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Phenotypic Variations in Plant Height and Root Traits under Moisture Stress in Maize Varieties from Hawassa, Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Author TTT carried out all experimental work, data acquisition and analysis, literature search. Author NMC was responsible for study concept, designing and coordinating the research and supervising the work. Author NMC also contributed to writing and manuscript preparation. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: Maize (*Zea mays* L.) is the third most important food grain for humankind after rice and wheat. Therefore, the aim of this study is to evaluate the phenotypic variations in eight maize varieties under moisture stress.

Materials and Methods: All the varieties were grown with 3 replications in 75 cm deep polyethylene bags containing soil from study area for 30 days under four moisture stress conditions i.e. 25%, 50%, 75% and 100% of Field Capacity (FC) in green house.

Results: Significant variation existed in plant height, primary root length, root dry weight and shoot dry weight under different moisture conditions. The plant height and primary root length of maize seedlings under drought condition decreased in all tested maize varieties from 100% to 25% of moisture content. The average primary root length ranged from 27.5 to 88 cm. Melkassa 02 variety showed highest primary root length whereas, lowest mean root length was observed in Hora variety. Root and shoot dry weight also showed significant differences among eight maize varieties at different moisture levels. Each variety was also evaluated for ratio of root to shoot dry weight at

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different moisture levels in comparison to control. At 25% of FC, Pioneer variety recorded highest value for root to shoot ratio of dry weight with 2.4 fold increased followed by Hora, BH140, and Melkassa 02. Melkassa 04 reported least value for root to shoot ratio.

Conclusion: Results of our study has major implication for future breeding in maize. Under different condition of moisture stress, variations in maize morphological characteristics were observed. Thus more sampling should be done in future where maize is grown under adequate drought tolerance strategy.

Keywords: Dry matter; maize; moisture stress; primary root length; plant height.

1. INTRODUCTION

Maize (*Zea mays* L.; 2n = 20), belongs to large and important family of Poaceae and was reported to be originated in Central America. It is the third most planted cereal crop after wheat and rice worldwide. Globally it is top ranking cereal in terms of productivity and has worldwide significance as animal feed, human food as well as source of large number of industrial products. It is used as a raw material for manufacture of large number of industrial products like corn starch and starch-based products as well as it is also utilized in fermentation and distillation industries. Because of these various applications demand for maize is increasing across the world [1].

In Ethiopia, it was introduced during the 1600s to 1700s [2]. Maize is cultivated in various region of Ethiopia which are geographically varies i.e. drought to high rainfall areas as well as from lowlands to highland region [3]. Currently, maize crop is cultivated in all agro ecological zones ranging from 500m.a.s.l.to 2400 m.a.s.l. which are classified in to four zones such as: high altitude moist (1800-2400 m.a.s.l.), mid altitude moist (1000-1800 m.a.s.l.), low altitude moist (below 1000 m.a.s.l.) and moisture stress areas (500-1800m.a.s.l with surplus production from western, south-western, southern and eastern parts of Ethiopia [4].

After its introduction, maize become an important cereal crop in Ethiopia as a source of food and economy and represents a shift in farmer's choice of crops. The total annual production and productivity of maize exceed over all other cereal crops, though it is surpassed by Teff in area coverage [5]. Therefore, considering its importance in terms of wide adaptation, total production and productivity, maize is one of the high priority crops to feed the increasing population of the developing country like Ethiopia [6].

Compared to other crop plants, maize has received special attention owing to its wide cultivation and its great significance among food crops. This can be seen from the fact that at mean annual growth rate of 1.62%, the total area of land under maize cultivation has increased significantly from 75,500 ha in 1961 to about 1.69 million ha in 2006/07. It constituted 12.8 % of the total area under cereal crops in 1961 and 20% in 2008. Annual production is more than 3.8 million tons, accounting for nearly 29% of the total cereal production in the country. The rates of increase in maize production and its share in the total cereal output have been 3.27% and 1.92 %, respectively. Average yields of the country have also increased from 9.6q/ha in 1961 to 22.29q/ha in 2007, growing at an annual rate of 1.62% [7].

Even though, maize can be cultivated in different agro ecological zones, drought stress is a major limitation to its production and due to global climate change [8]. Drought tolerance, escape and avoidance are the most desirable as the maintenance of crop productivity under drought stress is challenging [9].

One of the strategies for drought tolerance mechanism in plants is the development of deep root system. Those plants with ability to extend their root system under different environmental stress have advantage for survival [10]. The spatial arrangement of a root system has been shown to be important in agricultural systems. Understanding the contribution of specific root traits, root system function is critical for crop improvement because it allows identification of traits that contribute desired functions [11].

Therefore the objective of the proposed study is to evaluate the phenotypic variations in eight maize varieties under different moisture stress.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was conducted under controlled condition in greenhouse at Hawassa University, Hawassa, South Nations and Nationalities

Regional State (SNNPRS), Ethiopia. Hawassa is situated at an altitude of 1700 m.a.s.l. and it roughly lies between 6°83' to 70°17' N and 38°24' to 38°72' E. Hawassa receives an average annual rainfall of 955mm with mean annual temperature of 20°C [12].

2.2 Plant Material

Eight different varieties of maize were obtained from South Seed Enterprise (SSE) and Ethiopian Seed Enterprise (ESE). The description of all eight varieties used for the proposed study is highlighted in Table 1.

2.3 Experimental Design

All the experiments were conducted under at greenhouse research facility of Hawassa University, Hawassa, Ethiopia. The experiments were laid out in a Completely Randomized Block Design (CRBD) with three replications and four level of water content i.e. 25%, 50%, 75% and 100% of Field Capacity (FC). Substrate (2:1 v/v) of sand and soil from Hawassa University research center was thoroughly mixed and oven dried at 105°C. This media is suitable for root studies as it facilitates the root removal without damage [13]. After sample soil collection and oven treatment, field moisture capacity was calculated as follows:

Water (%) by mass:

Mass of water = wet mass – dry mass

Water (%) by mass =

wet mass - dry mass/ Dry mass x 100

Water (%) by volume:

Vol. of water = mass of water / density of water

The experiments were conducted in locally prepared wooden boxes. The substrates of the desired moisture treatments were separately prepared in different plastic containers by taking known quantity of soil with the addition of pre calculated water quantities. The grains of maize varieties were washed with 0.25% NaClO solution for 10 minutes for disinfection. After NaClO treatment, grains were rinsed with sterile distilled water to remove excess NaClO and were spread in a tray to germinate. Grains were allowed to germinate at 25°C in greenhouse. After incubation in greenhouse germinated seed was identified, separated and transplanted to plastic poly-ethylene bags in the wooden box. The plants were grown in deep plastic poly-ethylene bags (75cm height and 10cm diameter). All plastic poly-ethylene bags were mounted in wooden racks in Completely Randomized Block Design with three replications. The plants were watered daily for 30 days.

2.4 Methods of Data Collection

Plant height was measured as the vertical distance between the ground and the highest living part of the plant with a ruler/meter rule at 30th day. After measurement, excavation was done as per the reported methodology [14]. Thus, the excavated root was shaken briefly to remove a large fraction of the soil adhering to the roots. Most of the remaining soil was then removed by soaking the root in mild detergent at a concentration of 0.5%. In a third step, remaining soil particles were removed from the roots by vigorous rinsing at low pressure.

Primary root length was measured from the root origin to tip of the root, and primary root angles measured at 2cm away from the root origin. Angles of roots were measured using a large protractor [14].

Roots and shoots of seedlings were put in a brown paper bag and dried in an electric oven at 80°C for 72 hours. After drying, roots and shoots dry weight for each seedling were recorded by using a sensitive electronic balance. Other data set such as ratio of root to shoot dry matter and total dry matter were calculated for further analysis.

2.5 Methods of Data Analysis

The statistical package SPSS version 16.0 was used for data analysis. Different features of the software such as ANOVA, Least Significance Difference (LSD), Correlation and Regression Analysis was calculated and compared.

3. RESULTS AND DISCUSION

3.1 Plant Height (PH)

All maize varieties exhibited significant difference at all moisture levels. At 25% FC of moisture condition variety Melkassa 02 showed maximum mean plant height with decline about 19.5% followed by pioneer and Melkassa 04 as compared to their controlled moisture (100% FC)

Table 1. Description of eight maize varieties with their type and agro ecological adaptations (SNNPRS Bureau of Agriculture, 2012)

Sr.No.	Name of varieties	Altitude (m.a.s.l)	Annual rainfall (mm)	Type
1	BH 140	1000-1800	1000-1200	Hybrid
2	BH 540	1000-2000	1000-1200	Hybrid
3	BH 660	1600-2200	1000-1500	Hybrid
4	BH 661	1600-2200	1000-1500	Hybrid
5	Hora	1700-2400	1000-1200	OPV
6	Melkassa 02	1200- 1700	600-800	OPV
7	Melkassa 04	1000-1600	500-700	OPV
8	Pioneer	1600- 2000	800-1600	Hybrid

**OPV -Open Pollinated Varieties*

supply. While, least plant height was recorded in BH140 variety with a reduction of 46.6% as compared to its 100% FC (Fig. 1).

From this study, in all tested maize varieties as moisture treatment level decreased the plant height decreased which is in argument with Dek [16] as stated moisture stress imposed during the vegetative stage growth phase lessens the plant height. However, under well watered conditions, the absorption and transport of water and nutrients are higher due to high soil water potential. Soil moisture decreases nutrient transport to the root surfaces and roots are unable to absorb nutrients from the soil.

3.2 Primary Root Length and Angles

3.2.1 Primary root length (PRL)

The result of our study revealed that the average length of primary root of all maize varieties displayed a decreasing pattern as the moisture treatment levels decrease from 100% FC to 25% FC (Fig. 2). As moisture content decreased from 100% FC to 25% FC, Melkassa 02 and Hora variety showed maximum and minimum mean values in primary root length with 59.5% and 35% respectively as compared to their controlled field capacity (100% FC). On the other hand, maximum average primary root length was recorded for BH661 and Melkassa 02, while minimum for BH660 when moisture content decreased from 100% FC to50% FC. At 75% FC, statistically significant differences were not observed in primary root length except for BH 140 as compared to their controlled field capacity. A statistically significant variation of maize varieties was observed between different moisture treatment levels. From ANOVA results (Table 3), partitioning of the sum of squares of the components indicated the contribution of moisture treatment levels to be 59.5% of the total variation whereas, the remaining 3.6%, 0.6% and 8.13% contributed due to maize varieties, blocks, and moisture treatment maize varieties interactions respectively. Maximum variations, about 59.5% was due to moisture treatment level and no statistically significant difference observed due to varieties, blocks and variety moisture treatment interaction (Table 3). This might shows the influence of moisture treatment level on primary root length.

Thus, it was observed that the average primary root length was decreased as moisture treatment level decreased. This would indicate moisture stress during the vegetative growth stage might reduce the plant root length. An increase in root growth is advantageous to plant in drying soil and also important for seeding establishment [17]. It was also proved that root depth is important to avoid drought stress by the genotypes [18]. High moisture levels resulted in higher root growth with relatively the longest root length .And hence, rooting depth play a major role in drought resistance of crops [19].

3.2.2 Primary root angles (PRA)

The variation in the primary root lengths among different maize varieties is highlighted in Table 2. As moisture treatment level decreased from100% FC to 25% FC varieties BH140, BH540, Melkassa 04, Hora and pioneer showed steeper, whereas BH660 recorded as the shallowest angle at this level. This study might indicate varieties BH140, BH540, Melkassa 04, Hora and pioneer are better than others for water acquisition under moisture stress whereas maize variety BH660 is better for top soil foraging. Lynch [20] reported that varieties with shallow growth angles being superior for top soil foraging and steep growth angles being superior for water acquisition under drought stress, and thus the growth of steep root angles may be crucial for survival of maize seedlings under drought stress. The growth angle of roots is a primary determinant of root foraging depth. The growth angle of root is related to rooting depth, which in turn is closely correlated with the depth of soil resource acquisition.

3.3 Root and Shoot Dry Matter

3.3.1 Root dry weight (RDW)

Statistically significant difference in root dry weight was observed due to moisture treatment

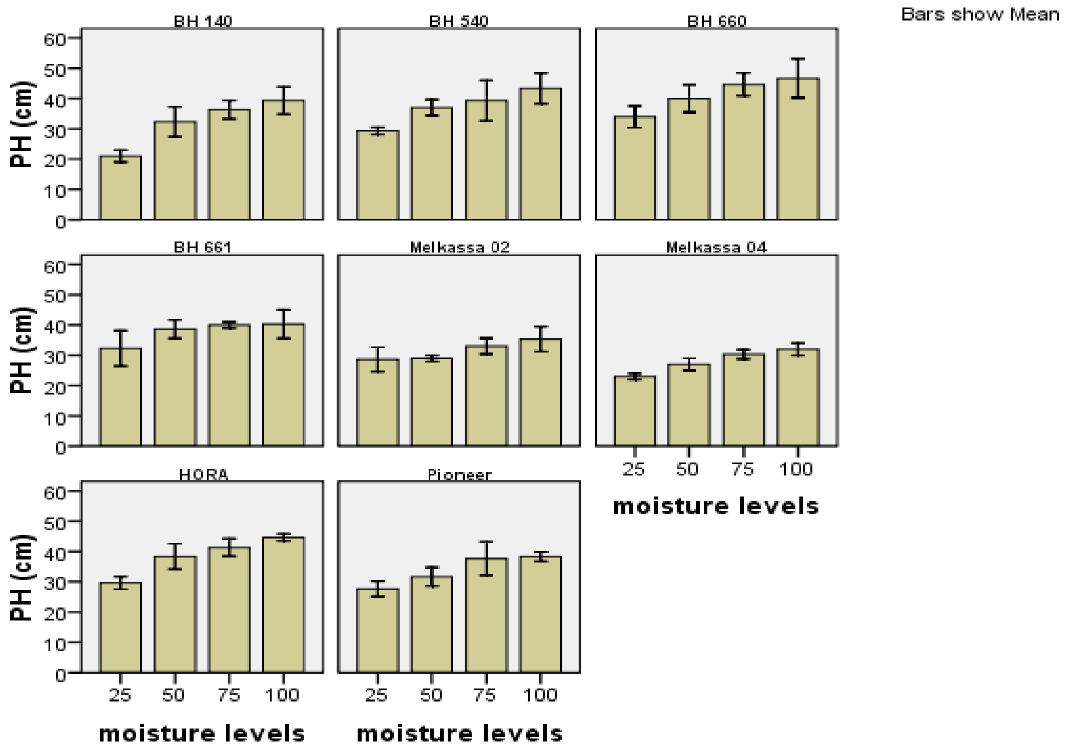

Fig. 1. Variations in plant height in eight maize varieties among four different levels of moisture treatment

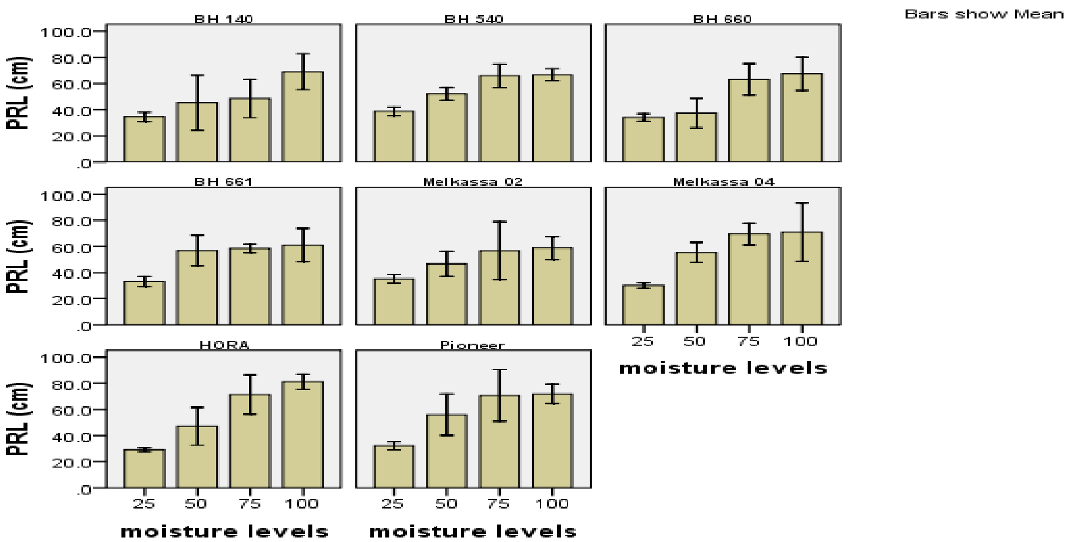

Fig. 2. Variations in primary root length in eight maize varieties among four different levels of moisture treatment

Table 2. Variations in primary root angles in eight maize varieties among four different levels of moisture treatment

Maize varieties	Moisture contents			
	25%FC	50%FC	75%FC	100%FC
BH 140	63	46	41	43
BH 540	78	56	43	63
BH 660	43	56	70	50
BH 661	50	61	55	50
Melkassa 02	68	56	60	68
Melkassa 04	73	61	75	66
Hora	71	58	68	63
Pioneer	68	63	63	66

level, maize varieties and variety treatment interaction (Table 2). From this study root dry weight might be influenced due to varieties, and moisture levels and the interaction between them. Genotype environment interaction is a term used to describe the interaction of environmental factors and genes (or particular sets of genes). A basic principle indicated by the genotype environment interaction is that even if all plants were created equal (same genotypes); they will not necessarily express their genetic potential in the same way when environmental conditions varies. The relatively large magnitude of maize variety moisture treatment level interaction implies more dissimilar plant genetic systems that control different physiological processes [21].

Root dry weight showed a significant difference between different moisture conditions in eight maize varieties (Table 4). At severe moisture stress i.e. 25% FC, highest root dry weight was recorded for variety Melkassa 02 with 2.6 fold increased followed by BH 140 and Melkassa 04, whereas relatively least mean RDW was recorded by Hora and BH661 as compared to their controlled moisture content (Fig. 3). On the other hand Melkassa 02, BH 140 and Melkassa 04 varieties also recorded maximum mean RDW as compared to their controlled field capacity (100%FC). Maize varieties with higher root dry weight known to be more tolerant to drought stress, and variety with low root dry are less tolerant to drought stress [22].

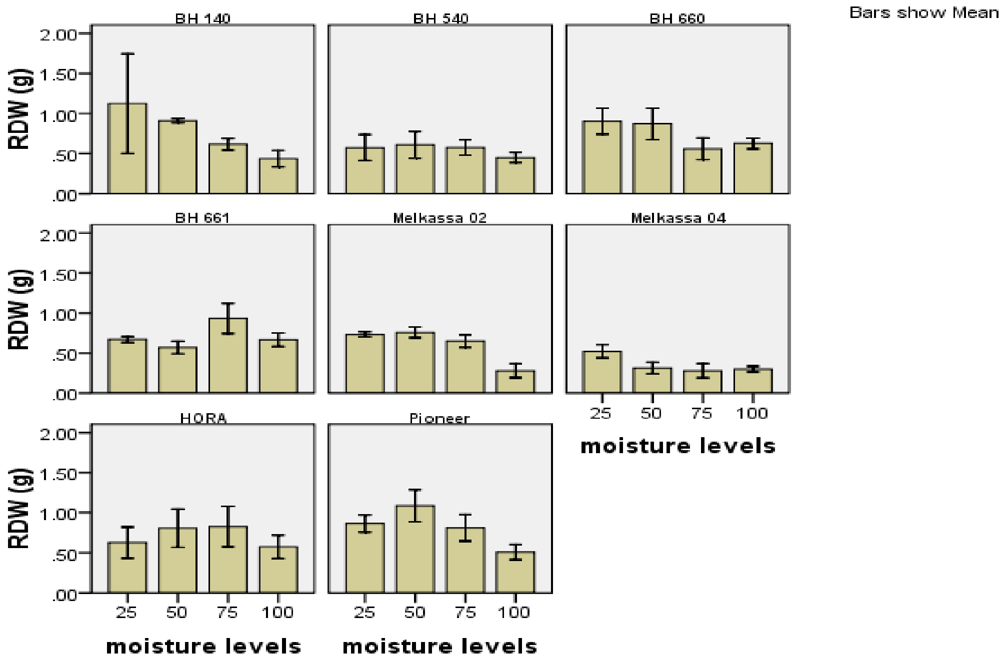

Fig. 3. Variations of root dry weight in eight maize varieties among four different levels of moisture treatment

3.3.2 Shoot dry weight (SDW)

When moisture content decreased from 100% FC to 25% FC, Melkassa 04 recorded highest shoot dry weight with 2.3 fold increase followed by Melkassa 02 and BH 140 varieties, whereas minimum SDW was recorded by Hora and Pioneer with as compared to their respective controlled field capacity (Fig. 4). It was also noted that at 25% FC, mean SDW decreased for all varieties except for varieties BH 140, Melkassa 02 and Melkassa 04 where SDW increased in comparison to control field capacity. Our study is supported by the report that shoot dry weights were decreased as moisture contents decreased [23]. Photosynthesis is arguably the most important of plant processes, and is essential for production of biomass. Greater level of shoot biomass accumulation would indicate higher growth rates. Another study stated that water deficit stress decrease the dry matter partitioning to ear at the critical stages and these factors determine the number of grains [24]. When photosynthesis is limited during water deficit at the grain filling stage the stored reserves are reutilized to fill grains [25].

3.3.3 Ratio of root to shoot dry weight (RDW/SDW)

As moisture level decreased from 100% FC to 25% FC, Pioneer recorded highest value for root to shoot ratio of dry weight with 2.4 fold increase followed by Hora, BH140 and Melkassa 02 varities in comparison to control. While, Melkassa 04 variety reported the least value for RDW/SDW. At 25% FC, all varieties except Melkassa 04 perform more in terms of RDW/SDW than their respective controlled field capacity (100% FC) (Fig. 5). This might indicate the dry matter of most of most varieties of root dry matter production was more than that of above ground dry matter production and an increase root growth than shoot. It was noted that water stress appears to increase the root growth as compared to the shoot, and this support the view that root growth may show a considerable morphological plasticity enabling them to cope with changes in soil moisture [26]. It was also supported by findings that the reduced watering regime was found to be compensated by the reduction of life cycle and by resource division to root during early growth stages to allow rapid establishment of plant [27]. And, thus a reduction in stem growth coupled with continued growth of root in drying soil must occur if water up take is to be maintained. The increase in ratio (root: shoot) was due to the reason that roots are comparatively less susceptible to water deficit condition than shoots growth. Soil water deficits often reduce shoot growth before root growth is reduced, resulting in increased root to shoot ratio in water stressed plants.

The high root to shoot ratio in drought resistant variety was due to inhibition of shoot growth compared with root growth. Root to shoot ratio has been used as a criteria for the determination of varietal differences in response to water stress [28].

Genotypic ability for high root to shoot ratio contributed to drought tolerance. It is more likely that maize crops were less tolerant to drought due to their high shoot dry weight and low root dry weight. And, hence root to shoot ratios might be used as a suitable selection criteria for the genotypic variation among the tested maize genotypes under water deficit conditions. Genotypes with high root to shoot ratio considered being more tolerant to drought stress and, hence root to shoot ratio, shoot and root dry weight values involves drought tolerance mechanisms [29].

3.3.4 Total dry matter (TDM)

Total dry matter productions of all varieties were evaluated between different moisture levels. At 50% FC, highest TDM was recorded for Melkassa 02 variety whereas, least TDM was observed for BH661. At 25% FC, Melkassa 04 variety showed the highest with 2.14 fold increase followed by Melkassa 02 variety while, Hora variety displayed least total dry matter production as compared to their respective controlled field capacity (100%FC) (Fig. 6).

It can be revealed that at 25% FC all varieties except Hora showed high ability to accumulate total dry matter production as compared to their controlled field capacity. Studies showed that any factor which affects the photosynthetic process will influence the total dry matter. Thus, this might indicate moisture stress could be causing strong inhibition of photosynthetic activity in Hora.

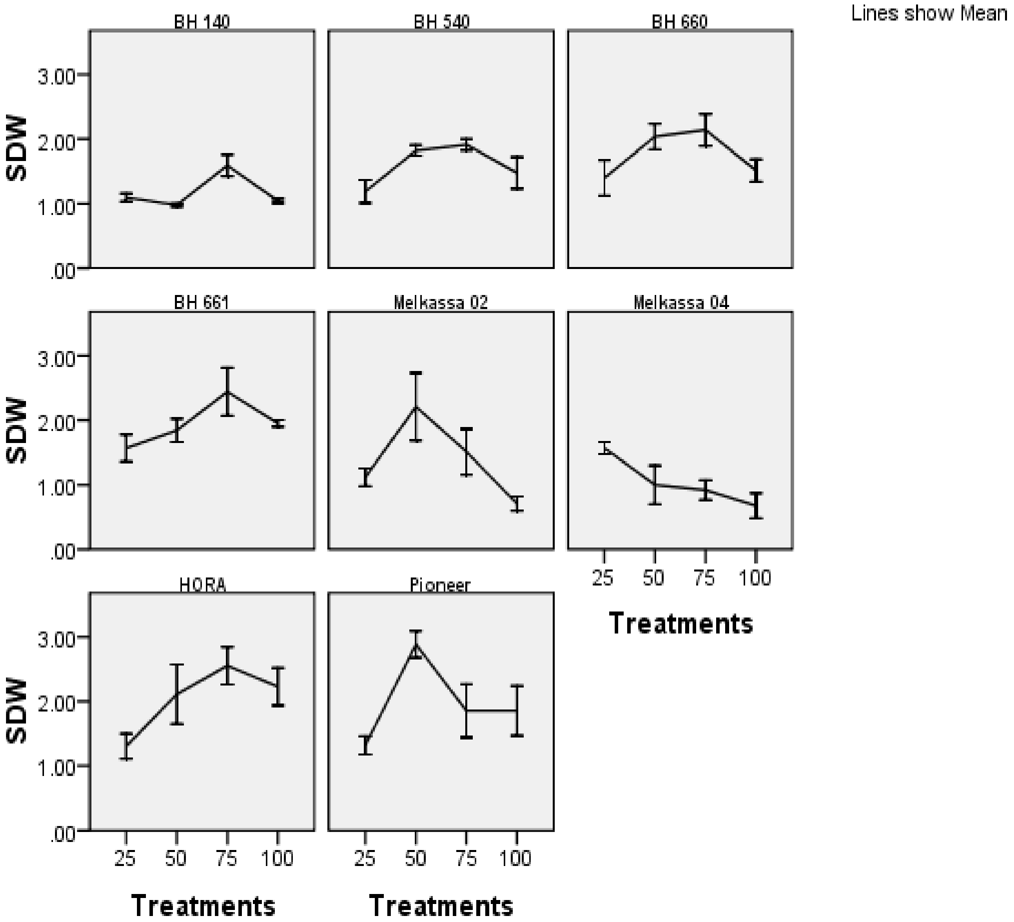

Fig. 4. Variations in shoot dry weight in eight maize varieties among four different levels of moisture treatment

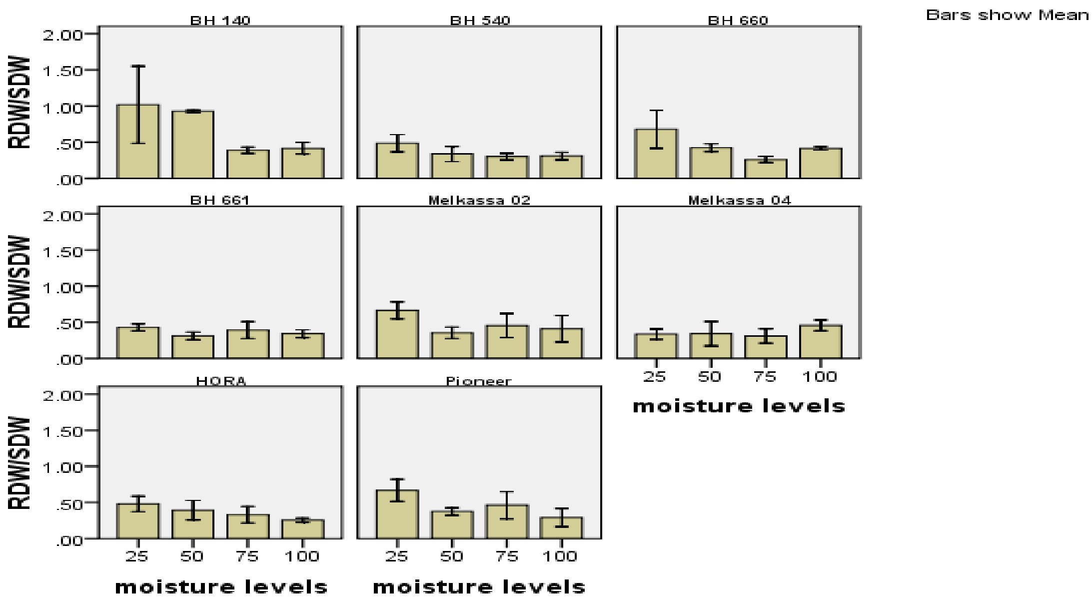

Fig. 5. Variations in ratio of root to shoot dry weight in eight maize varieties among four different levels of moisture treatment

Table 3. ANOVA result

Source of variation	Degree of freedom	Sum square(SS)	Mean square	F value	*P* value
Plant Height					
Varieties	7	1613.1	230.4	17.268	0.00
Treatment	3	1912.7	637.6	47.775	0.00
Block	2	23.3	11.6	0.872	0.423
Variety: treatment	21	232.1	11.1	0.828	0.67
Residuals	62	827.4	13.3		
Primary Root Length					
Varieties	7	1075	154	1.152	0.344
Treatment	3	17561	5854	43.902	0.00
Block	2	190	95	0.712	0.495
Variety: treatment	21	2398	114	0.856	0.643
Residuals	62	8267	133		
Primary Root Angle					
Varieties	7	4162	594.6	1.951	0.08
Treatment	3	632	210.7	0.691	0.56
Block	2	366	183.1	0.601	0.55
Variety: treatment	21	4558	217	0.712	0.80
Residuals	62	18901	304.8		
Total		28,619			
Root Dry Weight					
Varieties	7	1.8757	0.268	9.449	0.00
Treatment	3	1.1359	0.3786	13.352	0.00
Block	2	0.0812	0.0406	1.432	0.25
Variety: treatment	21	1.448	0.069	2.432	0.00
Residuals	62	1.7581	0.0284		
Shoot Dry Weight					
Varieties	7	1.8757	0.268	9.449	0.00
Treatment	3	1.1359	0.3786	13.352	0.00
Block	2	0.0812	0.0406	1.432	0.25
Variety: treatment	21	1.448	0.069	2.432	0.00
Residuals	62	1.7581	0.0284		
Root to Shoot Dry Weight Ratio					
Varieties	7	1.0318	0.14739	6.843	0.00
Treatment	3	0.8677	0.28924	13.428	0.00
Block	2	0.005	0.00252	0.117	0.89
Variety: treatment	21	1.0071	0.04796	2.227	0.01
Residuals	62	1.3355	0.02154		

ANOVA for various phenotypic characteristics in Maize under moisture stress

3.4 Phenotypic Correlations

Correlation was the measure of the extent of association occurring between two or more independent variables. It was reported that maize plants have long shoot system tend to have a deeper root system, while short plants tend to have shorter root [30]. The correlation analysis showed that the association of different plant traits with each other under four moisture treatment levels. Shoot dry weight (SDW) showed highly significant and positive association with total dry matter (TDM) (r=0.94). Root dry weight (RDW) also showed significant positive association with TDM and root to shoot ratio (RDW/SDW) (Table 3).

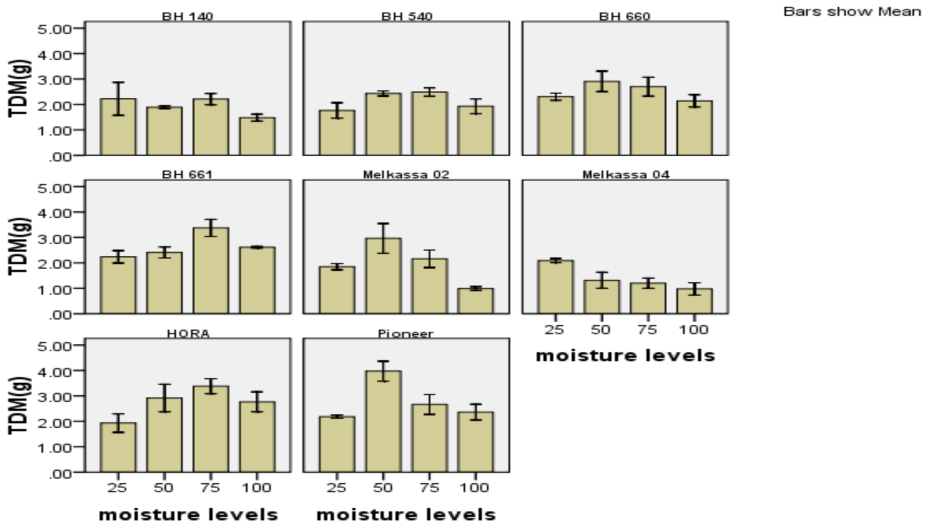

Fig. 6. Variations in total dry matter in eight maize varieties among four different levels of moisture treatment

Table 4. Pearson-Correlation coefficients comparisons for various plant traits under various moisture treatment levels

	PH	PRL	PRA	RDW	SDW	RDW/SDW	TDM
PH							
PRL	.456**						
PRA	-.216*	-.009					
RDW	-.110	-.295**	-.034				
SDW	.365**	.152	-.036	.382**			
RDW/SDW	-.409**	-.390**	-.002	.631**	-.434**		
TDM	.254*	.014	-.043	.667**	.943**	-.124	

**PH= plant height, PRL= primary root length, PRA= primary root angle, RDW= root dry weight SDW= shoot dry weight, RDW/SDW= ratio of root to shoot dry weight and TDM= total dry matter. *and ** show the significance at 0.05 and 0.01levels respectively*

SDW showed statistically significant and negative correlations with RDW/SDW. However, Malik et al. [31] reported a positive and significant association between RDW/SDW and SDW. Plant height (PH) showed moderately significant and positive association with primary root length (PRL).

4. CONCLUSION

Water deficit had paramount effects on root and shoot traits of maize varieties. Plant height and primary root length decreased with decrease in moisture levels, and a statistically significant and positive relationship between them observed. The results also indicated that primary root angles showed no significant correlation with any traits under moisture stress conditions. Plant height and primary root length traits were weak and negatively correlated with ratio of root to shoot dry weight under moisture stress condition. Significant correlation was observed between total dry matter with shoot dry weight and root dry weight. Similarly, ratio of root to shoot dry weight was highly associated with root dry weight under water deficit conditions. The ratio of root to shoot dry weight was identified as the major criterion for selection of maize varieties under moisture stress conditions. Based on this, Pioneer, Hora, BH 140 and Melkassa 02 varieties showed the best performances under moisture stress condition and varieties BH 540, BH 660 and BH 661 are found to be intermediate for moisture stress. However, Melkassa 04 was found to be poor among all maize varieties study under water deficient condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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