AGRONOMSKI GLASNIK 5-6/2016.
ISSN 0002-1954

Original scientific paper
Izvorni znanstveni članak

PRELIMINARY EVALUATION OF GRAIN AMARANTH (*AMARANTHUS* SPP.) ACCESSIONS FOR DROUGHT TOLERANCE BY MULTIVARIATE TECHNIQUE

POTOMCI ZA TOLERANTNOST NA SUŠU POMOĆU MULTIVARIJACIJSKE METODE

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ABSTRACT

The objectives of this experiment were to compare different drought tolerance indices for drought tolerance prediction and evaluate thirty accessions of grain amaranth (*Amaranthus* spp.) for drought tolerance using several drought tolerance indices. Seeds of thirty (30) accessions of grain amaranth collected from National Horticultural Research Institute (NIHORT), Ibadan were screened in 2011 at the screen house of NIHORT. Seeds were raised in nursery for three weeks and later transplanted into polyethylene bags. Water stress was imposed at 4, 6 and 8 weeks after transplanting (WAT) and the control was maintained at 100 % field capacity. The trial was a completely randomized design (CRD) laid out in a 4 × 30 factorial arrangement replicated three times. Agronomic data and drought tolerance indices were used to assess the performance of grain amaranth. Analysis of variance (ANOVA) was performed to establish significant effect ($P \leq 0.05$; F-test) of the treatments on the parameters taken, significant means were separated using standard error of the difference of means in post ANOVA t-tests. Result of the experiment showed that grain amaranth stressed at 4 and 6 WAT died before reaching maturity, water stress significantly ($P < 0.05$) reduced plant height, number of leaves and branches of grain amaranth. Grain amaranth at field capacity produced significantly ($P < 0.05$) higher seed yield than those stressed at 8WAT (54 and 25 gplant^{-1} respectively). Seed yield had significant positive correlation with root length (r = 0.86**), shoot dry weight (r = 0.79**), STI (r = 0.96**), GMP (r = 0.97**) and HM (r = 0.95**) but not with SSI. Cluster analysis indicated that the accessions tended to be categorized into three groups at 96 % similarity level, accession AMES5647, PI576464, PI576454 and PI576483 had the highest STI, GMP, MP, HM and was thus considered to be the most desirable cluster for both conditions. In conclusion, this study showed that selection for drought tolerance could be based on STI, GMP, MP, HM based on their significant positive correlation with grain yield.

Keywords: Accessions, drought tolerance, field capacity, grain amaranth, stress tolerance.

SAŽETAK

Ciljevi ovog pokusa bili su usporediti različite pokazatelje tolerantnosti na sušu za predviđanje tolerantnosti na sušu i procijeniti trideset potomaka zrnatog amaranta (*Amaranthus spp*.) na tolerantnost na sušu primjenom nekoliko pokazatelja tolerantnosti na sušu. Sjeme trideset (30) potomaka zrnatog amaranta sakupljeno u Nacionalnom poljoprivrednom istraživačkom institutu (NIHORT) u Ibadanu selekcionirano je 2011. godine u Selekcijskom centru NIHORT-a. Sjeme je uzgajano u rasadniku tri tjedna i zatim presađeno u polietilenske vreće. Uveden je vodeni stres 4, 6 i 8 tjedana nakon presađivanja (WAT), a kontrola je provedena u 100% terenskim uvjetima. Pokus je bio potpuno randomiziran plan (CRD) postavljen u faktorijalnom rasporedu

4 x 30 u tri ponavljanja. Upotrijebljeni su agronomski podaci i pokazatelji tolerantnosti na sušu za procjenu performance zrna amaranta. Obavljena je analiza varijance (ANOVA) da se ustanovi značajan učinak ($P< 0,05$ F-test) postupaka na uzete parametre, odijeljene su značajne srednje vrijednosti primjenom standardne pogreške srednje vrijednosti u t-testovima nakon ANOV-e. Rezultat pokusa je pokazao da je zrnati amarant pod stresom od 4 i 6 WAT-a uginuo prije dozrijevanja, stres od vode znatno ($P>0,05$) je smanjio visinu biljke, te broj listova i grančica amaranta. Amarant je u terenskim uvjetima dao značajno ($P<0,05$) veći prinos sjemena od amaranta pod stresom od 8 WAT-a (54 odnosno 25 $gbiljaka^{-1}$) Prinos sjemena bio je u znatnoj pozitivnoj korelaciji s duljinom korijena (r=0,86++), suhom težinom izdanka (r=0,79**), STI (r=0,96**, GMP (re=0,97** i HM(r=0,95**), ali ne sa SSI. Analiza klastera je pokazala da su potomci imali tendenciju kategorizacije u tri skupine na razini 96% sličnosti, potomci AMES 5647, PI576464, PI576483 i PI576483 imali su najviši STI, GMP, MP, HM i prema tome su smatrani najpoželjnijim klasterom u oba uvjeta. U zaključku, ovaj je rad pokazao da se selekcija na tolerantnost na sušu može temeljiti na STI, GMP, MP i HM na osnovi njihove značajne pozitivne korelacije s prinosom zrna.

Ključne riječi: potomci, tolerantnost na sušu, terenska sposobnost, zrnati amarant, tolerantnost na stress

INTRODUCTION

The edible amaranth (*Amaranthus* spp.) is a member of the genus Amaranthus of the Amaranthaceae family. It is probably the most important leafy vegetable of the lowland tropics of Africa and Asia (Grubben, 1977.). Its cultivation for grain amaranth dates as far back as 5,000 to 7,000 years ago in South America and was used as a vegetable in the early civilization 2,000 years ago (Grubben, 1977.). Currently, it is consumed by humans in diverse geographical regions from southwest United States to China, India, Nepal, Africa, South Pacific Islands, Caribbean, Greece, Italy, Russia (Stallknecht, et al., 1993.) and Asia (Grubben, 1977.). Advantages of amaranth include its tolerance to drought, adaptability to marginal and less fertile soils and low water requirement (i.e. high water use efficiency) to produce dry matter as a C_4 plant among others. Grain amaranth can be considered as an alternative drought resistance crop in the regions subjected to limited rainfall to increase arable lands surface. O'Brien and Price (2008.) also confirmed that amaranth tolerates poor fertility and drought, although the tolerance mechanism is not well understood.

Climate change, especially that caused by prolonged drought is one of the most serious climatic hazards affecting the agricultural sector of the continent. As most of the crop production activities in African countries hinge on rainfall, any adverse change in the climate would likely have a devastating effect on the sector in the region, and the livelihood of the majority of the population. For effective breeding of drought tolerant crop varieties, good selection criteria are needed to identify the drought tolerant genotypes. Findings of some earlier researchers, who reported different drought tolerance indices, indicate that drought indices which provide a measure of drought based on loss of yield under drought-conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2001.). These indices are either based on drought resistance or susceptibility of genotypes (Fernandez, 1992.).

Drought resistance is defined by Hall (1993.) as the relative yield of a genotype compared to other genotypes subjected to the same drought stress. Drought susceptibility of a genotype is often measured as a function of the reduction in yield under drought stress (Blum, 1996.). Rosielle and Hamblin (1981.) defined stress tolerance (TOL) as the differences in yield between the stress (Y_S) and non-stress (Y_P) environments and mean productivity (MP) as the average yield of Y_S and Y_P. Fischer and Maurer (1978.) proposed a stress susceptibility index (SSI) of the cultivar. Fernandez (1992.) defined a new advanced index (STI= stress tolerance index), which can be used to identify genotypes that produce high yield under both stress and non-stress conditions. Other yield based estimates of drought resistance are geometric mean (GM), mean productivity (MP) and TOL. Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting genetic variation to improve stress-tolerant cultivars (Clarke et.al., 1984.). The objectives of this experiment were therefore to compare different drought tolerance indices for drought tolerance prediction and evaluate thirty accessions of grain amaranth (*Amaranthus* spp.) for drought tolerance.

MATERIALS AND METHODS

Thirty (30) accessions of grain amaranth used for this screening were collected from NIHORT, Ibadan where the experiment was conducted in year 2011 in the screen house. The temperature and relative humidity of the screen house as described in figure 1 was collected using a Weather forecast station (BAR206). Seeds of grain amaranth were raised in a sterilized soil and regular watering was carried out in the nursery for three weeks after which the seedlings were transplanted into polyethylene bags filled with 5 kg of top soil at one seedling per pot. The trial was a completely randomized design (CRD) laid out in a 4 × 30 factorial arrangement replicated three times. The factors were time of water stress imposition (water stress at 4 WAT (W_1), water stress at 6 WAT (W_2), water stress at 8 WAT (W_3) and at 100 % field capacity which was the control (W4)) and thirty (30) accessions of grain amaranth (Table 1) making the total treatment to be one hundred and twenty (120), replicated three times to give three hundred and sixty (360) pots. Water stress was imposed by withdrawing water at 4, 6 and 8 WAT till the end of the experiment and water was applied at field capacity of the soil.

Table 1 Source of accessions used in the study.

Tablica 1. Izvori potomaka korišteni u ovom radu

S/No	Accession	Name	Origin	Species
1	AMES 5644	RRC-1044	Nigeria	*A. hybrid*
2	PI 337611	P373	Uganda	*A. hypochondriacus*
3	PI 477913	RRC-1011	Mexico	*A. cruetus*
4	PI 511719	NIQUA	Guatemala	*A. cruetus*
5	PI 641055	CEN/IB/97/AMA016	Nigeria	*A. viridis*
6	PI 604666	RRC-1027	US, Pennsylvania	*A. cruetus*
7	PI 590992	TIBET	China	*A. cruetus*
8	PI 590991	ZHENPING	China, Shanxi	*A. hypochondriacus*
9	PI 641043	CEN/IB/97/AMA003	Nigeria, Oyo	*A. cruetus*
10	PI 576480	TE81/760A	Nigeria	*A. cruetus*
11	PI576460	NHA/16B	Nigeria, Oyo	*A. cruetus*
12	PI576478	TE81/28	Nigeria	*A. cruetus*
13	PI576464	NHA/25A	Nigeria, Oyo	*A. cruetus*
14	PI576454	NHA/IB	Nigeria, Oyo	*A. cruetus*
15	PI576483	J82/645	Nigeria, Oyo	*A. dubius*
16	PI 576447	Unidentified 1	Nigeria, Oyo	*A. cruetus*
17	PI 576458	NHA/14	Nigeria, Oyo	*A. cruetus*
18	AMES 2055	RRC-117	Nigeria	*A. cruetus*
19	PI 641049	CEN/IB/97/AMA011	Nigeria, Oyo	*A. dubius*
20	PI 633596	JUMLA	Nepal	*A. hypochindriacus*
21	PI 538319	K266	US, Pennsylvania	*A. cruetus*
22	PI 515959	MONTANA-3	US, Montanan	*A. cruetus*
23	AMES5647	RRC-1047	Nigeria	*A. hybrid*
24	AMES1973	RRC-18B	Nigeria	*A. cruetus*
25	AMES1974	RRC-18C	Nigeria	*A. hybrid*
26	PI 584523	AMES21897	US, Colorado	*A. hypochondriacus*
27	PI641047	CEN/IB/97/AMA008	Nigeria, Oyo	*A. cruetus*
28	AMES1975	RRC-18D	Nigeria	*A. hypochondriacus*
29	PI 538326	D70-1	US, Pennsylvania	*A. hybrid*
30	PI 576465	NHA/25B	Nigeria, Oyo	*A. cruetus*

Data collection was carried out on plant height (cm) and number of leaves (at vegetative, reproductive and maturity stages) and also on shoot dry weight (gplant^{-1}), root dry weight (g), inflorescence length (cm), inflorescence weight (g), 1000 grain weight (g), grain yield (gplant^{-1}), root length (cm). To assess drought tolerance of grain amaranth accessions, Stress Tolerance Index (STI), Stress Susceptibility Index (SSI), Geometric Mean Productivity (GMP), Mean Productivity (MP), Tolerance Index (TOL), Harmonic Index (HM) and

Percentage reduction in grain yield were calculated based on grain yield in water stressed and optimal water supply conditions. Data collected were subjected to statistical analysis using GENSTAT 12th Edition Statistical Package. General linear model of Analysis of variance (ANOVA) was performed to establish significant effect (*P<0.05*; *F*-test) of the treatments on all the parameters taken using REML (Residual Maximum Likelihood). Significant means were separated using standard error of the difference of means in post ANOVA *t*-tests. Pearson moment correlation, Cluster analysis was also performed.

Leaf area = 0.5 (Length × Width) Pearcy *et al.* (1989.)
$STI = (ys)(yp) / (YP)^2$ (Fernandez, 1992.)
SSI = [(1-(ys/yp)] / SI, SI = 1-(YS/YP) (Fischer and Maurer, 1978.)
TOL = (YP-YS) (Rosielle and Hamblin, 1981.)
MP = (YP+YS) (Rosielle and Hamblin, 1981.)
GMP = √ (YP) (YS) (Fernandez, 1992.)
HM = 2(YP x YS) / (YP+YS) (Chakherchaman *et al.,* 2009)

Note: ys = Seed yield in water stressed condition, yp = Seed yield in optimal water regime, Ys = Mean seed yield in water stressed condition, Yp = Mean seed yield in optimal water regime.

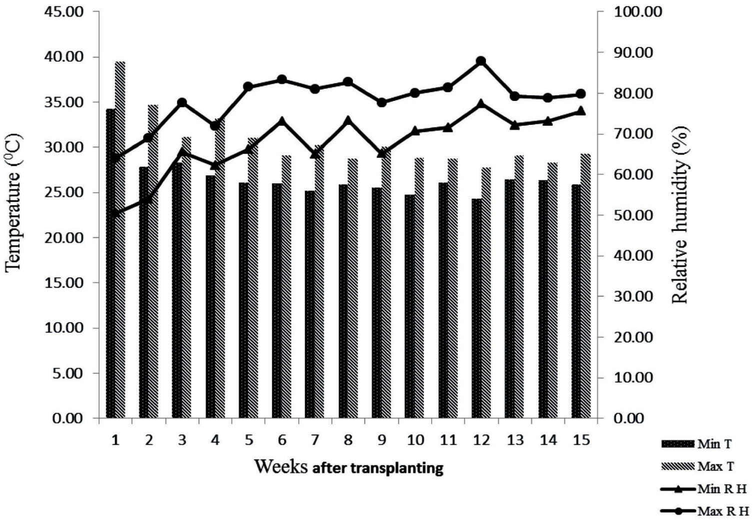


Figure 1: Distribution of mean temperature and mean relative humidity of the screen house

Slika 1 Raspodjela srednje temperature i srednje relativne vlage u Centru za selekciju

Table 2 Plant height and number of leaves of grain amaranth accessions as affected by water stress in Screen house.

Tablica 2. Visina biljke i broj listova potomaka zrnatog amaranta pod utjecajem vodenog stresa u Centru za selekciju

Treatments	Plant Height (cm)			Number of leaves		
	Vegetative	Reproductive	Maturity	Vegetative	Reproductive	Maturity
Water stress						
4WAT	63.73	0.00	0.00	36.32	0.00	0.00
6WAT	68.99	84.88	0.00	33.87	36.76	0.00
8WAT	71.31	92.11	106.00	27.96	31.34	34.38
100% Field capacity	69.14	90.80	106.40	30.71	34.50	37.06
Sig. *F*.(*P<0.05*)	**	**	ns	**	**	**
SED ± (3 d.f.)	1.67	1.66	1.48	1.06	1.05	0.82
Accessions						
AMES 5644	75.29	100.22	117.00	39.50	47.22	48.50
PI 337611	60.67	71.89	78.20	36.58	39.33	41.00
PI 477913	78.17	106.00	118.20	37.17	39.00	33.50
PI 511719	76.42	99.33	108.50	33.33	35.56	34.17
PI 641055	85.54	105.89	125.70	29.83	30.11	27.83
PI 604666	78.67	96.44	117.70	29.92	32.33	29.67
PI 590992	73.04	83.44	116.00	32.17	36.78	33.50
PI 590991	74.25	91.22	105.20	37.92	38.11	35.00
PI 641043	61.54	75.67	93.20	33.42	35.89	35.83
PI 576480	62.21	101.00	129.30	35.83	37.00	35.83
PI 576460	59.79	87.00	104.50	32.08	34.11	39.17
PI 576478	64.92	83.11	92.80	26.42	29.22	31.17
PI 576464	54.92	85.89	112.00	30.25	33.89	37.67
PI 576454	62.33	81.56	97.20	24.58	24.89	27.17
PI 576483	61.50	80.67	99.50	30.75	28.00	33.17
PI 576447	59.83	74.67	96.30	31.67	31.56	39.33
PI 576458	54.25	74.33	89.00	29.00	29.89	32.50
AMES 2055	57.25	79.56	95.50	40.08	42.11	36.33
PI 641049	71.75	88.44	97.00	35.83	39.33	46.00
PI 633596	77.79	110.67	127.70	30.33	33.56	33.33
PI 538319	71.00	95.22	117.20	27.75	28.78	32.33
PI 515959	78.17	101.56	112.30	27.25	29.33	34.33
AMES 5647	54.33	70.00	96.20	37.58	41.33	43.00
AMES 1973	67.67	89.67	100.70	29.25	31.78	35.83
AMES 1974	76.98	94.89	107.20	32.33	31.44	33.17
PI 584523	61.50	82.56	99.30	35.50	40.22	43.67
PI 641047	83.70	100.22	113.30	29.00	29.67	32.33

AMES 1975	58.38	76.78	99.30	29.83	31.78	35.33
PI 538326	81.58	110.44	128.50	29.17	32.33	37.17
PI 576465	65.38	79.56	91.80	32.08	31.44	33.67
Sig. *F*.(*P<0.05*)	**	**	**	**	**	**
SED ± (29 d.f.)	4.58	5.25	5.74	2.91	3.31	3.18

SED = standard error of difference of means, *or ** indicate significance at 5 % or 1 % probability level respectively, ns indicate Not significant.

RESULTS AND DISCUSSION

Water stress significantly affected plant height, number of leaves, root length, root and shoot weight, seed yield and yield components of grain amaranth. Plants stressed at 4 and 6 WAT died before reaching maturity stage while grain amaranths stressed at 8WAT were not significantly taller than those at 100 % field capacity (Tables 2 and 3). This is in line with the findings of Asghari et al., (2009.) that drought-stressed plants consequently exhibit poor growth and yield and in worst cases, the plants completely die. Moreover, grain amaranth at 100 % field capacity had significantly higher number of leaves, longer root, higher dry root and shoot weight than those stressed at 8 WAT. A similar pattern was observed on inflorescence weight, 1000 grain weight and grain yieldplant^{-1}. This could probably be due to the reason given by Allahmoradi et al., (2011.) that water stress affects various physiological processes associated with growth, development, and economic yield of a crop, because water stress inhibits cell enlargement more than cell division and it affects both elongation and expansion growth (Anjum et al., 2003.; Bhatt and Srinivasa Rao, 2005.; Kusaka et al., 2005.; Shao et al., 2008.). Significantly higher seed yield and yield components were produced by grain amaranths at 100 % field capacity than those stressed at 8 WAT could be as a result of significantly higher number of leaves leading to higher leaf area possibly disposing them to interception of more radiant energy and increased canopy photosynthesis. This result is in accordance with the report that water deficit stress mostly reduces leaf growth and in turn the leaf area in many species of plants like Populus (Wullschleger et al., 2005.), soybean (Zhang et al., 2004.) and many other species (Farooq et al., 2009.). Jaleel et al. (2009.) reported that drought stress affects growth, dry matter and harvestable yield in a number of plant species. Sadasivan et al. (1988.) also reported that water stress during vegetative phase reduces grain yield through restricted plant size leaf area and root growth which subsequently reduces the dry matter accumulation, number of pods per plant and low harvest index.

Table 3 Root length, dry root and shoot weight, grain yield and yield components of grain amaranth accessions as affected by water stress in Screen house.

Tablica 3. Duljina korijena, težina suhog korijena i izdanka, prinos zrna i prinos komponenata zrnatog amaranta pod utjecajem vodenog stresa u Centru za selekciju

Treatments	Root length (cm)	Root dry weight (g)	Shoot dry weight (g)	Inflorescence length (cm)	Inflorescence weight (g)	1000 grain weight (g)	Grain yield (g/plant)
Water stress							
4WAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6WAT	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8WAT	17.12	12.63	58.15	22.10	30.63	0.39	24.55
100% Field capacity	20.32	14.03	84.79	29.82	45.17	0.67	53.57
Sig. F. (P<0.05)	**	**	**	**	**	**	**
SED ± (3 d.f.)	0.28	0.22	0.49	0.23	0.44	0.01	1.19
Accessions							
AMES 5644	18.32	18.47	73.10	27.67	38.22	0.54	40.15
PI 337611	15.67	13.55	68.55	24.50	28.98	0.44	34.02
PI 477913	17.20	14.92	71.15	26.12	34.38	0.48	45.58
PI 511719	13.78	14.75	70.83	16.90	23.38	0.40	22.96
PI 641055	15.07	11.46	70.43	25.65	31.16	0.43	34.61
PI 604666	11.98	17.31	70.82	20.93	26.57	0.40	29.35
PI 590992	17.93	15.92	70.63	10.13	25.20	0.41	19.17
PI 590991	13.35	15.55	70.63	21.20	29.09	0.48	36.01
PI 641043	11.02	17.48	69.72	16.47	18.89	0.58	18.82
PI 576480	17.75	14.87	72.83	26.87	37.09	0.50	40.93
PI 576460	36.97	14.45	78.67	44.72	76.02	0.59	58.51
PI 576478	33.35	12.76	78.25	40.20	44.82	0.56	60.01
PI 576464	31.20	13.26	78.43	29.90	60.48	0.62	66.78
PI 576454	28.95	12.61	78.43	32.48	53.21	0.54	60.35
PI 576483	26.87	10.69	75.50	27.50	53.22	0.63	55.83
PI 576447	16.52	14.46	70.63	27.12	33.11	0.55	33.92
PI 576458	14.50	14.12	69.58	24.17	27.02	0.53	27.36
AMES 2055	12.22	12.94	69.38	21.17	23.06	0.51	29.16

PI 641049	12.28	14.01	67.42	17.50	22.37	0.50	23.09
PI 633596	13.82	13.15	66.98	23.37	24.30	0.49	29.96
PI 538319	19.05	11.80	65.57	28.97	47.17	0.59	46.23
PI 515959	14.75	11.24	69.00	13.60	20.98	0.50	22.18
AMES 5647	25.67	12.43	75.43	39.10	75.25	0.61	66.76
AMES 1973	24.23	11.95	74.80	29.08	48.44	0.62	53.88
AMES 1974	21.62	8.80	73.73	32.68	65.79	0.58	60.21
PI 584523	11.38	10.83	63.78	20.13	25.63	0.51	25.86
PI 641047	20.42	12.21	76.52	31.27	46.39	0.52	45.98
AMES 1975	19.52	11.99	75.95	36.97	47.96	0.55	44.38
PI 538326	10.28	11.79	62.67	20.60	26.46	0.65	23.70
PI 576465	15.95	10.19	64.70	21.73	22.33	0.52	18.86
Sig. F.(P<0.05)	**	**	**	**	**	**	**
SED $\pm$ (29 d.f.)	1.09	0.83	1.90	0.87	1.70	0.03	4.62

SED = standard error of difference of means, *or ** indicate significance at 5 % or 1 % probability level respectively.

Drought avoidance consists of mechanisms that reduce water loss from plants, due to stomatal control of transpiration, and also maintain water uptake through an extensive and prolific root system (Turner et al., 2001.; Kavar et al., 2007.). The root characters such as biomass, length, density and depth are the main drought avoidance traits that contribute to final yield under terminal drought environments (Subbarao et al., 1995; Turner et al., 2001.). A deep and thick root system is helpful for extracting water from considerable depths (Kavar et al., 2007.). Since roots are the only source to acquire water from soil, the root growth, its density, proliferation and size are key responses of plants to drought stress (Kavar et al., 2007.). In this study, grain amaranth at 100 % field capacity had significantly higher root length, root dry weight than those stressed at 8 WAT. This result might have contributed to higher grain yield/plant and yield components recorded in plants grown at 100 % field capacity than those stressed at 8 WAT. This is because root system is important in acquiring water for the plant (Jaleel et al., 2009.). This reason was also supported by the findings of Djibril et al. (2005.) that the development of root system increases water uptake in *Phoenix dactylifera*.

Significant varietal difference existed between the grain amaranth accessions evaluated. Accessions PI576480 and PI337611 were the tallest and the shortest with the height of 129.3 cm and 78.2 cm respectively at maturity (Table 2). Accession AMES5644 produced the highest number of leaves (49) and accession PI576454 produced the lowest number of leaves (Table 2). Accession PI576460 had the longest root (36.97 cm) while PI538326 had the shortest root (10.28 cm). The highest (18.47 g) and the lowest (8.80 g) root dry weight was produced by accessions AMES5644 and AMES1974 respectively. Moreover, accession PI576460 produced the highest shoot dry weight (78.67 g) while PI 538326 produced the lowest shoot dry weight of 62.67 g (Table 3). Accession PI 576460 had the highest inflorescence weight (76.0 g) and accession PI 538326 had the highest 1000 grain weight (0.65 g) while PI511719 and PI604666 had the lowest 1000 seed weight (0.40 g). Accession PI 576464 produced the highest grain yield plant^{-1} (66.78 g) and the lowest seed yield/plant (18.82 g) was produced by PI 641043 (Table 3). Identification of genotypic differences in cultivars tolerance to drought stress is needed for development of crops with reasonably high yield under water deficit (Naresh et al., 2013.). Result from this study showed that accessions that produced high yield also had longer root than those with low yield. This may be the mechanism adopted by these accessions to tolerate water stress. This result is in agreement with the result of Babar et al. (2013.) who found out that the synthetic ally derived genotypes of wheat with superior root traits had higher grain yield in water deficit condition. This probably could also be the reason why Thanh et al. (1999.) asserted that among the several factors contributing to enhance stress tolerance, root characters are considered to be a vital component of dehydration postponement mechanism since they contribute to regulation of plant growth and extraction of water and nutrients from deeper layers. Several researchers have reported the importance of a deep root system for extracting moisture and improving performance under water limited environments in various crops; Sinclair, 1994 in sorghum; Turner et al., 2001 in pulses; Kamoshita, 2002 in rice; Wasson et al., 2012 in wheat; Kashiwagi et al., 2006.

Table 4 Drought tolerance indices of thirty grain amaranth accessions under soil water stress.

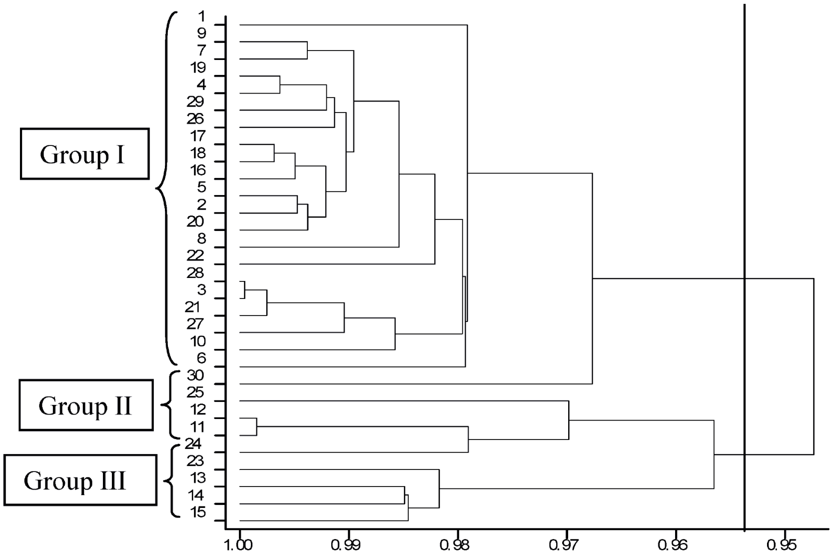
Tablica 4. Pokazatelji tolerantnosti na sušu trideset potomaka zrnatog amaranta pod stresom vode u tlu

ACCESSION	STI	SSI	TOL	MP	GMP	HM	% Reduction
AMES 5644	0.13	0.39	4.48	32.90	18.72	18.59	56.37
PI 337611	0.34	1.15	30.33	40.57	30.45	27.26	61.66
PI 477913	0.65	1.00	33.39	31.84	42.41	39.46	53.62
PI 511719	0.14	1.26	23.68	29.54	19.67	16.86	68.04
PI 641055	0.37	1.03	26.67	34.48	31.94	29.48	55.62
PI 604666	0.19	1.43	36.67	18.32	22.92	17.89	76.90
PI 590992	0.12	0.93	12.89	32.70	18.06	17.01	50.31
PI 590991	0.37	1.18	33.33	21.45	31.92	28.30	63.28
PI 641043	0.12	0.75	9.48	34.17	18.22	17.63	40.23
PI 576480	0.54	0.91	26.67	57.13	38.70	36.59	49.14
PI 576460	0.95	1.21	56.32	58.99	51.29	44.96	64.98
PI 576478	1.03	1.17	55.22	57.93	53.28	47.31	63.02
PI 576464	1.51	0.74	33.33	61.93	64.67	62.62	39.94
PI 576454	1.25	0.68	26.80	56.41	58.84	57.37	36.34
PI 576483	1.09	0.57	20.10	44.95	54.91	54.02	30.51
PI 576447	0.38	0.86	20.42	30.11	32.34	30.84	46.28
PI 576458	0.24	0.93	18.32	27.81	25.78	24.29	50.16
AMES 2055	0.28	0.82	16.52	27.05	27.96	26.82	44.16
PI 641049	0.16	1.13	20.24	29.03	20.75	18.65	60.94
PI 633596	0.24	1.25	30.24	38.04	25.87	22.33	67.07
PI 538319	0.69	0.91	30.00	30.06	43.73	41.36	49.00
PI 515959	0.16	0.86	13.40	52.69	21.15	20.16	46.40
AMES 5647	1.42	0.96	46.29	64.15	62.62	58.73	51.49
AMES 1973	0.71	1.35	61.62	54.12	44.20	36.26	72.76
AMES 1974	1.09	1.09	49.91	35.58	54.80	49.87	58.60
PI 584523	0.21	1.04	20.09	39.21	23.83	21.96	55.96
PI 641047	0.66	0.99	33.24	45.19	42.87	39.97	53.10
AMES 1975	0.61	1.01	33.27	31.11	41.14	38.14	54.53
PI 538326	0.16	1.16	21.56	17.01	21.11	18.80	62.53
PI 576465	0.13	0.39	4.48	8.31	18.72	18.59	21.25

STI means Stress Tolerance Index, SSI mean Stress Susceptible Index, TOL means Tolerance Index, MP means Mean Productivity, GMP means Geometric Mean Productivity, HM means Harmonic Productivity.

Results of drought tolerance indices revealed that PI 576464, AMES5647, PI 576454, AMES1974, PI 576483 and PI 576478 were the most tolerant accessions with STI equals to 1.51, 1.42, 1.25, 1.09, 1.09 and 1.03 respectively, and PI 590992, PI 641043, AMES5644, PI 576465 and PI 511719 were the most susceptible accessions with STIs equal to 0.12, 0.12, 0.13, 0.13, and 0.14 respectively (Table 4). AMES1973, PI576460, PI576478, AMES1974, AMES5647, PI604666, PI477913, PI576464, PI590991 and AMES1975 were calculated as ten best accessions in terms of TOL with the value as 61.6, 56.3, 55.2, 49.9, 46.3, 36.7, 33.4, 33.3, 33.3, and 33.3 respectively. AMES5644 and PI 604666 had the lowest and the highest SSI of 0.39 and 1.43 (Table 4). The percentage reduction of seed yield in stressed plants compared to plants at 100 % field capacity was calculated to range from 21 % to 49 % for the following accessions PI 576465, PI 576483, PI 576454, PI 576464, PI 641023, AMES2055, PI 576443, PI 515959, PI 538319 and PI 576480 (Table 4). Fernandez (1992.) defined STI as an index which could be used to identify genotypes that produced high yield under both stressed and non-stressed conditions. The other yield based estimates of drought resistance are GMP which is often used by breeders interested in relative performance, since drought stress can vary in severity in field environment over years (Ramirez and Kelly, 1998.). Akcura and Ceri (2011.) suggested that STI, GMP, MP, and HM could be used to identify genotypes that produce high yield under both stressed and non-stressed conditions. From this study, the most tolerant accessions have the ability to produce high yield in both stressed and non-stressed conditions according to Fernandez (1992.) and accessions with low value of SSI have stable yield in both environments (Fischer and Maurer, 1978; Nouri et al., 2011.).

Cluster analysis showed that the accessions tended to be categorized into three groups at 96 % similarity level based on drought tolerance indices. In this analysis, the third group (accession AMES5647, PI576464, PI576454 and PI576483) had the highest STI, GMP, MP, HM and was thus considered to be the most desirable cluster for both conditions. The second group comprised of accessions AMES1074, PI576478, PI576460 and AMES1973 while the third group comprised of the remaining accessions (Figure 2). Seed yield and yield components had significant positive correlation with one another and also with root length and shoot dry weight. Also, significant positive correlation existed between seed yield and yield components and drought indices except Stress Susceptible Index (SSI). Shoot dry weight had significant positive correlation with all the drought indices except SSI. Moreover, SSI had no significant correlation with any of the drought indices (Table 5). Significant positive correlation existed between seed yield and yield components. This indicates that increase in yield components (Inflorescence weight, Inflorescence length and one thousand seed weight) contributed to the increase in grain yield. Also, the significant positive correlation that existed between seed yield and drought indices except SSI indicated that these indices are suitable to screen drought tolerant and high yielding accessions. Similar results were reported by Moammadi et al. (2010.) and Talebi et al. (2009.). SSI had no significant correlation with seed yield and yield components and also with other drought indices.



Key: 1 = AMES 5644, 2 = PI 337611, 3 = PI 477913, 4 = PI 511719, 5 = PI 641055, 6 = PI 604666, 7 = PI 590992, 8 = PI 590991, 9 = PI 641043, 10 = PI 576480, 11 = PI 576460, 12 = PI 576478, 13 = PI 576464, 14 = PI 576454, 15 = PI 576483, 16 = PI 576447, 17 = PI 576458, 18 = AMES 2055, 19 = PI 641049, 20 = PI 633596, 21 = PI 538319, 22 = PI 515959, 23 = AMES 5647, 24 = AMES 1973, 25 = AMES 1974, 26 = PI 584523, 27 = PI 641047, 28 = AMES 1975, 29 = PI 538326, 30 = PI 576465.

Figure 2: Dendogram using average Ward method showing grouping of accessions based on tolerant indices.

Slika 2. Dendogram prikazuje primjenom prosječne Wardove metode svrstavanja potomaka na temelju pokazatelja tolerantnosti

Table 5 Simple correlation between seed yield, yield components and drought tolerance indices of thirty grain amaranth accessions grown in Screen house.

Tablica 5. Jednostavna korelacija između prinosa sjemena, prinosa komponenata pokazatelja tolerantnosti na sušu trideset potomaka zrnatog amaranta uzgajanog u Centru za selekciju

	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	0.86**	1									
3	0.85**	0.93**	1								
4	0.79**	0.85**	0.86**	1							
5	0.69**	0.74**	0.79**	0.83**	1						
6	0.76**	0.90**	0.96**	0.85**	0.75**	1					
7	0.05	-0.02	-0.02	-0.1	-0.04	-0.08	1				
8	0.70**	0.67**	0.71**	0.61**	0.55**	0.63**	0.64**	1			
9	0.54**	0.64**	0.70**	0.74**	0.70**	0.71**	0.02	0.51**	1		
10	0.80**	0.90**	0.97**	0.84**	0.75**	0.99**	-0.02	0.68**	0.70**	1	
11	0.77**	0.88**	0.95**	0.82**	0.74**	0.99**	-0.12	0.58**	0.69**	0.99**	1

Note: *or ** indicate significance at 5 % or 1 % probability level respectively.
1=Inflorescence length, 2=Inflorescence weight, 3=seed yield/plant, 4=Root length,
5=Shoot dry weight, 6=Stress Tolerance Index, 7=Stress Susceptible Index, 8=Tolerance Index,
9=Mean Productivity, 10=Geometric Mean Productivity, 11=Harmonic Mean.

CONCLUSION

In conclusion, this study showed STI, GMP, MP and HM were significantly correlated with grain yield and therefore could be suitable indices for screening of drought tolerance genotypes of grain amaranth. Moreover, based on these indices, accessions PI576464, PI576454, PI576483 and AMES 5647, AMES 1973 were the most tolerant varieties.

ACKNOWLEDGEMENT

The authors wish to acknowledge the effort of National Horticultural Research Institute, Ibadan for providing the screen house used for this study.

REFERENCES

1. Akcura, M. and Ceri, S. (2011.): Evaluation of drought tolerance indices for selection of Turkish oat (*Avena sativa* L.) landraces under various environmental conditions. Zemdirbyste- Agriculture. 98 (2):157-166.
2. Allahmoradi, P. Ghobadi, M. Taherabadi, S. and Taherabadi, S. (2011.): Physiological Aspects of Mungbean in Response to Drought Stress. IPCBEE vol. 9 (2011.) © (2011.) IACSIT Press, Singapoore Int. Conf. Food Eng. Biotechnol.
3. Anjum, F. Yaseen, M. Rasul, E. Wahid, A. and Anjum, S. (2003.): Water stress in barley (*Hordeum vulgare* L.). I. Effect on morphological characters. Pakistan Journal of Agricultural Science 40: 43–44
4. Asghari, M. T. Daneshian, J. and Farahani, H. A. (2009.): Effects of drought stress and planting density on quantity and morphological characteristics of chicory (*Cichorium intybus* L.) Asian Journal of Agricultural Sciences 1(1): 12-14
5. Babar, M. A. Mahmood, T. and Trethowan, R. M. (2013.): Relationship between root morphology and grain yield of wheat in north-western NSW, Australia. Australian Journal of Crop Science 7(13): 2108-2115.
6. Bhatt, R. M. and Srinivasa Rao, N. K. (2005.): Influence of pod load response of okra to water stress. Indian Journal of Plant Physiology 10: 54–59
7. Blum, A. (1996.): Constitutive traits affecting plant performance under stress. *In*: Edmeades, G. O., Banziger, M. Mickelson H. R. and Pena-Valdivia, C.B. (eds.), Developing Drought and Low N Tolerant Maize, Proceedings of the Symposium, Mexico D.F.: Cimmyt Pp.131–135.
8. Chakherchaman, S A. Mostafaei, H. Imanparast, L. and Eivazian, M. R. (2009.): Evaluation of drought tolerance in lentil advanced genotypes in Ardabil region, Iran. Journal of food, Agriculture and Environment 7(3-4): 283-288.
9. Clarke, J.M., Townley Smith, T.M. McCaig T.N. and Green, D.G.(1984.): Growth analysis of spring wheat cultivars of varying drought resistance. Crop. Sci., 24: 537-541.
10. Djibril, S. Mohamed, O. K. Diaga, D. Diégane, D. Abaye, B. F. Maurice, S. and Alain, B. (2005.): Growth and development of date palm (*Phoenix dactylifera* L.) seedlings under drought and salinity stresses. African Journal of Biotechnology 4: 968–972
11. Farooq, M. Wahid, A. Kobayashi, N. Fujita, D. and Basra, S. M. A. (2009.): Plant drought stress: effects, mechanisms and management. Agron. Sustain. Dev. 29: 185–212

12. Fernandez, G. C. J. (1992.): Proceedings of the International Symposium on Adaptation of Vegetables and Other Food Crops in Temperature and Water Stress, Publication, Tainan, Taiwan
13. Fischer, R A and Maurer, R. (1978.): Drought resistance in spring Wheat cultivars. I. Grain yield response. Australian Journal of Agricultural Research 29: 897-907
14. Grubben, G. J. H. (1977.): Tropical vegetables and their genetic resources. Royal Tropical Institute, Amsterdam, Netherlands.
15. Hall, A.E. (1993.): Is dehydration tolerance relevant to genotypic differences in leaf senescence and crop adaptation to dry environments? In: Plant Responses to cellular dehydration during environmental stress. (Eds.): T.J. Close and E.A. Bray, pp. 1-10.
16. Jaleel, C. A. Manivannan, P. Wahid, A. Farooq, M. Somasundaram, R. and Panneerselvam, R. (2009.): Drought stress in plants: a review on morphological characteristics and pigments composition. International Journal of Agricultural Biology, 11: 100–10
17. Kamoshita, A. (2002.): Mapping QTLs for root morphology of a rice population adapted to rainfed lowland conditions. Theor. Appl. Genet. 104: 880–893
18. Kashiwagi, J. Krishnamurthy, L. Crouch, J. H. and Serraj, R. (2006.): Variability of root length density and its contributions to seed yield in chickpea (*Cicer arietinum* L.) under terminal drought stress. Field Crops Research 95: 171–181.
19. Kavar T. Maras, M. Kidric M. Sustar-Vozlic J. and Meglic V. (2007.): Identification of genes involved in the response of leaves of *Phaseolus vulgaris* to drought stress. Molecular Breeding 21: 159–172.
20. Kusaka, M. Ohta, M. and Fujimura, T. (2005.): Contribution of inorganic components to osmotic adjustment and leaf folding for drought tolerance in pearl millet. Physiol. Plant. 125: 474–489
21. Mitra, J. (2001.): Genetics and genetic improvement of drought resistance in crop plants. *Curr. Sci.*, 80: 758-762.
22. Mohammadi, R. Armion, M. Kahrizi, D. and Amri, A. (2010.): Efficiency of screening techniques for evaluating durum wheat genotypes under mild drought conditions. International Journal of Plant Production. 4 (1): 11-24.
23. Naresh, R. K. Purushottam, S. P. S. Ashish, D. and Vineet, K. (2013.): Effects of water stress on physiological processes and yield attributes of different mungbean (L.) varieties. African Journal of Biochemistry Research. Vol. 7(5):55-62

24. Nouri, A. Etminan, A. Jaime, A. daSilva, T. and Mohammadi, T. (2011.): Aust. J. Crop Sci., 5(1):8-16.
25. O'Brien, G. K. and Price, M. L. (2008.): Amaranth Grain & Vegetable Types ECHO Technical Note Published 1983; revised by Larry Yarger 2008
26. Pearcy, R.W. Ehleringer, J. E. Monney, H. A. and Rundel, P. W. (1989.): Plant Physiological Ecology, Field Methods and Instrumentation. Chapman and Hall. New York, 423 pp.
27. Ramirez, V. P. and Kelly, J. D. (1998.): Euphytica, 99:127-136.
28. Rosielle, A. A. and Hamblin, J. (1981.): Crop Science Journal 21: 943-946
29. Sadasivan, R. Natrajaratnam, N. Dabu, R. Muralidharan, V. Rangasmay, S. R. S. (1988.): Response of Mungbean cultivars to soil moisture stress at different growth phases. Mungbean Proceeding of the Second International Symposium. AVRDC. Pp.260-262.
30. Shao H. B. Chu, L. Y. Shao, M. A. Abdul Jaleel, C. and Hong-Mei, M. (2008.): Higher plant antioxidants and redox signaling under environmental stresses. Comp. Rend. Biol. 331: 433–441
31. Sinclair, T. R. (1994.): Limits to crop yield? In: Boote, K. J. (Ed.), Physiology and Determination of Crop Yield. ASA, CSSA and SSSA, Madison, pp. 509–532.
32. Stallknecht, G. F. and Schulz-Schaeffer J. R. (1993.): Amaranth rediscovered. Pp. 211-218. In: J. Janick and J.E. Simon (eds.), *New Crops*. Wiley, New York.
33. Subbarao G.V., Johansen C., Slinkard A.E., Rao R.C.N. , Saxena N.P., Chauhan Y.S. (1995.): Strategies and scope for improving drought resistance in grain legumes. *Critical Reviews in Plant Science.* 14, 469–523.
34. Talebi, R. Fayaz, F. and Naji, A. M (2009.): Effective selection criteria for assessing drought stress tolerance in durum wheat (*Triticum durum* Desf.). Greenland Applied Plant Physiology 35 (1-2): 64-74
35. Thanh, N. O. Zheng, H. G. Dong, N. V. Trinh, L. N. Ali, M. L. and Nguyen, H. T. (1999.): Genetic variation in root morphology and microsatellite dna loci in upland rice (*Oryza sativa* L.) from Vietnam. Euphytica 105: 43–51.
36. Turner N. C. Wright, G. C. and Siddique, K. H. H. (2001.): Adaptation of grain legumes (pulses) to water-limited environments. In: Sparks DL (ed) Advances in Agronomy. 71: 193-231

37. Wasson, A. P. Richards, R. A. Chatrath, R. Misra, S. C. Prasad, S. V. S. Rebetzke, G. J. Kirkegaard, J. A. Christopher, J. and Watt, M. (2012.): Traits and selection strategies to improve root systems and water uptake in water-limited wheat crops. Journal of Experimental Botany 63:3485-3498
38. Wullschleger, S. D. Yin, T. M. DiFazio, S. P. Tschaplinski, T. J. Gunter, L. E. Davis, M. F. and Tuskan, G. A. (2005.): Phenotypic variation in growth and biomass distribution for two advanced-generation pedigrees of hybrid poplar. Canadian Journal of Forest Research 35:
39. Zhang, M. Duan, L. Zhai, Z. Li, J. Tian, X. Wang, B. He, Z. and Li, Z. (2004.): Effects of plant growth regulators on water deficit-induced yield loss in soybean. Proceedings of the 4th International Crop Science Congress, Brisbane, Australia

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Received –Primljeno:
20.07.2016.