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Original article

Investigation of tolerance and sensitivity indices of fodder Amaranth (*Amaranthus hypochondriacus* L.) under water deficit conditions via principal component analysis

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Extended abstract

Introduction

One of the crops that are considered as new sources of human nutrition as well as animal feed and poultry is the Amaranth. The leaves of most of the Amaranth species are used orally for human or animals use worldwide. According to the patterns of drought, irrigation management plays an important role in improving or enhancing crop yields, especially in arid and semi-arid regions. In this regard, identification of indices for tolerance and susceptibility to drought stress has always been of interest to researchers and it can be very effective. Many scientists have tried to find the best index for stress tolerance in plants. This study aimed to evaluate the best indices for determination of drought tolerance in forage Amaranth cultivars.

Materials and methods

Experimental research farm with a geographical position of 31 degrees 54 minutes north and 54 degrees 16 minutes west of 1215 meters above sea level is located in Yazd province. The tested cultivars were planted in plots of 40 m2 in two consecutive years (May 2018-19). The planting was done in a row, and immediately the first irrigation was done. Fertilization was done every two years according to soil analysis and plant requirement. Split-plot experiment based on a completely randomized block design with three replications was used for this study. The main factor, including four levels of water-deficit for the plant (50, 60, 70 and 80%) was considered. And Cim and Kharkovski, who all belong to the Amaranthus Hypochondriacus family, constituted the sub-factor of the test. Parameters such as yield, agricultural water productivity, leaf-to-stem weight ratio, stem diameter, plant height and crude protein percentage were investigated. Then, using dry forage yield of the Amaranth, famous indices were used to calculate resistance and stability of drought stress. In this essay, SAS 9.4 software was used for data

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analysis of variance and Statgraphics 18 software was applied for drawing graphs and principal components analysis.

Results

Combine analysis was performed for two years on all traits. Interaction effects revealed that with increasing drought stress, fresh forage yield in Amaranth cultivars was significantly reduced, as Loura and Cim had the highest yield at 50% water depletion conditions, while Loura and Kharkovski cultivars at 80% of water discharge showed the lowest yield. Agricultural water productivity also yielded similar results. The ratio of leaf to stem weight in the interaction of treatments had no significant difference. But the diameter and height of stems decreased significantly with increasing drought stress levels in all cultivars, but this decrease was more pronounced in Kharkovski. Subsequently, the principal component analysis was performed to evaluate the genotypes. It was found that the Cim cultivar is the most resistant to high levels of drought stress.

Conclusions

The results showed that with increasing drought stress levels, fodder yield significantly decreased in different cultivars. But despite the decrease in the yield, it seems that due to the quality of the forage, the relatively favourable production volume per hectare and due to the short growing season of the plant, it can be a desirable option even in low water areas. Since one of the objectives of this research was to select the optimal stress index for selection of superior cultivar for drought tolerance, by analyzing the principal component, we found that the Hm and MP indices with the yield under stress and non-stress conditions were the most valuable. However, while the Loura genotype had a higher yield under non-stress and even mild drought conditions, the Cim cultivar showed significantly better yield under drought stress. And in terms of indices, Kharkovski could never perform better than Cim.

Keywords: Amaranth, Biplot, Crude protein, Forage yield, Water deficit

Table 1. Climatic data of the experimental site (During the months of the experiment).

	Temperature (ºC)			Relative Humidity	Evaporation Rate	Monthly
Month	**Mean of Max.**	**Mean of Min.**	**Daily ave.**	(%)	(mm)	**Rainfall** (mm)
May 2018	34.95	21.08	28.34	19.78	12.63	7.8
June 2018	39.87	24.79	33.12	8.59	15.97	0
July 2018	39.25	25.82	33.08	11.22	16.34	0
May 2019	30.78	18.35	24.75	28.77	9.86	8.5
June 2019	39.04	25.21	32.47	12.69	15	0
July 2019	39.32	24.36	32.90	7.40	16.02	0

Table 2. Physical and chemical properties of the soil in the field before planting process (0–30 cm).

Year	K (p.p.m)	P (p.p.m)	N (%)	O.C (%)	pH	EC (dS/m)	FC Θv	PWP Θv	Soil texture
2018	157	13.6	0.017	0.205	7.2	4.9	24.4	10.8	**Sandy clay loam**
2019	138	7.3	0.021	0.254	7.2	4.5	-	-	**Sandy clay loam**

O.C: Organic Carbon; EC: Electrical Conductivity; FC: Field Capacity; PWP: Permanent Wilting Point; Θv: Volumetric Humidity.

Table 3. Effect of irrigation deficit treatments on the yield parameters of three cultivars of forage Amaranth and their interactions in the two successive years

Treatments	Fresh Yield	Water Productivity	Leaf to Stem Ratio	Stem diameter	Plant height	Crude Protein
	ton.ha^{-1}	kg.m^{-3}		mm	cm	%
Year						
2018	35.52	3.21	0.49	17.89	120.46	15.27
2019	36.71	3.39	0.50	18.19	123.69	15.16
Significance	ns	ns	ns	ns	ns	ns
irrigation deficit *levels*						
water-deficit 50% (1)	53.65 ^{a}	4.42 ^{a}	0.38 ^{c}	21.96 ^{a}	151.1 ^{a}	13.50 ^{d}
water-deficit 60% (2)	41.72 ^{b}	3.74 ^{b}	0.46 ^{bc}	20.55 ^{b}	138.1 ^{b}	14.62 ^{c}
water-deficit 70% (3)	28.98 ^{c}	2.86 ^{c}	0.54 ^{ab}	16.05 ^{c}	108.6 ^{c}	15.66 ^{b}
water-deficit 80% (4)	20.12 d	2.21 ^{d}	0.61 ^{a}	13.57 ^{d}	90.4 ^{d}	17.11 ^{a}
Significance	**	**	*	**	**	**
Genotypes						
Cim (C)	38.55 ^{a}	3.54	0.49	18.66 ^{a}	125.8	14.66 ^{b}
Kharkovski(Kh)	31.99 ^{b}	2.94	0.5	16.8 ^{b}	112.0	15.94 ^{a}
Loura(L)	37.82 ^{a}	3.44	0.5	18.65 ^{a}	128.3	15.07 ^{b}
Significance	*	ns	ns	*	ns	*
Interaction						
(1)×(C)	56.24 ^{a}	4.63 ^{ab}	0.45	22.39 ^{a}	152.5 ^{a}	13.02 ^{h}
(1)×(Kh)	46.32 ^{bc}	3.81 ^{c}	0.38	21.27 ^{bc}	147.0 ^{a}	14.35 ^{f}
(1)×(L)	58.40 ^{a}	4.81 ^{ab}	0.32	22.23 ^{ab}	153.8 ^{a}	13.13 ^{h}
(2)×(C)	42.19 ^{c}	3.79 ^{c}	0.46	19.89 ^{d}	130.2 ^{c}	13.95 ^{g}
(2)×(Kh)	36.24 ^{d}	3.25 ^{d}	0.45	20.29 ^{dc}	138.0 ^{bc}	14.86 ^{e}
(2)×(L)	46.74 ^{b}	4.19 ^{bc}	0.48	21.49 ^{ab}	146.1 ^{ab}	15.05 ^{e}
(3)×(C)	33.15 ^{d}	3.27 ^{d}	0.53	16.91 ^{e}	118.9 ^{d}	14.79 ^{e}
(3)×(Kh)	27.51 ^{e}	2.72 ^{e}	0.55	15.06 ^{g}	93.3 ^{e}	16.56 ^{c}
(3)×(L)	26.28 ^{ef}	2.59 ^{ef}	0.56	16.19 ^{ef}	113.5 ^{d}	15.65 ^{d}
(4)×(C)	22.62 ^{fg}	2.48 ^{ef}	0.56	15.43 ^{fg}	101.6 ^{e}	16.88 ^{b}
(4)×(Kh)	17.88 ^{h}	1.96 ^{g}	0.62	10.60 ^{h}	69.8 ^{f}	17.98 ^{a}
(4)×(L)	19.85 ^{gh}	2.18 ^{fg}	0.67	14.68 ^{g}	99.8 ^{e}	16.47 ^{c}
Significance	*	*	ns	**	**	**
CV (%)	12.02	12.86	9.46	8.91	9.47	5.02

Values within one column followed by different letters are significantly different at P≤0.05 according to Duncan's test. ^{ns}, no significance (P≤0.05). *, **, significance at P≤0.05, P≤0.01, respectively

Table 4. Comparison of the mean of stress tolerance and susceptibility indices in the cultivars of forage Amaranth in the two successive years

Genotypes	Yp (ton.ha^{-1})	Ys (ton.ha^{-1})	MP	TOL	GMP	SSI	STI	YSI	HM	Yr	RDI
mild drought stress											
Cim	8.07	6.19	7.13	1.88	7.05	0.97	49.94	0.77	6.97	0.22	1.00
Kharkovski	6.56	5.39	5.97	1.16	5.93	0.92	35.53	0.83	5.89	0.16	1.01
Loura	8.14	6.96	7.55	1.18	7.52	1.00	57.36	0.85	7.49	0.14	1.00
moderate drought stress											
Cim	8.07	5.23	6.65	2.84	6.48	0.98	42.14	0.65	6.32	0.34	1.00
Kharkovski	6.56	4.85	5.70	1.70	5.63	0.97	32.14	0.74	5.56	0.25	1.01
Loura	8.14	4.25	6.19	3.89	5.83	0.79	34.28	0.53	5.50	0.46	1.02
mild drought stress											
Cim	8.07	4.15	6.11	3.92	5.74	0.99	33.56	0.51	5.40	0.48	1.00
Kharkovski	6.56	3.15	4.86	3.40	4.52	0.98	20.75	0.49	4.21	0.50	1.01
Loura	8.14	3.80	5.97	4.34	5.49	0.22	30.66	0.48	5.08	0.51	1.02

Yp, fresh mean yield of the genotype under non-stress conditions; Ys, fresh mean yield of the genotype under stress conditions; MP, mean productivity; TOL, tolerance; GMP, geometric mean productivity; SSI, stress susceptibility index; STI, stress tolerance index; YSI, yield stability index; HM, harmonic mean; Yr, Yield reduction rate; RDI, relative drought index.

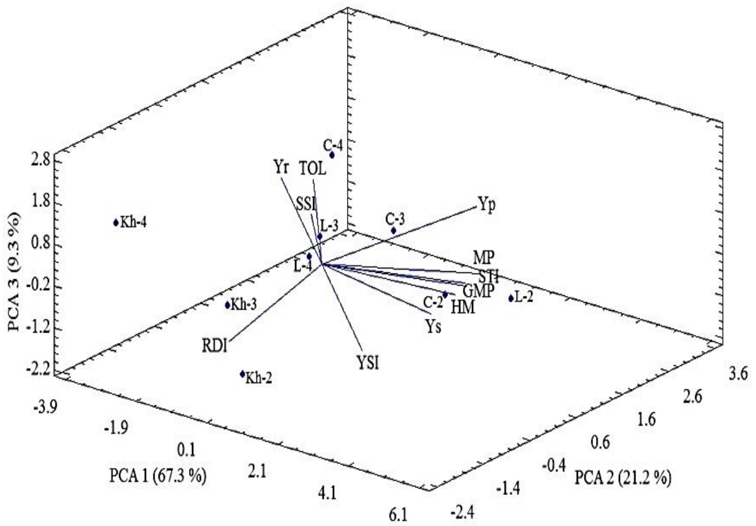

Fig. 1. 3D biplot of the first three principal components based on dry forage yield in drought stress and non-stress conditions with a focus on drought tolerance indices for three genotypes of fodder amaranth. PCA1, PCA2 and PCA3; First, second and third principal component respectively. C: Cim, KH: Kharkovski, L: Loura. 2, 3 and 4: 60, 70 and 80% plant available water depletion, respectively.

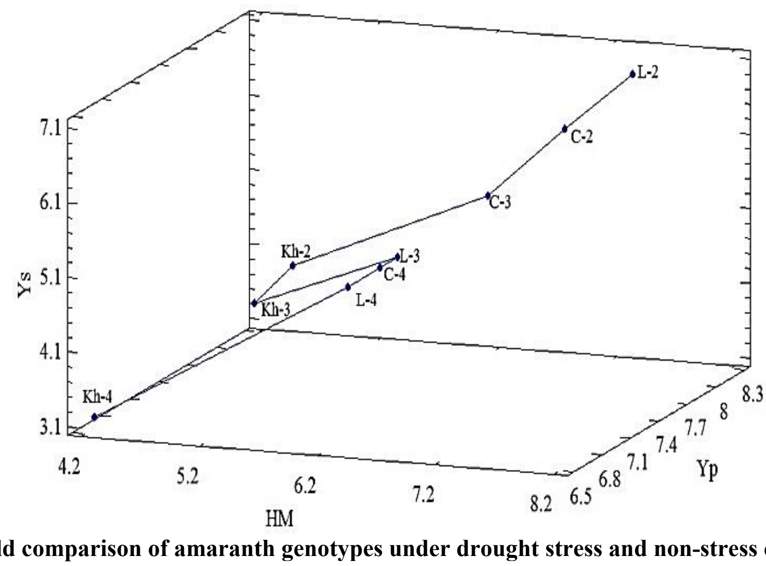

Fig. 2. 3D yield comparison of amaranth genotypes under drought stress and non-stress conditions with harmonic mean efficiency index. C: Cim, KH: Kharkovski, L: Loura. 2, 3 and 4: 60, 70 and 80% plant available water depletion, respectively.

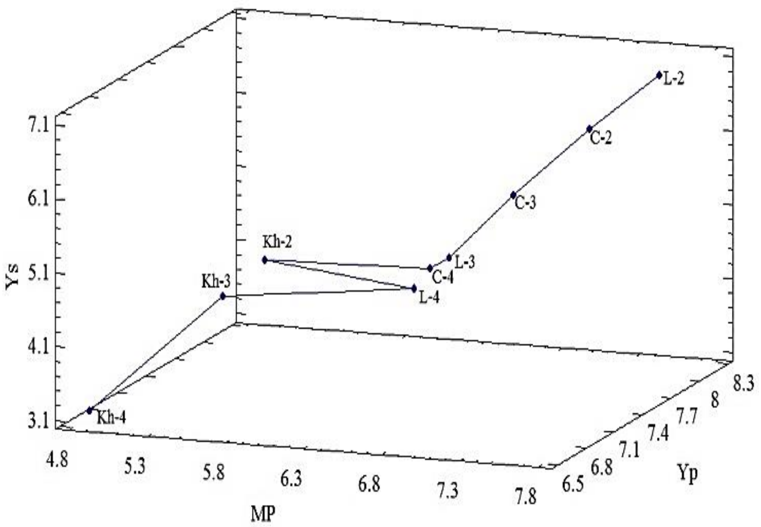

Fig. 3. 3D yield comparison of amaranth genotypes under drought stress and non-stress conditions with mean productivity index. C: Cim, KH: Kharkovski, L: Loura. 2, 3 and 4: 60, 70 and 80% plant available water depletion, respectively.