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Original article

Effect of β-estradiol application in enhancment of drought tolerance in different potato genotypes (*Solanum tuberosum* L.)

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Extended abstract

Introduction

Potato is an important food crop with high yields. However, when exposed to drought it suffers major yield losses. Considering its global importance and the increasing incidence of drought due to climate change, research toward drought tolerance in potatoes remains imperative. In vertebrates, estrogen, and androgen steroidal hormones have important functions in development and reproduction. Estrogens and estrogen-like compounds (xenoestrogens) from livestock manure, animal waste, and human waste (especially pharmaceutical waste), are being disposed of and excreted at high rates into the agricultural soil and groundwater all over the world. The aim of this study was to investigate the effect of the β-estradiol application on the tolerance of different potato genotypes to water deficit stress.

Materials and Methods

To study the effect of β-estradiol application in enhancement of drought tolerance in different potato genotypes, an experiment was conducted as a factorial split-plot arrangement with three replications in the greenhouse of Zare Gostar Arta Technology Company in Ardabil. Treatment of drought stress was reducing the amount of irrigation water (100, 60, and 40% of available water) and β-estradiol hormone at three levels of zero (control), 10^{-6} and 10^{-12} molar both in the main plots and 10 potato genotypes were placed in sub-plots. In the present study plant height, leaf relative water content, number of tubers per plant, tubers weight per plant, mean tubers weight, reducing sugar percentage, dry matter percent, protein tubers percent, starch percent, proline content, superoxide dismutase, catalase activity, and polyphenol oxidase were measured. Data were analyzed by using SAS software, 9.2, and also the mean of the studied traits were compared by LSD test at 5% probability level.

Results and discussion

The results of the analysis of variance showed that there was a significant difference among the drought levels in terms of all studied traits. Difference between β-estradiol levels in terms of plant height, number of tubers per plant, the weight of tubers per plant, mean tuber weight, the relative water content of leaves, tuber dry matter percent, protein tuber percent, percentage of starch, and catalase, polyphenol

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oxidase and superoxide dismutase contents was significant. Interaction effect of drought and hormone on plant height, tuber weight per plant, mean tuber weight, number of tubers per plant, tuber dry matter percent, the relative water content of leaves, reducing sugar percent, starch percent, catalase and polyphenol oxidase was significant. There was a significant difference between the studied genotypes in terms of all studied traits. Interaction effect of genotype × drought on plant height, the relative leaf water content, number of tubers per plant, tuber weight per plant, mean tuber weight, tuber dry matter percentage, protein percent, starch percent, proline content, catalase, and superoxide dismutase was also significant. Finally, the interaction of genotype × hormone on plant height, relative leaf water content, number of tubers per plant, tuber weight per plant, tuber weight mean, dry matter percent, protein percent and catalase content was significant. In all three drought levels, the highest number of tubers per plant allocated to two genotypes of G3 and G6. The highest relative water content was assigned to the G6 genotype, the highest percentage of regenerating sugar and the percentage of the dry matter assigned to the G3 genotype and the highest plant height, the percentage of starch and the percentage of protein assigned to the G4 genotype.

The results showed that under normal conditions, G6, G4, and G3 genotypes (with an average of 96.90, 93.77, and 92.04 g/plant respectively) had the highest tuber weight per plant. In drought treatment of 60% of usable water supply, although the highest tuber weight was assigned to G1 genotype, there was no significant differences between the mentioned genotype and G2, G3, G5, and G6 genotypes. Also, in drought treatment of 40% of usable water supply, there was only significantly difference between G6 and G9 genotypes. In this study, the use of β-estradiol (especially the level of 10^{-12} molar) in all three water deficit treatments significantly increased the plant height, mean tuber weight, relative water content, dry matter percentage, starch percentage, proline, catalase and polyphenol oxidase contents as compared with the control. Finally, the highest plant height, number of tubers per plant, tubers weight per plant, dry matter percentage, and protein content were assigned to the G4 genotype with 10^{-12} molar of β-estradiol. Finally, among the studied genotypes, G4 at the level of 10^{-12} (with an average of 62.21 g/plant) had the highest tuber weight per plant.

Conclusions

Based on the results of the present study, it can be stated that both G3 and G6 genotypes can be promising genotypes for cultivation under normal conditions and mild drought stress in the study area. In the drought treatment of 40% of usable water supply, only a significant difference was seen between G6 and G9 genotypes. It can be concluded that the response of the 10 genotypes to severe drought stress conditions was almost similar. Also, the genetic potential of G4 and G6 genotypes for uptake and use of β-estradiol was higher compared to other genotypes. Furthermore, the use of β-estradiol hormone can improve the quantitative and qualitative characteristics of potato genotypes under water deficit conditions.

***Keywords*:** Antioxidant, Dry matter, Tuber weight, Water deficit

Table 1. Analysis of variance of quantitative and qualitative characteristics of different cultivars of potatoes

S.O.V	df	Plant height	Relative water content	Number of minitubers per plant	Minitubers weight per plant	Average minituber weight	Soluble sugar percentage	Dry matter percentage
Replication	2	23.84	40.58	3.89	1464	9.50	0.0001	0.29
Drought	2	2744.73**	3395.87**	247.17**	136987**	2888.1**	0.00049*	0.48**
Hormone	2	650.50**	279.80**	9.53**	19839**	381.74**	0.00035^{ns}	0.34**
D×H	4	194.66**	128.22**	2.83*	17497**	154.58**	0.0065**	0.18*
Ea	16	20.24	15.44	0.80	383	2.60	0.00015	0.05
Genotype	9	65.07**	93.06**	3.15**	496**	2.53**	0.00023*	6.47**
D×G	18	63.61**	73.56*	18.71**	424**	5.08**	0.00018^{ns}	0.22**
H×G	18	21.08*	124.68**	0.94**	220**	1.68**	0.0001^{ns}	0.11*
D×H×G	36	16.00^{ns}	26.13ns	0.51^{ns}	17	0.07^{ns}	0.00009^{ns}	0.05^{ns}
Eb	162	11.86	21.63	0.46	22	0.09	0.00014	0.058
CV(٪)	-	*7.42*	*5.96*	*20.04*	*13.33*	*4.29*	*3.81*	*2.19*

Table 1. Continued

S.O.V	df	Protein percentage of minitubers	Starch Percentage	Proline content	Superoxide dismutase	Catalase	Polyphenol oxidase
Replication	2	0.0001	44.38	10496	0.06	1.16	0.068
Drought	2	0.0028**	180.42**	1031237**	22.36**	57.35**	5.86**
Hormone	2	0.0022**	42.71**	79952**	0.81*	7.98**	4.54**
D×H	4	0.00003^{ns}	1.38^{ns}	35668*	0.01^{ns}	2.73**	4.71**
Ea	16	0.0002	1.32	9267	0.05	0.27	0.18
Genotype	9	0.021**	4.18**	5656**	0.49**	0.57**	0.39**
D×G	18	0.001**	12.79**	70.20^{ns}	0.56****	0.09**	0.08^{ns}
H×G	18	0.006**	1.38^{ns}	97.00^{ns}	0.008^{ns}	0.11**	0.07^{ns}
D×H×G	36	0.0004^{ns}	1.05^{ns}	82.00 ^{ns}	0.007^{ns}	0.028^{ns}	0.06^{ns}
Eb	162	0.0005	0.78	80.00	0.19	0.032	0.07
CV(٪)	-	*3.92*	*7.61*	*5.18*	*7.49*	*3.57*	*6.44*

**,* and ^{ns}: Significant at 1 and 5%, and non-significant, respectively

Table 2. Mean comparison of treatment resulting from the interaction of potato genotypes and drought stress levels in terms of effect on the studied traits

Drought	Genotype	Plant height	Number of minitubers per plant	Minitubers weight per plant	Avarage minituber weight	Leaf relative water content
		cm		g/plant	g	%
Normal (100%)	1	54.66^{ab}	5.11^{c}	74.25^{d}	14.29^{e}	88.33^{a}
	2	54.22^{bc}	4.22^{d}	56.44^{e}	13.24^{f}	87.77^{ab}
	3	51.11^{cd}	5.77^{ab}	92.04^{ab}	15.07^{cd}	83.88^{bc}
	4	57.55^{a}	5.33^{bc}	93.77^{ab}	16.60^{a}	78.88^{d-g}
	5	49d^{ef}	5.00^{c}	82.42^{c}	15.70^{b}	80.27^{cde}
	6	49.11^{def}	6.11^{a}	96.90^{a}	15.75^{b}	90.00^{a}
	7	54.22^{bc}	5.00^{c}	77.36^{d}	15.18^{c}	87.77^{ab}
	8	55.00^{ab}	4.77^{cd}	73.94^{d}	14.90^{d}	88.75^{a}
	9	49.55^{de}	4.77^{cd}	77.45^{d}	15.33^{c}	81.94^{cd}
	10	45.44^{gh}	5.00^{c}	77.97^{d}	15.08^{cd}	76.80^{e-h}
60% usable water	1	43.88^{h-k}	2.77^{ef}	22.39^{f}	8.33^{h}	74.86^{g-j}
	2	45.55^{gh}	2.55^{efg}	21.74^{fg}	8.72^{g}	76.94^{e-h}
	3	46.22^{fgh}	3.00^{e}	20.98^{fg}	7.28^{i}	77.77^{d-g}
	4	50.22^{de}	2.55^{efg}	17.43^{ghi}	6.91^{jk}	79.72^{d-f}
	5	47.88^{d-g}	2.55^{efg}	20.21^{fg}	8.15^{h}	79.86^{c-f}
	6	47.44^{efg}	2.77^{ef}	19.22^{fgh}	7.20^{i}	77.63^{d-g}
	7	44.66^{g-j}	2.22^{fgh}	15.31^{hi}	7.04^{ij}	75.83^{f-i}
	8	45.22^{ghi}	2.22^{fgh}	14.78^{i}	6.88^{jk}	76.52^{e-h}
	9	47.77^{efg}	2.23^{fgh}	15.48^{hi}	7.25^{i}	79.72^{c-f}
	10	45.00^{ghi}	2.00^{ghi}	13.42^{ij}	6.71^{k}	76.25^{e-h}
40% usable water	1	39.11^{lm}	2.22^{fgh}	8.79^{kl}	4.12^{m}	68.88^{kl}
	2	37.55^{m}	2.44^{efg}	8.66^{kl}	3.70^{o}	66.94^{l}
	3	39.66^{lm}	2.66^{ef}	9.33^{jkl}	3.73^{o}	69.58^{kl}
	4	42.11^{i-l}	2.00^{ghi}	9.31^{jkl}	4.66^{l}	74.72^{kl}
	5	42.12^{i-l}	2.00^{ghi}	8.07^{lk}	4.03^{mn}	72.63^{h-k}
	6	40.66^{klm}	2.22^{fgh}	9.74^{jk}	4.51^{l}	78.88^{d-g}
	7	41.11^{kl}	2.22^{fgh}	9.21^{jkl}	4.17^{m}	71.38^{jk}
	8	40.77^{klm}	1.44^{i}	5.47^{kl}	4.19^{m}	70.97^{jkl}
	9	44.88^{ghi}	1.55^{i}	5.17^{l}	3.61^{o}	76.11^{e-i}
	10	41.44^{jkl}	1.66^{hi}	6.25^{kl}	3.84^{no}	71.80^{ijk}

Table 2. Continued

Drought	Genotype	Leaf Relative Water Content	Soluble sugar	Dry Matter	Protein Tubers	Starch
		----------%----------				
Normal (100%)	1	88.33^{a}	0.654^{b-e}	20.72^{cde}	0.86^{lm}	9.72^{op}
	2	87.77^{ab}	0.635^{ghi}	20.09^{ijk}	0.83^{m}	9.33^{p}
	3	83.88^{bc}	0.654^{a}	21.07^{a}	0.88^{lm}	9.87^{op}
	4	78.88^{d-g}	0.628^{ijk}	19.88^{kl}	0.93^{i-k}	10.49^{j-o}
	5	80.27^{cde}	0.606^{m}	19.18^{n}	0.93^{i-k}	10.49^{j-o}
	6	90.00^{a}	0.648^{def}	20.51^{efg}	0.90^{klm}	10.12^{nop}
	7	87.77^{ab}	0.647^{def}	20.49^{fg}	0.91^{kl}	10.24^{l-p}
	8	88.75^{a}	0.616^{lm}	19.50^{m}	0.90^{klm}	10.15^{n-p}
	9	81.94^{cd}	0.651^{cde}	20.62^{d-g}	0.99^{ghi}	11.21^{h-m}
	10	76.80^{e-h}	0.640^{fgh}	20.26^{hi}	0.92^{jkl}	10.32^{k-p}
60% usable water	1	74.86$_{g-j}$	0.659^{abc}	20.87^{abc}	0.97^{h-k}	10.93^{j-n}
	2	76.94^{e-h}	0.635^{ghi}	20.1^{l}	1.01^{gh}	11.38^{f-k}
	3	77.77^{d-g}	0. 666^{a}	21.08^{a}	1.02^{fgh}	11.55^{e-j}
	4	79.72^{d-f}	0.637^{f-i}	20.17^{ij}	1.11^{de}	12.57^{cde}
	5	79.86^{c-f}	0.618^{kl}	19.57^{m}	1.06^{d-g}	11.97^{d-i}
	6	77.63^{d-g}	0.645^{efg}	20.41^{gh}	1.05^{efg}	11.86^{d-i}
	7	75.83^{f-i}	0.661^{abc}	20.88^{abc}	0.99^{g-j}	11.15^{i-n}
	8	76.52^{e-h}	0.621^{kl}	19.66^{lm}	1.00^{ghi}	11.29^{g-l}
	9	79.72^{c-f}	0.654^{a-d}	20.77^{bcd}	1.06^{efg}	11.23^{g-l}
	10	76.25^{e-h}	0.633^{hij}	20.03^{jk}	1.00^{ghi}	11.23^{g-l}
40% usable water	1	68.88^{kl}	0.657^{a-d}	20.79^{bcd}	1.21^{ab}	13.71^{ab}
	2	66.94^{l}	0.636^{ghi}	20.13^{ij}	1.20^{bc}	13.60^{abc}
	3	69.58^{kl}	0.662^{abc}	20.95^{ab}	1.13^{cd}	12.80^{bcd}
	4	74.72^{kl}	0.638^{f-i}	20.21^{hij}	1.27^{a}	14.45^{a}
	5	72.63^{h-k}	0.623^{jkl}	19.72l^{m}	1.08^{def}	12.26^{d-h}
	6	78.88^{d-g}	0.639^{fgh}	20.23^{hij}	1.09^{def}	12.29^{d-g}
	7	71.38^{jk}	0.654^{cde}	20.70^{c-f}	1.20^{bc}	13.60^{abc}
	8	70.97^{jkl}	0.634^{ghi}	20.07^{ijk}	1.22^{ab}	13.80^{ab}
	9	76.11^{e-i}	0.653^{cde}	20.69^{c-f}	1.10^{de}	12.40^{def}
	10	71.80^{ijk}	0.635^{ghi}	20.09^{ijk}	1.00^{hg}	11.35^{f-k}

Means with same letters in each column have no significant difference at the 5% probability level

Table 3. Mean comparison of treatment resulting from the interaction of B-Estradiol and drought stress levels in terms of effect on the studied traits

Drought	β-stradiol	Plant height	Number of minitubers per plant	Minitubers weight per plant	Avarage minituber weight	Relative water content
	M	cm		g/plant	g	%
Normal (100%)	0	50.26^{b}	3.93^{c}	39.03^{c}	10.33^{c}	83.75^{a}
	10^{-12}	53.10^{a}	6.33^{a}	124.16a	19.67^{a}	84.83^{a}
	10^{-6}	52.60^{a}	5.06$_{b}$	76.99b	15.34^{b}	84.83^{a}
60% usable water	0	43.70^{d}	2.46^{de}	15.749^{e}	6.69^{f}	75.79^{d}
	10^{-12}	48.66^{b}	2.2^{e}	14.46^{e}	8.06^{d}	78.53^{b}
	10^{-6}	46.80^{c}	2.80^{de}	21.05^{d}	7.59^{e}	78.16^{bc}
40% usable water	0	36.33^{f}	2.13^{ef}	6.56^{f}	3.22^{i}	69.08^{f}
	10^{-12}	40.06^{e}	1.83^{f}	8.83^{f}	4.85^{g}	75.83^{cd}
	10^{-6}	46.43^{c}	2.16^{ef}	8.63^{f}	4.10^{h}	71.66^{e}

Table 3. Continued

Drought	β-estradiol	Dry Matter Percent	Starch Percent	Proline content	Superoxide dismutase	Catalase	Polyphenol oxidase
	M	----------%----------		----------µmol g^{-1} FW----------			
Normal (100%)	0	20.11^{c}	9.01^{f}	517.65^{e}	5.55^{c}	5.13^{e}	3.34^{e}
	10^{-12}	20.34^{ab}	9.97^{e}	574.51^{d}	5.62^{c}	6.20^{d}	3.78^{cd}
	10^{-6}	20.24^{b}	11.60^{c}	521.61^{e}	5.59^{c}	6.17^{d}	3.76^{d}
60% usable water	0	20.35^{ab}	10.90^{d}	601.62^{c}	5.62^{c}	6.21^{d}	3.91^{c}
	10^{-12}	20.36^{ab}	12.17^{bc}	701.88^{b}	5.63^{c}	6.51^{c}	3.78^{d}
	10^{-6}	20.34^{ab}	11.69^{c}	601.35^{c}	5.62^{c}	6.20^{d}	4.24^{b}
40% usable water	0	20.27^{b}	12.58^{b}	649.02^{b}	6.21^{b}	7.24^{b}	3.76^{d}
	10^{-12}	20.34^{ab}	13.31^{a}	751.29^{a}	6.71^{a}	7.64^{a}	4.80^{a}
	10^{-6}	20.46^{a}	13.18^{a}	754.81^{a}	6.50^{a}	7.30^{b}	3.80^{cd}

Means with same letters in each column have no significant difference at the 5% probability level

Table 4. Mean comparison of treatment resulting from the interaction of potato genotypes and β-estradiol levels in terms of the effect on the studied traits

β-Estradiol	Genotype	Plant height	Number of minitubers per plant	Minitubers weight per plant	Avarage minituber weight
M		cm		g/plant	g
شاهد Control	1	43.88^{i-n}	3.00^{e-j}	22.73^{ijk}	7.56^{j}
	2	40.88^{mn}	3.11^{e-i}	22.52^{jk}l	7.08^{k}
	3	42.44^{k-n}	3.33^{c-g}	23.03^{ij}	6.31^{m}
	4	44.44^{g-l}	2.22^{k}	22.57^{jkl}	7.184^{k}
	5	44.11^{h-m}	2.88^{f-j}	16.52^{m}	7.119^{k}
	6	42.00^{lmn}	3.44^{b-f}	25.28^{hij}	6.50l^{m}
	7	45.33^{e-k}	2.44^{jk}	17.61^{m}	6.67^{l}
	8	44.88^{f-l}	2.66^{h-k}	18.25^{lm}	6.47l^{m}
	9	45.55^{e-k}	2.77^{g-k}	18.59^{klm}	6.328^{m}
	10	40.77^{n}	2.55ijk	17.40^{m}	6.26^{m}
10^{-12}	1	45.55^{e-k}	3.55^{a-e}	46.21^{c}	10.47^{c}
	2	47.33^{c-h}	3.22^{d-h}	37.29^{f}	9.959^{d}
	3	47.44^{c-g}	4.11^{a}	57.32^{b}	10.82^{b}
	4	51.55^{ab}	3.88^{abc}	62.21^{a}	11.57^{a}
	5	47.33^{c-h}	3.33^{c-g}	48.04^{c}	10.92^{b}
	6	47.22^{c-h}	3.77^{a-d}	54.53^{b}	11.35^{a}
	7	48.44^{b-e}	3.22^{d-h}	46.67^{c}	10.93^{b}
	8	46.11^{d-j}	3.00^{e-j}	46.80^{c}	10.75^{b}
	9	48.11^{c-f}	3.22^{d-h}	53.33^{b}	11.37^{a}
	10	43.66^{j-n}	3.22^{d-h}	48.99^{c}	10.468^{c}
10^{-6}	1	48.22^{cde}	3.55^{a-e}	36.48^{f}	8.70^{ghi}
	2	49.11^{bcd}	2.88^{f-j}	27.03^{ghi}	8.620^{hi}
	3	47.11^{c-i}	4.00^{ab}	40.00^{ef}	8.954^{g}
	4	53.88^{a}	3.77^{a-d}	41.76^{de}	9.41^{f}
	5	47.55^{c-g}	3.33^{c-g}	40.09^{ef}	9.86^{de}
	6	48.00^{c-f}	3.88^{abc}	46.04^{cd}	9.61^{ef}
	7	46.22^{d-j}	3.77^{a-d}	37.59^{ef}	8.79^{gh}
	8	50.00^{bc}	2.77^{g-k}	29.14^{gh}	8.74^{ghi}
	9	48.55^{b-e}	2.55^{ijk}	26.12^{hij}	8.509^{i}
	10	47.44^{c-g}	2.88^{f-j}	31.25$_{g}$	8.916^{g}

Table 4. Continued

β-Estradiol	Genotype	Leaf relative water content	Dry matter percentage	Protein percentage of minitubers	Catalase
M		----------%----------			µmol g^{-1} FW
Control	1	74.86^{g-l}	20.61^{d}	0.97^{i-n}	6.30^{klm}
	2	71.11^{l}	19.98^{gh}	0.90^{mn}	6.11^{mno}
	3	73.05^{jkl}	20.99^{ab}	0.94^{k-n}	6.42^{jkl}
	4	80.83^{b-e}	20.21^{ef}	0.98^{g-l}	6.18^{lmn}
	5	74.16^{i-k}	19.41^{j}	0.98^{g-l}	5.94^{o}
	6	74.72^{h-l}	20.19^{efg}	0.93l^{mn}	6.18^{mno}
	7	76.66^{e-k}	20.62^{d}	1.00^{e-k}	6.31^{klm}
	8	76.11^{f-k}	19.62^{ij}	0.99^{f-l}	6no
	9	76.94^{e-j}	20.60^{d}	1.01^{e-k}	6.30^{klm}
	10	70.97^{l}	20.20^{efg}	0.90^{n}	6.18^{mno}
10^{-12}	1	80.27^{b-f}	20.85^{bc}	1.01^{e-k}	6.81^{b-e}
	2	81.38^{bcd}	20.14^{fgh}	1.05^{c-h}	6.59^{e-j}
	3	78.88^{c-h}	21.08^{a}	1.05^{c-h}	6.88^{a-d}
	4	72.50^{k-l}	19.98^{gh}	1.14^{ab}	6.55f^{g}
	5	79.44^{c-f}	19.59^{ij}	1.05^{c-h}	6.43^{jk}
	6	88.36^{a}	20.59^{d}	1.04^{c-h}	6.73^{c-j}
	7	77.79^{d-i}	20.73^{cd}	1.07^{b-e}	6.73^{c-j}
	8	82.50^{bc}	19.67^{i}	1.02^{d-j}	7.01^{a}
	9	80.69^{b-e}	20.74^{cd}	1.06^{c-f}	7.11^{a}
	10	79.30^{c-f}	20.12^{fgh}	0.97^{j-n}	6.92^{abc}
10^{-6}	1	76.94^{e-j}	20.97^{abc}	1.07^{cde}	6.73^{c-g}
	2	79.16^{c-g}	20.21^{ef}	1.09^{bcd}	6.52^{g-k}
	3	79.30^{c-f}	21.03^{ab}	1.04^{c-i}	6.76^{c-f}
	4	80.00^{cf}	20.06^{fgh}	1.19^{a}	6.47^{h-k}
	5	79.16^{c-g}	19.47^{ij}	1.05^{c-g}	6.29^{klm}
	6	84.44^{ab}	20.36^{e}	1.06^{c-f}	6.56^{f-g}
	7	80.55^{b-e}	20.74^{cd}	1.02^{d-j}	6.67^{d-i}
	8	77.63^{d-i}	19.94^{h}	1.11^{bc}	6.43^{ijk}
	9	80.13^{b-f}	20.73^{cd}	1.07b^{-e}	6.67^{d-h}
	10	74.58^{h-l}	20.06^{fgh}	1.05^{c-g}	6.47^{h-k}

Means with same letters in each column have no significant difference at the 5% probability level

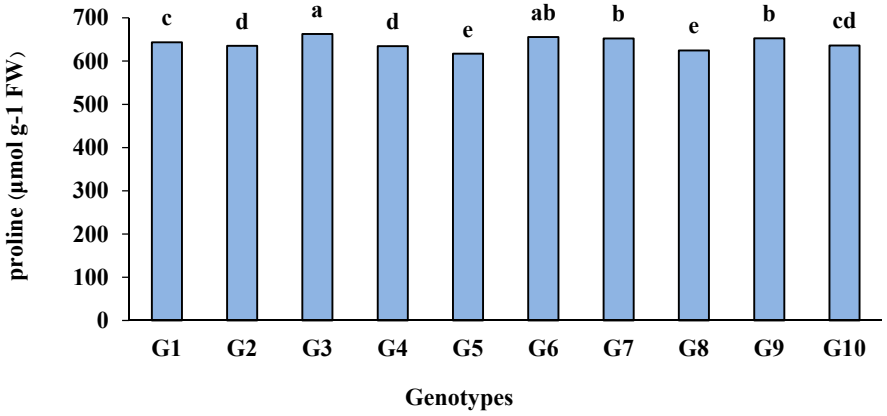

Fig. 1. Comparison of potato genotypes means under average drought stress and β-estradiol levels in terms of leaf proline content

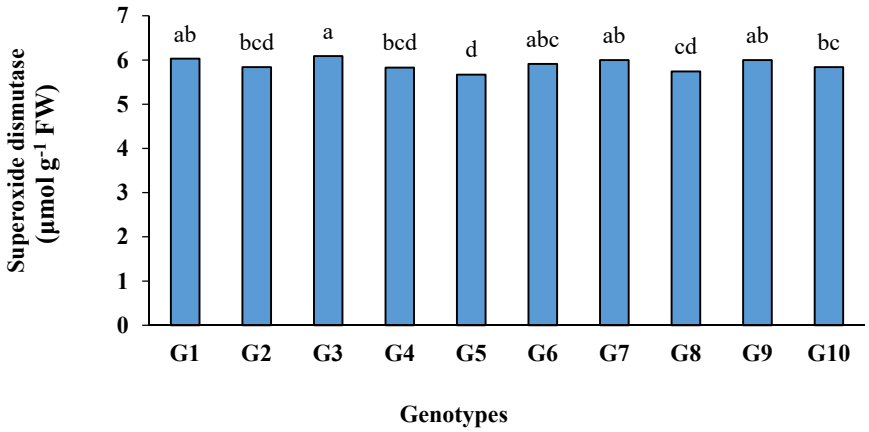

Fig. 2. Comparison of potato genotypes means under average drought stress and β-estradiol levels

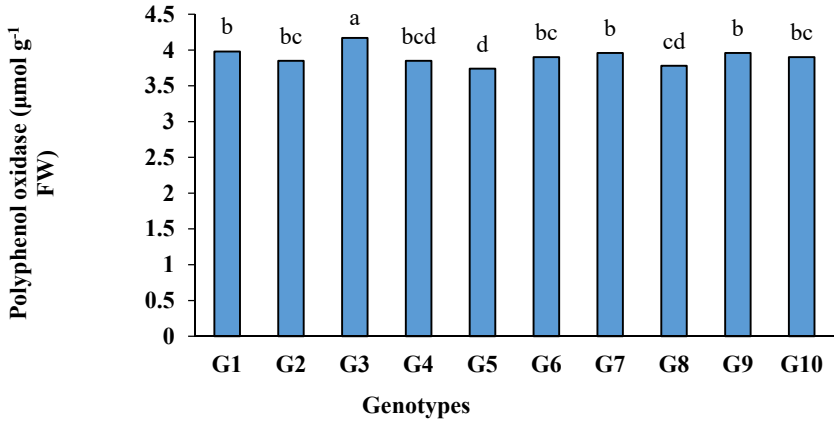

Fig. 3. Comparison of potato genotypes means under average drought stress and β-estradiol levels in terms of leaf polyphenol oxidase content