e-ISSN:2320-0189
p-ISSN:2347-2308

Research and Reviews: Journal of Botanical Sciences

Performance of Durum Wheat Genotypes under Drought and Terminal Heat Stress Conditions in Changing Climatic Conditions

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Research Article

Received date: 25/05/2016

Accepted date: 20/08/2016

Published date: 23/08/2016

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Keywords: Chla fluorescence, heat stress,drought stress, durum wheat, genotypes.

ABSTRACT

Durum wheat (*Triticum durum* L.), is an economically important crop, contributing in human nutrient and numerous past food products hence is of great commercial importance. Its production is restricted due to multiple environmental stresses *i.e.,* drought and heat stress. Here comparative analysis of durum wheat varieties such as MACS 3125, HI 8627, DBP 02-08 and IWP 5013 was done by studying physiological, yield and yield contributing traits to evaluated their performance under stress conditions during late sown conditions. The study showed that there is significant difference in yield and yield contributing traits *i.e.,* grain yield/plant, 1000 grain weight, biomass/plant, number of tiller/plant, sedimentation value and total carotene content in stress tolerant and sensitive genotypes. In addition, it was observed that physiological traits like canopy temperature, Chlorophyll (Chl)-*a* fluorescence and root coring could be used as stress markers in field conditions to screen stress tolerant and sensitive wheat genotypes under adverse conditions. This finding suggests that durum wheat genotypes are found to differ in their ability to respond to drought and high temperature, thereby tolerance durum genotypes could be useful as genetic stock to develop wheat tolerant varieties in breeding programs. In addition there is significant difference in traits like canopy temperature, Chl-*a* fluorescence and root coring in stress tolerant and sensitive genotypes. This suggests that these parameters can prove to be reliable parameters to assess stress tolerance.

INTRODUCTION

Durum wheat account around 10 to 11% wheat is growing area around the world, accounting about 8% of the total wheat production, it serves as the raw material for numerous foods such as macaroni, pasta products and semolina in the nourishment of world population. In India durum wheat, can serves as good supplement of nutrient for the large population as it is good source of protein, total carotene and micronutrients and due to more market value in national and international market, it helps to support India economy. However, due to huge yield reduction and quality loss of wheat crop due to drought and heat stress particularly at the time of grain filling is receiving great concern to develop stress tolerance wheat cultivars [1-3]. Physiological responses of wheat crop to stress have been found to effectively determine genotype resistance or susceptibility [4]. The drought and heat stress at anthesis and grain-filling stages accelerate maturity and significantly reduce grain size, weight and yield [5]. There is scope of developing durum wheat under unfavourable conditions; especially high temperature and water deficit [6,7]. Plant photosynthetic rate, metabolism and other plant activities are affected by these stress All these impaired physiology of wheat plant under stress restrict plant growth and productivity, particularly when it occurs during reproductive stages [4,8]. There is urgent need for immediate attention to developed stress tolerance wheat genotypes by combination different approaches. Plant breeders always look for appropriate and repeatable indicators to screen germ-plasms for stress tolerance [9,10]. Canopy temperature, Chlorophyll (Chl)-*a* fluorescence, root coring and other physiological parameters might be helpful to identify tolerable germplasm to overcome yield loss under drought and terminal heat stress [11-13]. There are many *in vitro* studies of bread wheat plants in combination with genetic manipulation to develop heat tolerant wheat but they are of limited success. Therefore, the complex physiological–genetic approach could be useful to acquire stress tolerance in wheat to minimize the farmer's risk for reduced yield and low quality grain product. Therefore, for the first time in central India experiment was conducted for the evaluation of durum wheat genotypes in field conditions to check the performance of stress tolerate and sensitive genotypic response to drought and late heat stress.

MATERIAL AND METHODS

Experimental Conditions

The durum wheat genotypes (*Triticum durum* L.) viz., MACS 3125, HI 8627, DBP-02-08 and IWP 5007 were selected for field experiment at Indian Agricultural Research Institute-Regional Station, Indore (M.P), India. The experimental field is situated between 22˚37′ N latitude to 75˚50′ E longitude at 557m above MSL having semi-arid and humid climate with a temperature range of 23˚C to 41˚C and 7˚C to 29˚C in summer and winter seasons, respectively. In this area, most of the rainfall is received during south-west monsoon *i.e.,* between June to September, with occasional showers in winter. Sowing was done under very late sown condition i.e., 25th of December in line format of 2.5 m long, two row each keeping the row to row distant 18 cm and in randomized block design over the 3 years. Weakly maximum and minimum temperature were recorded. Genotypes MACS 3125, HI 8627 were taken as heat tolerant and DBP-02-08 and IWP 5007 were taken heat sensitive.

Irrigation Conditions and Data Recoding

Very late sowing was done on 25th of December to maintain the heat stress conditions at the time of grain filling, nitrogen, phosphorus and potassium applications @ 100, 50 and 25 kg ha^{-1}, respectively and only one irrigation were provided for seed germination and to maintain the water stress conditions throughout the plant cycle. Canopy temperature, chlorophyll fluorescence, number of tillers/plant, biological yield/plant, number of grains/spike, 1000 grain weight, grain yield/plant, sedimentation value and total carotene content were measured at different stages of plant life cycle from vegetative stage to maturity and further.

Canopy Temperature

Canopy temperature measurements were made using a hand-held infrared thermometer (Model LT-300 sixth sense, USA). Six measurements were taken 3 times during pre-anthesis (18°C to 23°C) and 3 times during post-anthesis (33°C to 39°C) period, at the time interval of eight days at 0.5 m from the edge of the line and 0.5 m above the canopy with an angle of 30-60° from the horizontal approximately. Canopy temperatures (CT) were measured between 12:00 to 14:00 hours on cloudless and bright days taking all the precautions to avoid errors.

Chlorophyll Fluorescence

Measurement of fast kinetics of Chl *a* fluorescence: The polyphasic Chlorophyll *a* (Chl *a*) fluorescence was measured using a Plant Efficiency Analyzer (PEA, Hansatech, King's Lynn, Norfolk, UK) during vegetative stage (normal temperature and water stress) and post anthesis (grain filling conditions) *i.e.,* after facing high temperature conditions and water stress. Leaves were dark adapted for 15 min before fluorescence measurements. Details can be seen in [14].

Root Coring

After harvesting, root coring of high yielding and low yielding durum wheat cultivars was done. Soil samples with roots were taken from different soil depths *viz*. 10, 20, 30, 40 and 50 cm. The roots were thoroughly washed, air-dried and observations on root length, root diameter, root volume and root weight were recorded using Win-Rhizo Scanner Root Analyzer.

Yield Contributing Traits

Yield and yield contributing components like grain yield/plant, biological yield/plant, 1000 grain weight, number of tillers/plant, number of grains/spike, sedimentation value, total carotene were recorded. Data analysis was done using software SPAR 1.

RESULTS AND DISCUSSION

To evaluate the performance of durum wheat genotypes against drought and terminal heat stress, two stress tolerant genotypes and two sensitive durum wheat genotypes based on the yield performance were examined for consecutive three years under field conditions of central India. The mean and range of the yield and yield components has been tabulated in **Table 1 (Figure 1).** There is significant difference among the traits in stress tolerance and stress sensitive genotypes. The mean of grain yield were 20.2 g and 10.5 g in stress tolerant and stress sensitive genotypes. The mean values of 1000 grain weight and biomass/plant were 41.8, 41.4 and 36.1, 31.8 respectively, similarly number of grains/spike and canopy temperature showed the mean values 51.1, 21.3, 25.3 and 40.0, 21.2, 26.4. Sedimentation value showed mean values of 21.7 and 24.7 respectively, in stress tolerance and stress sensitive genotypes. Here stress tolerant genotypes showed higher means values of the traits; this shows the adaptability of the stress tolerant genotypes under adverse conditions. In contrast, number of tiller/ plant and total carotene content showed mean value of 39.3, 3.8 and 42.3, 4.1 indicating the possibility to improve these traits in stress tolerant genotypes, high value of carotene content in heat sensitive genotypes also indicate that during stress conditions the plants increase the release of their secondary metabolism to recover themselves from stress conditions [15,16]. In this study, canopy temperature has been used as one of the selection parameter for durum wheat genotypes evaluation for tolerance to drought and high temperature stress in plant breeding which can help for mass selection in early generations [13,17]. Canopy temperature is the temperature of plants and/or the vegetative cover. It is generally measured with infrared thermometers. It is often used to indicate vegetative water status and is used in models for estimating transpiration rates and sensible heat transport from vegetation. Canopy Temperature is a function of a number of environmental factors, principally soil water status, air temperature, relative humidity, transpiration and incident radiation [18]. In this study, it was found that stress tolerant genotypes showed low canopy temperature along with high grain yield during pre-anthesis stage as well as during grain filling period; while sensitive genotypes showed higher canopy temperature and low grain yield this shows that if the canopy temperature is low the plant adaptation to stress conditions is more **(Figure 2).** It can maintain its growth and development in proper way under adverse conditions and it will help in selection the tolerable genotypes under stress conditions [13,17]

Table 1. Mean, minimum and maximum of heat and drought tolerable and sensitive durum wheat genotypes.

Traits	Heat tolerant genotypes			Heat sensitive genotypes		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
TGW (g)	41.8	42.9	40.6	36.1	39.0	32.2
BM/pl.(g)	41.4	46.2	38.4	31.8	35.2	28.
NT/pl	9.8	10.8	8.6	7.5	9.6	6.6
NG/spike	51.1	56.6	42.6	40.0	47.2	34.0
SDS (ml)	31.7	35.0	28.0	24.7	28.0	22.0
T.Car. (ppm)	3.8	4.3	3.2	4.1	5.2	3.2
CT (veg.)(°C)	21.3	21.8	20.7	21.4	21.8	20.7
CT (GF) (°C)	25.3	25.6	25.0	26.4	26.8	25.8
GY/pl (g)	20.2	21.6	19.0	10.5	12.5	9.1

Note: TGW- 1000 grain weight; BM/pl.- Biomass/plant; NT/pl.- Number of tillers/plant; NG/spike- Number of grains/spike; SDS- Sedimentation value; T. Car.- Total carotene content; CT- Canopy temperature (vegetative and grain filling stages of plant growth); GY/pl. Grain yield/plant

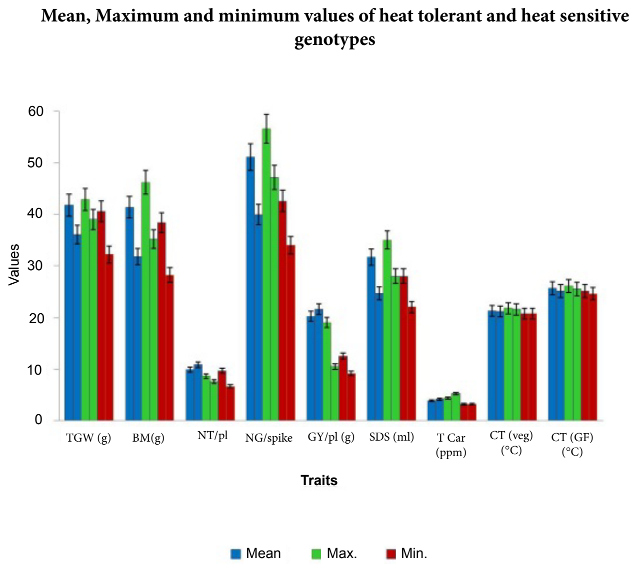

Figure 1. Graphical representation of different traits of heat tolerant and heat sensitive genotypes Mean, Maximum and Minimum of different traits under very late sown conditions. (TGW= Thousand grain weight; BM= Biomass/plant; NT= Number of tillers/plant; GY= Grain yield/plant; SDS= Sedimentation value; T. Car. = Total carotene; CT= Canopy temperature; SD= Standard deviation; SE= Standard error).

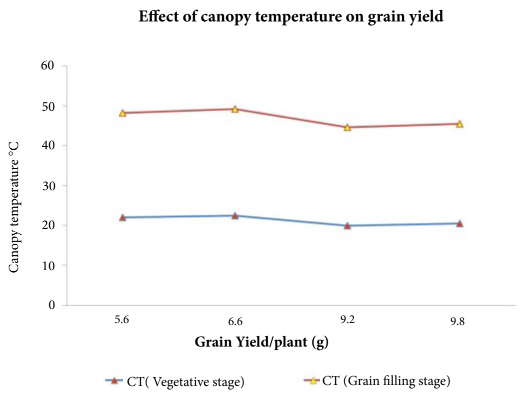

Figure 2. Effect of cooler canopy temperature on grain yield.

Yield and Yield Contributing Traits

Yield components

The stress factors like heat and drought stress negatively affects plant growth and development and causes a sharp decrease of plant productivity [19]. The effect of stress can be overcome by planting stress tolerance cultivars. This study showed that stressed tolerant high yielding cultivars showed high yield and yield contributing traits **(Table 2) (Figure 1).** In stressed tolerant high yielding cultivars, grain yield/plant was observed to be 20.8 g and 19.6 g respectively whereas in stress sensitive cultivars grain yield/plant was 11.1 g and 9.8 respectively. Similarly biomass/plant was observed higher in stress tolerant cultivars (42.7 g and 40.1g) and low in stress susceptible cultivars (32.1g and 31.5g); 1000 grain was found higher in stress tolerant cultivars (41.5g and 42.0 g) while, it was found low in stress susceptible cultivars (38.2 g and 34.0 g); number of grains/spike was more in stress tolerant cultivars (47.7 and 54.5) while, low in stress susceptible cultivars (43.5 and 36.5); number of tillers/plant was more in stress sensitive cultivar (44.0 and 34.7) whereas, less in stress tolerable cultivars (45.7 and 39.0). Similarly quality characters were also affected in the susceptible cultivars which showed low sedimentation value in stress tolerant cultivars (29.3 ml and 34.0 ml) and low in stress susceptible cultivars (27.0 ml and 22.3 ml); total carotene content was (4.2 ppm and 3.4 ppm) in stress tolerant and (3.2 ppm and 5.0 ppm) in stress sensitive durum wheat genotypes; while physiological parameters also difference in the stress tolerant and susceptible cultivars, canopy temperature was high in stress susceptible cultivars before anthesis and after anthesis respectively (20.9˚C, 21.7˚C and 25.4˚C, 25.2˚C) while, canopy temperature was cooler in stress tolerant cultivars (21.1˚C, 21.8˚C and 25.9˚C, 26.8˚C); Looking overall results, it is clear that these physiological parameters in addition with some yield contributing traits could explain some of the mechanisms which indicate tolerance to stress conditions and help in developing stress tolerant varieties [20,21].

Table 2. Yield and yield contributing traits of high yielding and low yielding cultivars under water and heat stress conditions.

Varieties	TGW(g)	BM/pl (g)	NT/pl	NG/pl	GY/pl (g)	SDS (ml)	T.Car. (ppm)	CT (°C)	CT (°C)	SD ±	SE
MACS3125	41.5	42.7	10.2	49.7	20.8	28.7	4.2	20.0	24.6	16.6	0.81
HI 8627	42.0	40.1	9.0	54.7	19.6	34.7	3.4	20.5	25.0	17.7	0.81
DBP02_08	38.2	32.1	7.2	37.0	8.6	26.1	3.2	22.0	25.6	13.3	0.78
IWP5007	34.0	31.5	7.8	34.3	9.8	27.3	3.1	22.0	26.2	12.1	0.77

Note: TGW= Thousand grain weight; BM= Biomass/plant; NT= Number of tillers/plant;
GY= Grain yield/plant; SDS= Sedimentation value; T. Car. = Total carotene;
CT= Canopy temperature; SD= Standard deviation; SE= Standard error.

Associations of Grain Yield and Yield Contributing Traits

Grain yield showed highly significant and positive associations with 1000 grain weight, biomass/plant, number of tillers/plant, sedimentation value, total carotene content **(Table 3).** While highly significant and negative association with CT (vegetative and grain filling stages) indicating that these traits plays an important role to improve the yield of genotypes depending upon the adaptability of the genotypes under stress conditions [22,23].

Table 3. Associations of yield and yield contributing traits under stress conditions.

Traits	TGW (g)	BM(g)	NT/pl	NG/sp.	SDS (ml)	T. Car. (ppm)	CT (veg.) (°C)	CT (GF) (°C)
BM(g)	0.86**							
NT/pl	0.89**	0.78**						
NG/spike	-0.02	0.07	0.27					
SDS (ml)	0.73**	0.85**	0.65*	-0.18				
T. Car. (ppm)	0.80**	0.90**	0.76**	0.02	0.93**			
CT (veg.) (°C)	-0.24	-0.51	-0.1	0.09	-0.42	-0.49		
CT (GF) (°C)	0.1	0.05	0.17	-0.06	0.31	0.34	0.26	
GY/pl (g)	0.83**	0.91**	0.66*	0.21	0.80**	0.83**	-0.65*	-0.60*

TGW= Thousand grain weight; BM= Biomass/plant; NT= Number of tillers/plant;
Note:GY= Grain yield/plant; SDS= Sedimentation value; T. Car. = Total carotene; CT= Canopy temperature; SD= Standard deviation; SE= Standard error. **= 1% significant; *= 5% significant

Chlorophyll A (Chl A) Fluorescence

Another parameter that is been used in the study to conform the liability of stress tolerant and sensitive genotypes was chlorophyll fluorescence. Use of a chlorophyll fluorescence technique as a tool to investigate stress tolerance in plants has been reported by [24-27]. When dark adopted leaf is exposed to saturating light it exhibits a polyphasic rise called O-J-I-P fluorescence transient; the O to J phase (ends at ~2 ms), the J to I phase (ends at ~30ms) and I to P phase (ends at ~500ms). The shape of the O-J-I-P fluorescence rise has been related to a major change in the photosynthetic electron transport. Chlorophyll *a* fluorescence transient was measured before **(Figure 3a)** and after stress **(Figure 3b)** in stress tolerant (MACS 3125, HI 8627) and sensitive (DBP 02-08, IWP 5070) durum wheat genotypes to evaluate the effect of high temperature on the photochemical efficiency of

PS II. It is evident from the **Figure 3a** that the shape of the curve is different in tolerable and sensitive durum wheat cultivars indicating their different efficiencies to carry out photochemical events. However after heat and water stress, the photochemical efficiency of tolerable genotypes is not affected significantly while a decrease in fluorescence intensity is observed in sensitive genotypes **(Figure 3b).** This clearly indicates that low yielding cultivars are much more susceptible to heat and water stress.

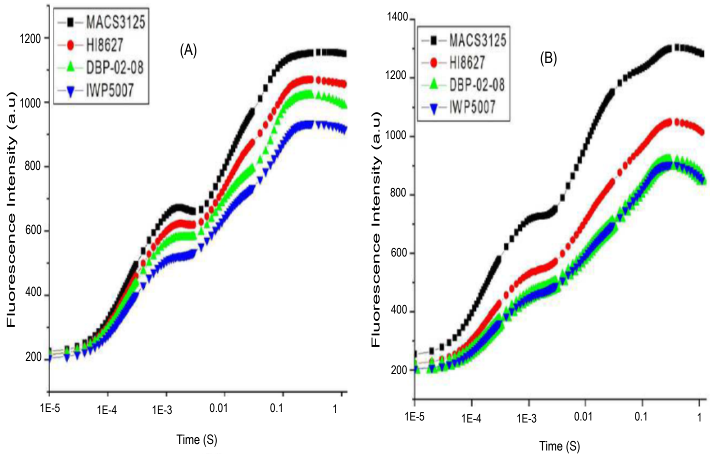

Figure 3. Chl-a fluorescence transients in heat tolerant and heat sensitive durum wheat genotypes.

Root Coring

Plant root is one of the most important traits that indicate the status of the plant health and adaptability of the plant to stress conditions. The water uptake rate increase with increase in root density depending on root age and soil water status. In the present study one stress tolerant (MACS 3125) and one stress sensitive (DBP 02-08) were selected for root coring. It was observed that the roots of high yielding cultivars were more in weight as well as in length as compared to the low yielding cultivars at different level of soil depth **(Table 4).** Stress tolerant genotype (MACS 3125) developed its root get into the deeper soil to absorb more and more water for the soil depth. Therefore, the root density (293.9 cm) was more in the deeper soil depths in the stress tolerable genotype, at the same time these cultivars also spread their roots at the surface (61.5 cm) to absorb more moisture and water from the soil surface whereas low yielding cultivars were able to penetrate their root lesser (284.5 cm). Similar pattern was found with the root weight (43.0 cm) indicating that the stress tolerant genotype adopt to stress conditions by developing more roots to absorb more water for the soil **(Figure 4)** reported that increased root length occurred at the expense of lateral root number and further emphasized that longer root length may help to explore nutrients deeper in the soil profile particularly where water is limited and high temperature stress conditions [12,28]. Selection of durum wheat genotypes with better grain yield and tolerance is the principal aim of wheat production. In this study, terminal heat stress caused significant changes in yield, yield contributing and physiological parameters. But there is significant difference among the traits in high yielding and low yielding durum wheat genotypes indicating that the genotypes HI 8627 and MACS 3125 is well adopted in the stress conditions. These genotypes can be used as stress tolerant genotypes and in breeding programs to develop stress tolerance varieties, in contrast stress sensitive durum wheat genotypes *i.e.,* DBP 02-08 and IWP 5070 showed significant low values of traits. In addition there is significant difference in traits like canopy temperature, Chl *a* fluorescence and root coring in stress tolerant and sensitive genotypes. This study concludes that the durum wheat genotypes affected by prolonged stress (drought and heat) are found to differ in their ability to respond, thereby tolerance, which could be useful as genetic stock to develop durum wheat tolerant varieties in breeding programs. In addition, physiological parameters like canopy temperature, Chl-*a* fluorescence and root coring measurements can serves as reliable tools to detect stress tolerance and susceptibility. The added advantage of these three parameters is that they are quick, easy to measure in field conditions, reliable and provide results compatible with earlier used conventional methods and portable equipments are also available to use directly in field conditions.

Table 4. Root weight and root length of one high yielding and one low yielding genotypes at different soil depth under water and heat stress conditions.

Soil Depth (cm)	High yielding cultivar MACS 3125			Low yielding cultivar DBP 02-08			High yielding cultivar MACS 3125			Low yielding cultivar DBP 02-08		
	Mean	Range		Mean	Range		Mean	Range		Mean	Range	
		Min	Max		Min	Max		Min	Max		Min	Max
Up to 10	53.5	42.6	64.4	36.9	28.5	45.2	201.9	137.9	270.6	195.6	120.5	265.8
Up to 20	59.2	45.8	72.5	40	26.7	53.2	239.7	177.9	327.5	228	128.2	301.4
Up to 30	61.5	47.6	75.3	41.8	27.9	55.6	270.8	195.9	368.5	277	185.7	345.6
Up to 40	58.8	48.3	69.3	43	28.3	57.6	287.9	210.5	396.5	284.5	192.1	365.2
Up to 50	61.4	47.9	74.9	42.3	28.9	55.7	293.9	225.3	425.5	208.1	190.6	362.5
SD±	3.2	2.4	4.5	2.5	0.8	4.9	38.2	33.8	60.7	47.3	35.8	43.2
SE	0.23	0.22	0.25	0.25	0.17	0.3	0.38	0.42	0.41	0.43	0.47	0.36

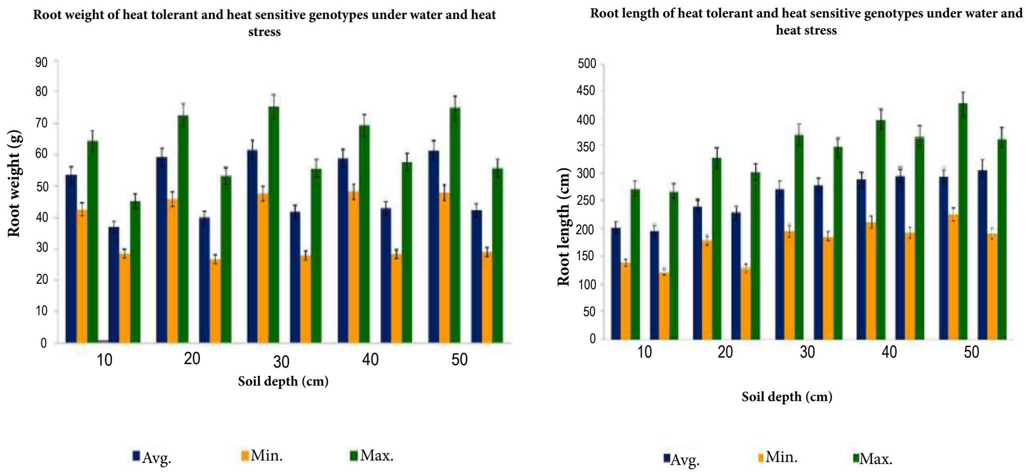

Figure 4. Root length and weight of heat/drought tolerant and sensitive durum wheat genotypes.

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