – Diyala Agricultural Sciences Journal, 9:89–97.

Al-Mfargy, O.K.A., Al-Mfargy, F.M.M. 2015. Effect of fertilizer type on quantitative and qualitative yield characters of tomato (*Lycopersecun esclantum* Mill.) and some estimate genetic parameters. – Diyala Agricultural Sciences Journal, 7:202–216.

Al-Shammari, A.M.A., Abood, M.A., Hamdi, G.J. 2018. Tecamin flower® foliar application to alleviate water deficit effects on growth, yield and water use efficiency of tomato. – Agraarteadus, 29:115–120. DOI: 10.15159/jas.18.10

Black, C.A. 1965. Methods of soil analysis: Part 1, Physical and Mineralogical Properties. – American Society of Agronomy, Madison, Wisconsin, 770 p. DOI: 10.2134/agronmonogr9.1

Bota, J., Conesa, M.A., Ochogavia, J.M., Medrano, H., Francis, D.M., Cifre, J. 2014. Characterization of a landrace collection for Tomàtiga de Ramellet (*Solanum lycopersicum* L.) from the Balearic Islands. – Genetic Resources and Crop Evolution, 61: 1131–1146. DOI: 10.1007/s10722-014-0096-3

Casals, J., Pascual, L., Cañizares, J. Cebolla-Cornejo, J., F. Casañas, F., Nuez, F. 2012. Genetic basis of long shelf life and variability into Penjar tomato. – Genetic Resources and Crop Evolution, 59:219–229. DOI: 10.1007/s10722-011-9677-6

Conesa, M., Galmés, J., Ochogavía, J.M., March, J., Jaume, J., Martorell, A., Francis, D.M., Medrano, H., Rose, J.K.C., Cifre, J. 2014. The postharvest tomato fruit quality of long shelf-life Mediterranean landraces is substantially influenced by irrigation regimes. – Postharvest Biology and Technology, 93: 11–121. DOI: 10.1016/j.postharvbio.2014.02.014

Conesa, M.A., Fullana-Pericàs, M., Granell, A., Galmés, J. 2020. Mediterranean long shelf-life landraces: an untapped genetic resource for tomato Improvement. – Frontiers in Plant Science, 10:1–21. DOI: 10.3389/fpls.2019.01651

Cuartero, J., Fernández-Muñoz, R. 1999. Tomato and salinity. –Scientia Horticulturae, 78:83–125.

Dariva, M.D., Pessoa, H.P., Copati, M.G.F., de Almeida, G.Q., Filho, M.N.C., de Toledo Picoli, E., A., da Cunha, F.F., Nick, C. 2021. Yield and fruit quality attributes of selected tomato introgression lines subjected to long-term deficit irrigation. – Scientia Horticulturae, 289:110426. DOI: 10.1016/j.scienta.2021.110426

Day, P.R. 1965. 43-5 Hydrometer method of particle size analysis. – In Methods of soil analysis: Part 1. Physical and Mineralogical Properties. Black, C.A. (Ed.). – American Society of Agronomy, Madison, Wisconsin, USA, pp. 562–563.

Du, T., Kang, S., Zhang, J., Davies, W. J. 2015. Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security. – Journal of Experimental Botany, 66:2253–2269. DOI: 10.1093/jxb/erv034

FAOSTAT. 2021. – Food and agriculture data. http://www.fao.org/faostat Accessed 07/01/2019.

Fayezizadeh, M.R., Ansari, N.A.Z., Albaji, M., Khaleghi, E. 2021. Effects of hydroponic systems on yield, water productivity and stomatal gas exchange of greenhouse tomato cultivars. – Agricultural Water Management, 258:107171. DOI: 10.1016/j.agwat.2021.107171

Fullana-Pericàs, M., Conesa, M.A., Gago, J., Carbó, M.R., Galmés, J. 2022. High-throughput phenotyping of a large tomato collection under water deficit: Combining UAVs' remote sensing with conventional leaf-level physiologic and agronomic measurements. – Agricultural Water Management, 260:107283. DOI: 10.1016/j.agwat.2021.107283.

Giovannoni, J.J. 2006. Breeding new life into plant metabolism. – Nature Biotechnology, 24:418–419. DOI: 10.1038/nbt0406-418

Giuliani, M.M., Carucci, F., Nardella, E., Francavilla, M., Ricciardi, L., Lotti, C., Gatta, G. 2018. Combined effects of deficit irrigation and strobilurin application on gas exchange, yield and water use efficiency in tomato (*Solanum lycopersicum* L.). – Scientia Horticulturae, 233:149–158. DOI: 10.1016/j.scienta.2018.01.052

Giuliani, M.M., Gagliardi, A., Nardella, E., Carucci, F., Amodio, M.L., Gatta, G. 2019. The effect of strobilurin on ethylene production in flowers, yield and quality parameters of processing tomato grown under a moderate water stress condition in Mediterranean area. – Scientia Horticulturae, 249: 155–161. DOI: 10.1016/j.scienta.2019.01.050

Hamdi, G.J. 2022. Estimate the genetic distance and genetic parameters of growth characteristics and yield of tomato using half diallel cross under water stress. – PhD Thesis. University of Diyala, Baqubah, Iraq, 28/06/2022, 218 pp.

Jackson, M.L. 1958. Soil chemical analysis. – Verlag: Prentice-Hall Inc, Englewood Cliffs, NJ., USA, pp. 251–252.

Klee, H.J., Giovannoni, J.J. 2011. Genetics and control of tomato fruit ripening and quality attributes. – Annual Review of Genetics, 45:41–59. DOI: 10.1146/annurev-genet-110410-132507

Liu, J., Hu, T., Feng, P., Yao, D., Gao, F., Hong, X. 2021. Effect of potassium fertilization during fruit development on tomato quality, potassium uptake, water and potassium use efficiency under deficit irrigation regime. – Agricultural Water Management, 250:106831. DOI: 10.1016/j.agwat.2021.106831

Lu, J., Shao, G., Cui, J., Wang, X., Keabetswe, L. 2019. Yield, fruit quality and water use efficiency of tomato for processing under regulated deficit irrigation: A meta-analysis. – Agricultural Water Management, 222:301–312. DOI: 10.1016/j.agwat.2019.06.008

Lu, J., Shao, G., Gao, Y., Zhang, K., Wei, Q., Cheng, J. 2021. Effects of water deficit combined with soil texture, soil bulk density and tomato variety on tomato fruit quality: A meta-analysis. – Agricultural Water Management, 243:106427. DOI: 10.1016/j.agwat.2020.106427

Medrano, H., Tomás, M., Martorell, S., Flexas, J., Hernández, E., Rosselló, J., Pou, A., Escalona, J.M., Bota, J. 2015. From leaf to whole-plant water use efficiency (WUE) in complex canopies: limitations of leaf WUE as a selection target. – The Crop Journal, 3:220–228. DOI: 10.1016/j.cj.2015.04.002

Mickelbart, M.V., Hasegawa, P.M., Bailey-Serres, J. 2015. Genetic mechanisms of abiotic stress tolerance that translate to crop yield stability. – Nature Reviews Genetics, 16:237–251. DOI: 10.1038/nrg3901

Patanè, C., Scordia, D., Testa, G., Cosentino, S.L. 2016. Physiological screening for drought tolerance in Mediterranean long-storage tomato. – Plant Science, 249:25–34. DOI: 10.1016/j.plantsci.2016.05.006

Sacco, A., Cammareri, M., Vitiello, A., Palombieri, S., Riccardi, R., Spigno, P., Grandillo, S. 2017. Italian traditional tomato varieties: a focus on the campania region. In I Congrés de La Tomaca Valenciana: La Tomaca Valenciana d'El. – Perelló, 17 de Maig de 2017, pp. 179–193. DOI: 10.4995/TOMAVAL2017.2017.6526

Sallume, M.O., Abood, M.A., Hamdi, G.J., Sarheed, B.R. 2020. Influence of foliar fertilization of amino decanate® on growth and yield of eggplant (*Solanum melongena*) under water stress condition. – Research on Crops, 21:557–562. DOI: 10.31830/2348-7542.2020.087

The Tomato Genome Consortium. 2012. The tomato genome sequence provides insights into fleshy fruit evolution. – Nature, 485:635–641. DOI: 10.1038/nature11119

Wang, D., Kang, Y., Wan, S. 2007. Effect of soil matric potential on tomato yield and water use under drip irrigation condition. − Agricultural Water Management, 87: 180–186.

Wu, Y., Yan, S., Fan, J., Zhang, F., Xiang, Y., Zheng, J., Guo, J. 2021. Responses of growth, fruit yield, quality and water productivity of greenhouse tomato to deficit drip irrigation. – Scientia Horticulturae, 275:109710. DOI: 10.1016/j.scienta.2020.109710

Wu, Y., Yan, S., Fan, J., Zhang, F., Zhao, W., Zheng, J., Guo, J., Xiang, Y., Wu, L. 2022. Combined effects of irrigation level and fertilization practice on yield, economic benefit and water-nitrogen use efficiency of drip-irrigated greenhouse tomato. – Agricultural Water Management, 262: 107401. DOI: 10.1016/j.agwat.2021.107401

Zhao, T., Nakano, A., Iwasaki, Y. 2021. Differences between ethylene emission characteristics of tomato cultivars in tomato production at plant factory. Journal of Agriculture and Food Research, 5:100181. DOI: 10.1016/j.jafr.2021.100181