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Effect of water stress on yield and physiological traits among selected African tomato (*Solanum lycopersicum*) land races

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Abstract

Expansion of tomato farming in dryland regions of Kenya has the potential to improve livelihoods and food security of rural farmers. However, the crop is very sensitive to water deficit that has made its expansion in dry-land regions of the country to nearly impossible. Crop landraces have been continuously used to develop varieties adapted to abiotic stresses such as drought. In Africa, tomato has a rich genetic resource base which is largely undocumented and whose knowledge can aid in the identification of genotypes with desirable traits for breeding. The objective of this study was to evaluate the variation in response to water stress on yield and physiological traits of twenty (20) African tomato accessions from the World Vegetable Centre and the National Genebank of Kenya. Planting was done in a greenhouse in a randomized complete block design with three replications and subjected to four soil moisture levels of 100% Pot capacity (PC), 80% PC 60% PC and 40% PC. The response to water stress was mainly dependent on the genotype and reduction in moisture significantly reduced the SPAD value, leaf relative water content, stomatal conductance, the number of fruits per plant and fruit weight per plant. However, canopy temperature increased with the decrease in moisture level. Variations among accessions for fruit weight per plant ranged from 521-2404.3 g (100% PC), 421.3-2020.7 g (80% PC), 359.3-1768.3 g (60% PC) and 127.3-1487.7 g (40% PC). This variability shows the potential among the African tomato accessions for breeding drought-tolerant tomato varieties.

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Introduction

Tomato (*Solanum lycopersicum)* is a fruit vegetable that belongs to the family Solanaceae which consists of approximately 100 genera and 2500 species, including several plants of agronomic importance such as potato, eggplant, pepper, and tobacco (Olmstead *et al*., 2008). The crop which is the second most important vegetable crop cultivated in the world (Foolad, 2007) is native to South America (Blanca *et al*., 2012). Tomato fruits are cooked as vegetables or used as salad and sometimes processed to tomato paste, tomato sauce, tomato juice and ketchup. According to Mbaka *et al*., (2013), tomato is an economically important horticultural crop in Kenya that has the potential of improving the livelihood of the poor rural farmers. Consumption of tomato fruit has gained importance due to its rich antioxidant property known to reduce cancer incidences (Wamache, 2005). According to Wang *et al.,* (2011), tomato fruit contains lycopene, β-carotene, ascorbic acid and phenolic compounds, which have nutritional benefits to consumers.

One of the major constraints to tomato production in dryland areas of Kenya is the lack of adequate rainfall. This is because the crop is very sensitive to water deficit that reduces fruit yield and results in possible crop failure (Sibomana *et al*., 2013). The current global warming, which causes fluctuations in precipitation distribution, further increases the risk of this plant being repeatedly exposed to drought (Miyashita *et al*., 2005). However, provisions of appropriate amount of water and breeding for drought tolerance are few of the practices that can ameliorate these challenges in dry lands. According to Nuruddin, (2003), sensitivity to water deficit varies among different crops and genotypes. Such variations have been found in crop landraces which are often characterized by good stress tolerance and local adaptability (Newton *et al*., 2010).

According to Torrecillas *et al.,* (1995), tolerance to water stress can be found in wild species of crops. These genotypes have the potential of growing under conditions that present minimum water. This characteristic is important and can be introduced into commercial varieties with good agronomic characteristics (Ashraf, 2010). African tomatoes are landraces with dynamic populations, distinct identities and lack of formal crop improvement. To date, a large number of these landraces have been collected and stored in genebanks and research organizations. However, very few of them have been systematically evaluated for their adaptability to drought (Robertson and Labate, 2007). It is for this reason that this study aimed at estimating the variability among selected African tomato accessions in yield and physiological traits under varying moisture levels.

Materials and methods

Study site

The study was conducted at the University of Nairobi's Upper Kabete Campus field station, Kenya, in the year 2015. It is geographically located at an altitude of 1940 meters above sea level and between latitude 1° 14' 20' South and 1° 15' 15'North and longitude 36° 44' East.

Treatment and treatment allocation

Seeds of 20 African tomato accessions sourced from the World Vegetable Centre (AVRDC) and the National Genebank of Kenya were used (Table 1). Four (4) weeks old seedlings were transplanted into 10 liter pots and arranged in a randomized complete block design (RCBD). Ten kilograms of sterilized air dried soil (a mixture of sand, topsoil, and manure at the ratio of 2:4:1) was used to fill the pots. Four pots with one seedling each were randomly assigned to each of the four watering regimes throughout their growth cycle. The amount of water added was determined based on the percentage of pot water capacity (Sibomana *et al*., 2013). Treatments included: 100% of pot capacity (PC) or control (3000 ml), while stress was achieved by applying 80% (80% of PC), 60% (60% of PC) and 40% (40% of PC) of the amount of water applied to the control plant (Sibomana *et al*., 2013). The pots were covered with black plastic material to prevent evaporation and placed on top of a plastic paper to avoid direct contact with the soil surface.

Table 1. List of selected African tomato landraces evaluated in the study.

SL. No.	Accession name	Species name	Origin
1	GBK 050580	*S. lycopersicon*	Kenya
2	GBK 050580	*S. lycopersicon*	Kenya
3	RVI01896	*S .lycopersicon*	Madagascar
4	RVI02100	*S. lycopersicon*	Madagascar
5	RVI02107	*S. lycopersicon*	Madagascar
6	VI005871	*S. lycopersicon*	Morocco
7	VI005874	*S. lycopersicon*	Morocco
8	VI005876	*S. lycopersicon*	Morocco
9	VI005895	*S. lycopersicon*	Egypt
10	VI006826	*S. lycopersicon*	Ethiopia
11	VI006841	*S. lycopersicon*	Ethiopia
12	VI006847	*S. lycopersicon*	Ethiopia
13	VI006881-B	*S. lycopersicon*	Zimbabwe
14	VI006972	*S. lycopersicon*	Tanzania
15	VI007539	*S. lycopersicon*	South Africa
16	VI007540	*S. lycopersicon*	South Africa
17	VI008234	*S. lycopersicon*	Nigeria
18	VI030379	*S. lycopersicon*	Mauritius
19	VI030852	*S. lycopersicon*	South Africa
20	VI037948	*S. lycopersicon*	Zambia

Data collection

Data were taken at 50% days to flowering from three randomly tagged tomato plant accessions for SPAD value, leaf relative water content (LRWC), stomatal conductance and canopy temperature. Numbers of fruits per plant and weight of fresh fruits per plant were recorded as candidate plants had their fruits attain physiological maturity.

Chlorophyll measurements were done on two fully opened leaves in each plant using SPAD (Minolta SPAD 502 chlorophyll meter). Leaf relative water content (LRWC) was calculated according to Yamasaki and Dillenburg (1999) formula, LRWC (%) = [(FM – DM)/(TM – DM)] x 100. Stomatal conductance was determined using a leaf porometer (Model Sc-1, Decagon Devices, Pullman, USA) and expressed in millimoles per meter squared seconds (mmol/m^{2}s) as suggested by Chakhchar *et al.*, (2016). Canopy temperature was measured according to Turner *et al.* (1986) using an infra-red thermometer (Model THI-500, TASCO, Japan).

Statistical analysis of data

All the data collected were subjected to the analysis of variance (ANOVA) using GENSTAT Release 7.2 Discovery Edition 15. Treatment means were separated using Fisher's least significant difference (F-LSD) at 5 % level of significance.

Results

SPAD value

SPAD value was significantly ($P<0.05$) reduced by moisture deficit (Table 2). Similarly, variation among accessions was significant and ranged from 48.3 to 58.1 (100% PC), 47.6 to 57.1(80% PC), 46.8 to 56.9 (60% PC) and 46.3 to 56.8 (40% PC).

Table 2. Mean values for SPAD value and leaf relative water content among the 20 selected tomato accessions grown in the greenhouse under different water levels.

	SPAD value					Percentage leaf relative water content				
Accession name	100%PC	80%PC	60%PC	40%PC	Mean	100%PC	80%PC	60%PC	40%PC	Mean
GBK 050580	52.00	50.67	50.03	49.97	50.67	94.38	92.73	62.24	43.05	73.10
GBK 050589	52.27	51.77	50.60	50.27	51.23	92.94	92.86	58.93	42.86	71.90
RVI01896	55.80	54.07	51.73	47.57	52.29	77.17	68.24	58.34	54.82	64.64
RVI02100	53.97	51.57	51.20	50.27	51.75	85.12	77.55	65.78	47.31	68.94
RVI02107	51.73	50.37	50.07	49.30	50.37	80.10	75.34	52.41	47.14	63.75
VI005871	54.77	53.53	51.73	49.27	52.33	77.94	75.76	60.65	56.00	67.59
VI005874	51.30	51.00	49.77	48.57	50.16	86.15	81.11	74.13	49.86	72.81
VI005876	57.67	57.60	56.93	56.77	57.24	80.55	69.29	54.61	49.35	63.45
VI005895	56.67	54.23	53.70	52.63	54.31	86.79	83.80	67.87	47.88	71.58
VI006826	52.10	50.73	49.73	49.40	50.49	89.27	80.50	72.25	63.62	76.41
VI006841	49.83	48.47	47.63	47.60	48.38	88.40	87.43	53.06	47.21	69.02
VI006847	57.27	54.17	53.53	50.27	53.81	84.14	76.36	65.81	46.36	68.17
VI006881-B	51.40	49.10	47.97	47.30	48.94	85.40	82.16	57.40	55.40	70.09
VI006972	55.43	54.87	52.43	51.73	53.62	84.04	82.91	54.62	49.85	67.85
VI007539	50.70	49.50	48.20	46.87	48.82	85.63	76.32	61.61	48.98	68.14
VI007540	53.63	52.37	50.60	50.30	51.73	76.75	72.02	68.18	53.91	67.72

	SPAD value					Percentage leaf relative water content				
Accession name	100%PC	80%PC	60%PC	40%PC	Mean	100%PC	80%PC	60%PC	40%PC	Mean
VI008234	48.30	47.57	46.80	46.30	47.24	81.38	75.57	64.47	59.43	70.21
VI030379	56.43	55.87	53.87	51.60	54.44	86.98	80.35	58.74	53.50	69.89
VI030852	52.83	52.20	51.30	47.77	51.02	85.04	83.51	73.33	51.40	73.32
VI037948	58.10	56.13	55.83	50.93	55.25	87.92	73.31	66.53	46.81	68.64
MEAN	53.61	52.29	51.18	49.73		84.80	79.36	62.55	50.74	
l.S.D (P<0.05) Acc	1.22**							5.50**		
l.S.D (P<0.05)ML	0.55**							2.46**		
l.S.D (P<0.05)Acc*ML	2.44ns							10.99**		
CV%	2.90							9.80		

Acc -accession, ML- Moisture level, PC-field capacity, **-Highly significant, ns-Not significant.

Relative water content

Water stress had significant (P<0.05) effect on relative water content, and differences among genotypes were significant (Table 2). Values for RWC ranged from 76.8 to 94.4% (100% PC), 68.2 to 92.9% (80% PC), 52.4 to 74.1% (60% PC) and 42.9 to 63.6% (40% PC). Highest reduction in relative water content was in accessions VI037948 (80% PC), VI006841 (60% PC) and GBK 050580 (40% PC) while it was recorded lowest in GBK 050589 (80% PC), VI007540 (60% PC) and VI005871 (40% PC).

Canopy temperature

Results showed that there were significant differences (P≤0.05) in canopy temperature among the genotypes (Table 3). Canopy temperatures ranged from 21.6°C to 28.9°C (100% PC), 25.0°C to 31.0°C (80% PC), 27.7°C to 32.5°C (60% PC) and 30.8°C to 34.6°C (40% PC). Moisture stress increased canopy temperature with the highest increase observed in VI007540 (80% PC), VI006881-B (60% PC) and VI005876 (40% PC). Similarly, least increases were recorded in VI006972 at 80% PC, GBK 050580 at 60% PC and RVI02107 at 40% PC.

Stomatal conductance

Water stress significantly (P≤0.05) reduced the stomatal conductance in the 20 tomato genotypes (Table 3). Stomatal conductance for the different moisture levels ranged from 207.7 mmol/m²s to 287.5 mmol/m²s (100% PC), 115.5 mmol/m²s to 196.7 mmol/m²s (80% PC), 104.0 mmol/m²s to 100.1 mmol/m²s (60% PC) and 74.0 mmol/m²s to 100.1 mmol/m²s (40% PC). Minimum reduction was recorded in RVI01896 at the three water stressed conditions, while maximum reduction was observed in VI006881-B at 80% and 60% PC as well as in VI007579 at 40% PC.

Table 3. Mean values for canopy temperature and stomatal conductance among the 20 selected tomato accessions grown in the greenhouse under different water levels.

	Canopy temperature (°C)					Stomatal conductance (mmolm⁻²s)				
Accession number	100%PC	80%PC	60%PC	40%PC	Mean	100%PC	80%PC	60%PC	40%PC	Mean
GBK 050580	28.23	28.93	30.00	30.77	29.48	228.57	183.83	119.00	90.40	155.40
GBK 050589	25.60	31.03	31.43	34.43	30.62	235.05	168.33	119.63	90.63	153.40
RVI01896	23.47	25.03	27.73	33.87	27.52	207.67	166.87	128.00	93.23	148.90
RVI02100	27.70	29.33	30.90	31.60	29.88	215.20	196.67	133.73	86.67	158.10
RVI02107	28.30	29.27	30.20	30.77	29.63	227.13	183.95	126.08	93.65	157.70
VI005871	28.87	29.63	32.27	33.43	31.05	261.87	127.62	112.55	90.38	148.10
VI005874	23.50	27.30	30.33	31.53	28.17	260.20	194.78	137.75	100.10	173.20
VI005876	21.60	26.57	30.77	32.80	27.93	231.97	174.95	118.18	95.98	155.30
VI005895	24.00	27.87	31.63	33.50	29.25	238.47	191.80	128.07	94.22	163.10
VI006826	24.00	28.60	30.50	33.93	29.26	287.47	165.10	127.57	86.37	166.60
VI006841	24.60	29.93	32.50	34.60	30.41	264.17	184.27	133.67	90.05	168.00
VI006847	25.33	27.53	31.37	32.13	29.09	223.92	115.50	103.97	90.05	133.40
VI006881-B	22.13	27.03	32.37	33.23	28.69	275.97	134.65	110.65	92.12	153.30
VI006972	25.37	26.03	30.67	33.30	28.84	245.80	195.13	155.67	86.47	170.80
VI007539	23.97	28.17	31.87	32.50	29.12	283.13	176.57	137.13	87.45	171.10

	Canopy temperature (°C)					Stomatal conductance ($mmolm^{-2}s$)				
Accession number	100%PC	80%PC	60%PC	40%PC	Mean	100%PC	80%PC	60%PC	40%PC	Mean
VI007540	22.50	28.60	32.43	33.37	29.23	254.16	135.58	107.97	87.55	146.30
VI008234	25.50	29.73	32.33	32.80	30.09	254.63	175.22	134.05	73.95	159.50
VI030379	22.63	27.27	31.90	33.33	28.78	231.10	126.47	113.27	89.30	140.00
VI030852	24.80	27.57	31.10	34.13	29.40	248.63	153.65	115.93	86.40	151.20
VI037948	24.33	27.63	31.53	33.70	29.30	271.55	183.32	115.52	92.97	165.80
MEAN	24.82	28.15	31.19	32.99		247.33	166.71	123.92	89.90	
l.s.d(P<0.05) Acc	1.02**					8.82**				
l.s.d.(P<0.05)ML	0.46**					3.94**				
l.s.d.(P<0.05)Acc*ML	2.04**					17.63**				
cv%	4.30					7.00				

Acc-accession, ML-water level, Acc*ML- interaction, **-Highly significant.

Number of fruits per plant

The main effects (genotype and moisture treatments) were significant for number of fruits per plant and fruit weight per plant (Table 4). Average fruit count per plant ranged from 15.0 to 243.6 (100% PC), 12.6 to 211.0 (80% PC), 9.0 to 158.3 (60% PC) and 5.6 to 126.6 (40% PC). Accession VI037948 was the most sensitive to water stress recording the highest reduction in number of fruits while least reduction was in VI005876. On the basis of fruit weight per plant, genotype VI005895 exhibited better results than most other genotypes at 80%, 60% and 40% PC treatments. Thus, it can be considered the most water stress tolerant genotype among the 20 genotypes. Lowest reduction in fruit weight was observed in accession GBK 050580 while highest reduction at 80% PC was observed in VI030852 as well as in VI007540 at 60% and 40% PC.

Table 4. Mean values for total number of fruits per plant and total fruit weight per plant among the 20 selected tomato accessions grown in the greenhouse under different water levels.

	Total number of fruits per plant					Total fruit weight per plant (g)				
Accession name	100%PC	80%PC	60%PC	40%PC	Mean	100%PC	80%PC	60%PC	40%PC	Mean
GBK 050580	189.83	181.33	112.33	87.00	142.62	574.70	532.00	504.70	466.30	519.00
GBK 050589	164.67	152.33	144.67	123.33	146.25	521.00	421.30	359.30	268.30	392.00
RVI01896	105.67	98.00	86.00	71.67	90.33	639.70	567.00	440.00	347.30	498.00
RVI02100	20.67	19.00	15.67	12.00	16.83	1759.70	1536.70	1205.30	874.00	1344.00
RVI02107	19.00	18.33	15.67	11.33	16.08	2225.00	2020.70	1623.30	1131.70	1750.00
VI005871	21.33	20.33	18.67	15.00	18.83	1917.00	1743.70	1450.70	1142.00	1563.00
VI005874	21.67	20.33	17.67	16.00	18.92	1864.00	1723.00	1421.70	1232.70	1560.00
VI005876	17.67	17.33	15.67	13.33	16.00	1019.00	966.30	787.00	127.30	725.00
VI005895	41.00	38.33	35.33	32.00	36.67	2228.30	1979.00	1768.30	1487.70	1866.00
VI006826	37.00	34.33	29.67	27.00	32.00	1947.70	1744.00	1431.70	1184.70	1577.00
VI006841	147.00	130.67	115.67	101.00	123.58	1334.00	1259.00	1057.00	782.70	1108.00
VI006847	114.33	105.33	95.67	86.00	100.33	1168.30	1000.70	842.00	616.00	907.00
VI006881-B	180.67	151.67	130.33	109.67	143.08	610.30	460.00	366.70	253.00	422.00
VI006972	145.00	133.67	109.33	99.00	121.75	1781.30	1537.30	1108.30	974.70	1350.00
VI007539	15.00	12.67	9.00	6.67	10.83	1109.30	852.30	567.00	299.00	707.00
VI007540	19.67	16.33	11.00	8.33	13.83	2174.70	1783.70	1091.30	817.30	1467.00
VI008234	52.67	48.33	42.33	38.00	45.33	1560.30	1359.70	1117.70	891.70	1232.00
VI030379	23.67	18.67	15.67	12.00	17.50	1468.30	1128.00	897.70	655.30	1037.00
VI030852	49.67	46.67	43.67	39.67	44.92	2404.30	1985.70	1651.00	1436.00	1869.00
VI037948	243.67	211.00	158.33	126.67	184.92	1000.30	769.30	510.70	371.70	663.00
MEAN	81.49	73.73	61.12	51.78		1465.40	1268.50	1010.10	768.00	
l.s.d(P<0.05) Acc	4.88 **					66.40**				
l.s.d.(P<0.05)ML	2.18**					29.70**				
l.s.d.(P<0.05)Acc*ML	9.75**					132.80**				
CV%	9.00					7.30				

Acc - accession, ML- Moisture level, PC-field capacity, **-Highly significant.

Correlation analysis

A significant relationship between fruit yield and physiological traits was observed (Table 5). Fruit yield correlated positively with relative water content and stomatal conductance. However, it recorded a significant but negative correlation with canopy temperature.

Table 5. Correlation between fruit yield and physiological traits among the studied accessions.

	FWPP	RWC	SPAD	CP	SC
FWPP	-				
RWC	0.33**	-			
SPAD	0.12^{ns}	0.27*	-		
CP	-0.28*	-0.68**	-0.37**	-	
SC	0.40**	0.77**	0.25*	-0.84**	-

FWPP-fruit weight per plant, RWC-relative water content, SPAD-chlorophyll levels, CP-canopy temperature, SC-stomatal conductance, **highly significant correlation, *significant correlation, ns-not significant correlation.

Discussion

Effect of water stress on physiological traits

SPAD values decreased with increase in moisture deficit. This finding conforms to that by Gong *et al.*, (2005) who found that reduction in chlorophyll content under moisture deficit could be attributed to the fact that water stress damages the photosynthetic apparatus by causing changes in the chlorophyll contents and components.

According to Yamasaki and Dillenburg (1999), relative water content (RWC) is an appropriate physiological measure of plant water status under water stress condition. In the current study, relative water content reduced with an increase in moisture stress. Similar reductions were reported in tomato by Sibomana *et al.* (2013) who noted that decreased leaf water potential leads to stomatal closure and ultimately results in low transpiration.

An increase in canopy temperature under moisture deficit, as observed in this study, confirms the findings of Siddique *et al.*, (2001). According to the authors, the increase in temperature probably occurs due to the decrease in plant transpiration caused by the closure of stomata, this being the main cooling mechanism for plants.

Reduction in stomatal conductance with increased level of moisture deficit was observed. This finding is in consonance with that of Sibomana *et al.* (2013). According to Turan *et al.* (2009), during water stress, plants respond by closing their stomata to protect themselves from excessive water loss during transpiration.

Effect of water stress on fruit yield

According to Ramadasan *et al.* (1993), the final yield of the crop is a product of combined effects of stress on growth and physiological processes. Reduction in fruit yield with increased level of water stress could be attributed to a decline in photosynthesis due to the decreases in chlorophyll content, leaf area, and efficiency of carbon fixation and closure of stomata. Yield reduction could also be associated to decline in nutrient uptake under moisture stress conditions. According to Kozlowski, (1972), most of the water is required for the development of reproductive organs since the growth of the flower and fruit involves the rapid accumulation of dry matter and water.

Effect of water stress on correlation analysis among the traits

Positive and significant association of fruit yield with relative water content (RWC) and stomatal conductance, as observed in this study, is in agreement with the results of David (2002). This author reported that the reduction of relative water content caused a strong reduction in photosynthesis, transpiration, and stomatal conductance. This shows that plants with both high relative water content and high stomatal conductance tend to yield higher than those with lower RWC and restricted stomatal conductance.

Conclusion

Response to varying water levels among the traits evaluated depended largely on the tomato genotype. Reduction in moisture led to a decrease in the SPAD value, leaf relative water content, stomatal conductance, and fruit yield. However, canopy temperature significantly increased among all the accessions with the reduction in moisture levels. Significant interactions between accessions and moisture level clearly indicate the importance of moisture level in physiological processes and fruit formation in tomato production.

Variation among the accessions to varying moisture levels as observed in this study indicates a rich source of diversity among the African tomato germplasm. This finding provides an opportunity to select genotypes that have the potential of being used to breed drought-tolerant tomato varieties. The positive and significant correlations between fruit yield, stomatal conductance, and leaf relative water content clearly indicates that crop improvement for drought tolerance in tomato should focus on these traits. Similar work can be carried out under field conditions in different agro-ecological conditions. Further investigation may be carried out to compare these landraces against commercial varieties grown in Kenya.

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