https://doi.org/10.17221/181/2023-PSE

The effect of exogenous application of salicylic acid and ascorbic acid on forage quality and yield of maize (*Zea mays* L.) under water deficit conditions

Navvab Haji Hassani Asl[1], Farhad Farah Vash[1], Mohsen Roshdi[2], Bahram Mir Shekari[1], Mehdi Gaffari[3]*

[1]Department of Agricultural Management, Tabriz Branch, Islamic Azad University, Tabriz, Iran
[2]Department of Agronomy and Plant Breeding, Khoy Branch, Islamic Azad University, Khoy, Iran
[3]Agriculture and Natural Resource Research Center of Plant and Seed, Karaj, Iran
**Corresponding author: farahvash@iaut.ac.ir*

Citation: Asl N.H.H., Vash F.F., Roshdi M., Shekari B.M., Gaffari M. (2024): The effect of exogenous application of salicylic acid and ascorbic acid on forage quality and yield of maize (*Zea mays* L.) under water deficit conditions. Plant Soil Environ., 70: 142–153.

Abstract: The effects of the foliar application of plant growth regulators (PGRs), salicylic acid (SA) and ascorbic acid (AA) were studied on yield and some qualitative traits of corn silage under drought stress in a field experiment conducted in the Agricultural and Natural Resources Research Center of Khoy in two consecutive years. The experiment was performed in four replications as a split plot in a randomised complete blocks design. Irrigation treatment was in two levels, ir75 and ir150, and the foliar applications of SA and AA at seven levels (100, 200, and 300 ppm, as well as a control treatment). The amount of water consumed in ir75 and ir150 during 10 and 7 times irrigation was 6 000 and 4 200 m^3/ha, respectively. Malondialdehyde (MDA) content was increased over the plant growth period in both ir75 and ir150, but with the difference that its range was 3.72 to 12.9 nmol/g FW (fresh weight) under ir75 and 12.5–109.5 nmol/g FW under water shortage conditions. The results show that ir150 decreased plant height, forage yield, ear weight, and nitrogen uptake *versus* ir75. In plants treated with SA and AA, nitrogen uptake and chlorophyll content increases (45–33%) were observed compared to the control plants under ir75. In most traits, there was no significant difference between AA and SA levels, but plants treated with SA100 showed higher protein yield, dry forage yield, and ear yield.

Keywords: antioxidant; drought tolerance; forage yield; plant hormone; resistance

Water scarcity is the main factor limiting crop production worldwide, including Iran. Unfortunately, the intensity of water scarcity is growing due to global warming and severe climatic perturbations so that vast parts of the world are annually losing their production potential and are deserted (Dijkman et al. 2017, Schoppach et al. 2017, Schyns et al. 2019, Bijani et al. 2020). In recent years, production costs have surpassed cropping revenue in some parts of Iran. In these conditions, farmers are unable to keep farming and have to migrate to urban areas (Kheiri et al. 2017, Savari et al. 2020).

Maize (*Zea mays* L.) is a crop that supplies a great part of the forage requirement of ranchers in hot regions, but it is sensitive to water stress at all growth stages so that water scarcity reduces its growth significantly (Khalid Hussein and Qader Khursheed 2014, Kumar et al. 2019). Drought stress and water scarcity influence the photosynthesis potential of plants, thereby injuring them, especially their chlorophyll and carotenoid contents, and increasing the peroxidation of lipids and proline (Hayat et al. 2012, Ullah et al. 2019). To tolerate stress, plants have developed various mechanisms, such as a change in morphology and developmental pattern, as well as physiological and biochemical responses. The induction of drought tolerance in plants by applying ascorbic acid (AA) can have many applications in agriculture

https://doi.org/10.17221/181/2023-PSE

Table 1. Physical and chemical characteristics of the soil

Depth (cm)	Clay	Silt	Sand	Soil texture	OC	TNV	SP	N	pH	EC (dS/m)	K	P
	(%)				(%)						(mg/kg)	
0–30	29	46	25	clay-loam	0.72	11.2	47	0.162	7.9	1.23	282	18.7

OC – organic carbon; TNV – total neutralising value; SP – saturation percentage; EC – electrical conductivity

(Hamada 2000, Maghsoudi et al. 2019). AA is the most abundant antioxidant that protects plant cells from oxidising factors and positively influences cell division, differentiation, and photosynthesis (Zhang 2013). There are reports as to the positive effect of AA in water deficit conditions on increasing leaf area, plant height, spike length, and grain weight of barley (Habibi 2012), increasing pod number and oil yield of soybean (Mohamed and Akladious 2014), increasing root yield of sugar beet (Khodadadi et al. 2020), and improving forage properties of sorghum (Arefi et al. 2016). Higher levels of AA applied to wheat plants significantly increased their grain yield, straw yield, protein content, protein yield, plant height, spike length, number of spikelets per spike, and water use efficiency (Bakry et al. 2013). Similarly, Muhammad et al. (2019) reported that the foliar application of AA at a rate of 200 mg/L increased proline accumulation, photosynthesising pigments, and grain and forage yield of maize.

Salicylic acid (SA) is a naturally-occurring hormone that is involved in adjusting the physiological processes of crops (Wang et al. 2010) and enhancing their resistance to environmental stresses (Kolupaev et al. 2011). SA influences many morphological and physiological traits of plants (Maghsoudi and Arvin 2010) and induces defensive mechanisms against biotic and abiotic stresses. It has been shown that the foliar application of SA to 30-day-old mustard plants increased their pod number and seed yield, and the maximum seed yield and pod numbers were obtained from the treatment of 10 mol/L (Fariduddin et al. 2003).

The present research aimed to explore the effect of the foliar application of plant growth regulators (PGRs) at different rates on inducing drought tolerance and improving forage quality and yield of maize under water deficit conditions.

MATERIAL AND METHODS

Experimental site. The field experiment was conducted on clay-loam soil at the Agricultural and Natural Resources Research field of Khoy in West Azerbaijan province, Iran, in 2013 and 2014. The area is located at latitude 44°55'N and longitude 38°32'E with an elevation of 1 157 m a.s.l. Soil sampling was performed before the experiment to determine soil characteristics, for which the field soil was sampled from a depth of 0–30 cm in 8 spots. Then, they were sent to a laboratory to determine soil texture and chemical composition. Properties of experimental soil samples are given in Table 1, and weather parameters are given in Table 2.

Experimental design and treatments. The two-year field experiments were carried out as a split plot based on a randomised complete blocks design (RCBD) with four replications. The main plots were irrigation levels (ir75 and ir150 mm evaporation from Class A evaporation pan), and the sub-plots were foliar applications of SA and AA (PGRs) at seven levels (SA and AA at 100, 200, and 300 ppm and a control treatment).

Irrigation time was uniform for all plots from the planting date to the stage of 12–14 leaves, and after 12–14 leaves, irrigation treatments (ir75 and

Table 2. Weather parameters (Khoy, Iran) in two years

Month	Temperature average (°C)		Total rainfall (mm)		Evaporation average (mm)	
	2014	2014	2013	2013	2014	2013
June	22.4	0.6	19.4	20.9	7.2	6.1
July	26.4	0.1	5.9	24.8	9.7	7.1
August	26.0	0	0	27.2	9.8	10.3
September	23.5	0.3	0.1	21.9	7.1	6.8
October	21.2	6.2	12.7	20.6	4.8	3.9

https://doi.org/10.17221/181/2023-PSE

ir150) were applied until the end of the season. The irrigation times for the ir75 and ir150 treatments, respectively, were 10 and 7, and the total water consumption for the two treatments was 6 000 and 4 200 m^3/ha, respectively. A volumetric water meter was used to calculate water consumption. The foliar application was performed in two steps, one 40 days after emergence and the second at tassel emergence. When PGRs were applied, the control treatment was sprayed with distilled water.

Sowing. After field preparation, the plots were prepared with sowing rows at 5–6 m length, an inter-row spacing of 60 cm, and an on-row inter-plant spacing of 15 cm. The plots were spaced by 1.20 m and the replications by 2 m. According to the soil analysis, 280 kg/ha nitrogen fertiliser from a urea source was applied at three stages – before sowing, rapid growth initiation at the 6-8-leaf stage, and before tassel emergence. The maize cultivar sown for the research was Siloking, which is a single-cross hybrid produced by Martonvásár in Hungary. The hybrid is a mid-maturing cultivar. It was sown on July 2 in both years and harvested on October 19 in the first year and October 17 in the second year.

Measurements. To measure leaf chlorophyll, the top leaves of three plants were taken at the full pollination stage. The chlorophyll *a* and chlorophyll *b* content were determined by Arnon's (1967) method.

Leaf malondialdehyde (MDA) content was measured at 50, 70, 90 and 110 days. MDA content was assayed as an excellent indicator of oxidative stress and is usually measured to assess the extent of lipid peroxidation in leaf tissues by the Del Rio et al. (2005) method. MDA concentration was determined by using thiobarbituric acid to be able to form stable complex thiobarbituric acid-reactive substances (TBARS). Absorbance was read at 600 nm. MDA concentration was calculated using a 155 mmol/cm molar extinction coefficient.

The fresh and dry forage samples were oven-dried at 60 °C for 72 h to determine their dry matter content (Miron et al. 2005). The samples ground with a 1-mm net were kept at 600 °C for 4 h to determine their ash content (Miron et al. 2005). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were estimated using Van Soest et al.'s (1991) procedure. Additionally, heat-resistant amylase was also employed to measure NDF. Raw protein content was found using an Auto-Analyser Kjeltec 1030 (Tecator, Hoganas, Sweden) by the procedure described in AOAC (2000). Protein yield was estimated by multiplying protein concentration by total dry forage yield. The sulfuric phenol method measured the water-dissolved carbohydrate content (WDC) (Buysse and Merckx 1993). Dry matter digestibility (DMD) was also estimated based on ADF using the formula of Oddy et al. (1983):

$$\text{Dry matter digestibility (\%)} = 88.9 - (0.779 \times \text{ADF})$$

The plants were harvested from 1 m^2 in the middle rows of each plot at the grain filling stage (to measure plant height, stem and leaf fresh weight, and fresh forage yield) and physiological maturity stage (to measure ear weight and dry forage yield).

Statistical analysis. Experimental data were analysed statistically using ANOVA. The significance of the effect of treatment was determined by the magnitude of the *F*-value ($P \leq 0.05$). When a significant *F*-test was obtained for the treatments, separation of means was done using the LSMEANS procedure with *LSD* (least significant difference) adjustment at $P = 0.05$. Statistical analysis of the results was performed using a general linear model (GLM) in SAS software version 9.2 (USA). To obtain the effect of the year and its changes on the treatments, we used Pross GLM. In addition, we had some missing plots, so it was better to use GLM as recommended by statisticians. Also, comparing the mean, done by the LSMEANS method, was more compatible with Pross GLM. Requests PROC GLM reread the input data set when necessary instead of writing the necessary values of dependent variables to a utility file.

PROCGLM analyses data within the framework of general linear models. PROCGLM handles models relating continuous dependent variables to one or several independent variables. The dependent variables can be classification variables, dividing the observations into discrete groups, or continuous variables. Thus, the GLM procedure can be used for many different analyses, including simple regression. Multiple regression analysis of variance (ANOVA), especially for unbalanced data analysis of covariance response surface models

RESULTS

MDA content. MDA is considered a suitable indicator for membrane lipid peroxidation. Oxygen free radicals or lipid peroxidation reactions selectively decompose unsaturated fatty acids in plant membranes and cause the accumulation of aldehydes, hydrocarbons, etc. Therefore, MDA is measured to measure the amount of damage done to plant

https://doi.org/10.17221/181/2023-PSE

cells and to find out the involvement of oxygen free radicals as a result of stress.

Data on MDA content measured 50, 70, 90, and 110 days after emergence (DAE) show that in both years, MDA content was increased over the plant growth period in both ir75 and ir150 conditions so that the maximum MDA content was observed at 110 DAE. In ir75, MDA ranged from 2.56 to 14.8 nmol/g FW (fresh weight) in the first year (Figure 1A) and from 3.72 to 12.9 nmol/g FW in the second year (Figure 1B), while in the ir150, it was in the range of 12.5–109.5 nmol/g FW in the first year (Figure 1A) and 9.76–87.4 nmol/g FW in the second year (Figure 1B). In ir75, the PGR levels did not differ significantly at 50, 70, and 90 DAE, but at 110 DAE, in which the highest MDA content was observed, PGR-treated plants had lower MDA content. However, in ir150, the PGRs reduced MDA content *versus* ir75 at all times except for 110 DAE, and in both years, SA levels, especially SA2, exhibited lower MDA content than AA levels.

Leaf chlorophyll content. In the first year, the main effect of ir150 was significant on chlorophyll *a*; in the second year, the interactive effect of ir150 and PGRs was significant on chlorophyll *a* (Table 3). The comparison of the means for the interactive effect of irrigation and PGRs on chlorophyll *a* reveals that ir150 in all treatments reduced chlorophyll *a* by 20.9–28.7%. Similarly, most treatments had lower chlorophyll content than the control in ir75. But, in ir150, all treatments except for AA1 and AA2 outperformed the control significantly (Table 3).

Plant height. Based on data variance analysis, the interaction of PGRs and irrigation was significant for plant height in both years (Table 3). According to the comparison of the means, in both years, the tallest plants were related to treating SA1 in ir75, but ir150 did not cause significant differences between the two hormone levels. However, they had higher plant height than the control (Table 3).

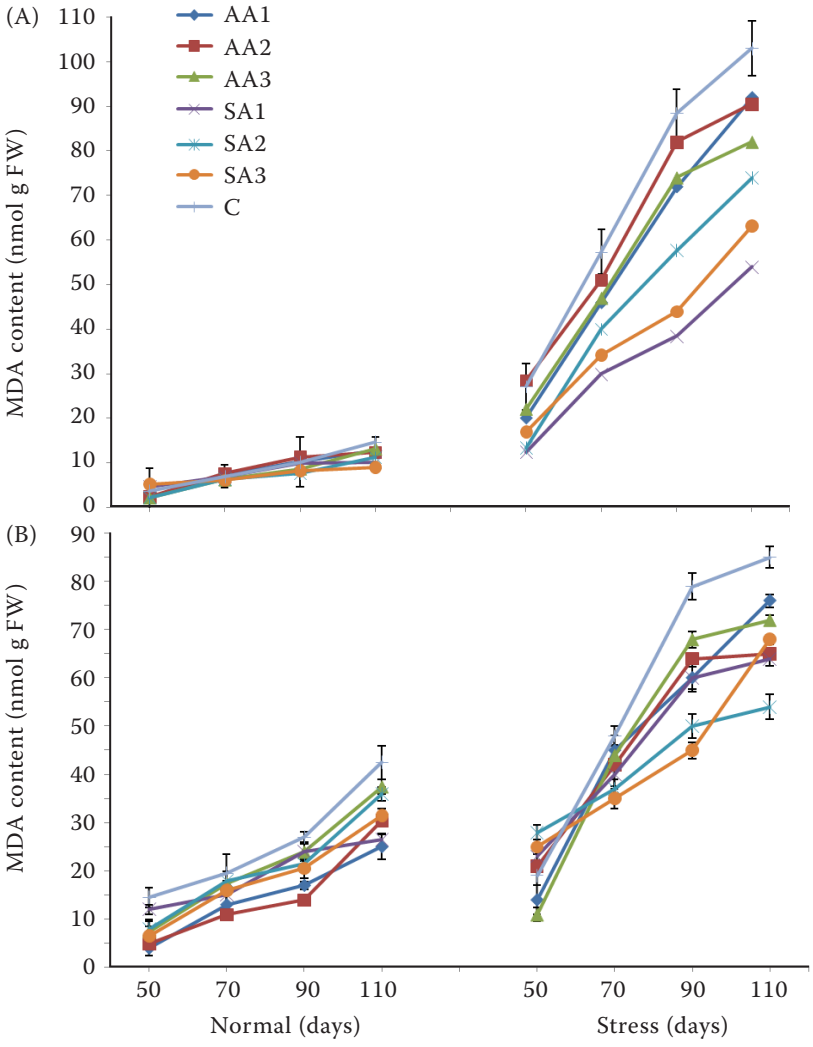

Figure 1. Effect of salicylic acid (SA) application include: SA1 – 100 ppm; SA2 – 200 ppm; SA3 – 300 ppm; ascorbic acid (AA) application include: AA1 – 100 ppm; AA2 – 200 ppm; AA3 – 300 ppm; C – control treatment in the normal and stress irrigation on leaf malondialdehyde (MDA) contents in the maize growth stage ((A) 2013 and (B) 2014. FW – fresh weight

https://doi.org/10.17221/181/2023-PSE

Table 3. ANOVA and mean comparison of salicylic acid (SA) and ascorbic acid (AA) effect on morphological traits and forage components under water deficit conditions in two years

Source of variance	*df*	Plant height (cm)	Fresh ear weight	Fresh forage yield	Dry forage yield	Ear/forage
			(t/ha)			
2013						
R	3	168^{ns}	44.6**	54.62^{ns}	2.074^{ns}	29.2**
I	1	19 396**	564.0**	4 905**	228**	31.5**
PGR	6	410^{ns}	29.2**	181**	5.88**	13.48^{ns}
I × M	6	3 820**	48.4**	69.1**	2.77^{ns}	42.5**
2014						
R	3	346^{ns}	42.68**	53.3^{ns}	2.502^{ns}	40.19**
I	1	18 567**	344.7**	3 699**	176.5**	57.00**
PGR	6	383**	13.09^{ns}	83.83*	4.70**	3.709^{ns}
I × PGR	6	320.1*	24.1*	29.01^{ns}	1.163^{ns}	31.46**
Irrigation	PGRS			**2013**		
	AA1	236 ± 10.1^{b}	33.5 ± 4.0^{a}	85.0 ± 1.51^{a}	18.40 ± 0.17^{a}	39.4 ± 4.8$^{c–f}$
	AA2	230 ± 21.8^{b}	28.9 ± 3.8^{b}	75.8 ± 4.04^{b}	16.8 ± 0.90^{ab}	38.0 ± 3.21$^{d–g}$
	AA3	220 ± 20.6^{c}	25.3 ± 1.0$^{b–e}$	73.4 ± 6.40^{b}	16.33 ± 1.43^{b}	34.7 ± 3.7^{g}
Ir75	SA1	252 ± 26.5^{a}	35.8 ± 5.3^{a}	86.2 ± 10.8^{a}	18.60 ± 2.38^{a}	41.5 ± 1.7$^{a–d}$
	SA2	233 ± 14.6^{b}	27.5 ± 2.7^{b}	71.2 ± 9.10^{b}	15.81 ± 2.02^{b}	38.8 ± 2.0$^{c–f}$
	SA3	234 ± 24.7^{b}	28.3 ± 1.8^{b}	69.8 ± 8.3^{bc}	15.5 ± 1.69^{bc}	40.8 ± 2.63$^{b–e}$
	control	237 ± 31.7^{b}	27.1 ± 3.5^{bc}	71.8 ± 5.3^{b}	15.8 ± 1.20^{b}	37.7 ± 2.70$^{e–g}$
	AA1	192 ± 8.2^{d}	21.5 ± 4.9^{ef}	57.7 ± 8.7^{de}	12.7 ± 1.88^{de}	36.8 ± 3.6^{fg}
	AA2	187 ± 11.6^{de}	22.4 ± 1.5$^{d–f}$	56.5 ± 4.2^{de}	12.5 ± 0.94^{de}	39.5 ± 1.1$^{b–f}$
	AA3	193 ± 10.4^{d}	25.6 ± 1.8$^{b–d}$	57.4 ± 1.8^{de}	12.6 ± 0.45^{de}	44.6 ± 2.02^{a}
Ir150	SA1	195 ± 7.2^{d}	23.4 ± 3.9$^{c–f}$	62.4 ± 4.0^{cd}	13.5 ± 0.77^{de}	37.2 ± 4.0$^{e–g}$
	SA2	194 ± 4.6^{d}	26.7 ± 2.3^{bc}	62.7 ± 3.1^{cd}	13.8 ± 0.70^{cd}	42.7 ± 1.5^{ab}
	SA3	183 ± 14.1^{e}	21.6 ± 1.1^{ef}	51.4 ± 2.5^{e}	11.78 ± 1.02^{e}	42.1 ± 1.1$^{a–c}$
	control	166 ± 9.9^{f}	20.7 ± 1.8^{f}	53.9 ± 1.74^{e}	11.92 ± 0.40^{e}	38.3 ± 2.3$^{d–g}$
				2014		
	AA1	241 ± 3.16^{bc}	29.6 ± 5.40^{ab}	76.59 ± 5.44^{a}	16.87 ± 1.04^{a}	38.4 ± 4.83^{c}
	AA2	235 ± 513^{c}	29.2 ± 3.26$^{a–c}$	77.91 ± 2.35^{a}	17.30 ± 0.52^{a}	37.4 ± 3.25^{cd}
	AA3	230 ± 7.30^{c}	25.5 ± 1.11$^{c–e}$	74.42 ± 7.28^{ab}	16.55 ± 1.57^{a}	34.5 ± 3.07^{d}
Ir75	SA1	255 ± 7.21^{a}	30.2 ± 7.21^{a}	75.31 ± 11.66^{a}	16.45 ± 2.33^{a}	39.6 ± 3.71^{bc}
	SA2	244 ± 18.5^{ab}	28.2 ± 2.40$^{a–c}$	74.14 ± 9.04^{ab}	16.65 ± 1.63^{a}	38.2 ± 2.38^{c}
	SA3	241 ± 24.8^{bc}	29.0 ± 1.01$^{a–c}$	75.29 ± 3.59^{a}	16.71 ± 0.80^{a}	38.5 ± 1.41^{c}
	control	238 ± 30.2^{bc}	26.1 ± 2.75$^{b–d}$	67.39 ± 6.63^{bc}	14.78 ± 1.26^{b}	38.6 ± 1.63^{bc}
	AA1	200 ± 8.19^{d}	21.3 ± 2.20^{f}	55.47 ± 0.73^{e}	12.32 ± 0.16^{de}	38.3 ± 4.06^{c}
	AA2	196 ± 6.38^{d}	22.9 ± 1.28$^{d–f}$	58.48 ± 3.29^{de}	12.98 ± 0.73$^{c–e}$	39.1 ± 1.03^{bc}
	AA3	199 ± 2.16^{d}	26.1 ± 1.94$^{b–d}$	58.72 ± 3.31^{de}	13.07 ± 0.76^{cd}	44.4 ± 1.42^{a}
Ir150	SA1	196 ± 4.91^{d}	22.0 ± 3.98^{ef}	58.71 ± 4.70^{de}	12.98 ± 1.06$^{c–e}$	37.1 ± 3.86^{cd}
	SA2	201 ± 2.83^{d}	27.2 ± 2.12$^{a–c}$	65.14 ± 3.05^{cd}	14.46 ± 0.68^{bc}	41.7 ± 1.58^{ab}
	SA3	195 ± 7.60^{d}	22.8 ± 1.54$^{d–f}$	59.17 ± 2.83^{de}	13.19 ± 0.70^{cd}	38.6 ± 1.42^{bc}
	control	171 ± 8.16^{e}	20.7 ± 0.89^{f}	51.56 ± 2.54^{e}	11.45 ± 0.56^{e}	40.1 ± 0.73^{bc}

*P < 0.05; **P < 0.01; R – replication; I – irrigation; PGRS – plant growth regulators. Means within a column followed by the same letter are not significantly (P < 0.05) different according to the *LSD* test (mean ± standard deviation, n = 3)

https://doi.org/10.17221/181/2023-PSE

Ear fresh weight. It was found that the main effects of irrigation and PGRs interactive effects were significant on ear weight in both years (Table 3). The interactive effects of irrigation and PGRs on ear weight also showed that lower rates of the PGRs were more effective than their higher rates in increasing ear fresh weight so that the maximum ear weight in both years and both irrigation conditions was obtained from SA1 and AA1 (Table 3).

Forage yield (fresh and dry) and ear/forage. In both years, fresh and dry forage yields were influenced by the interactive effect of irrigation and PGRs (Table 3). It was found by comparing the means that in both years under ir75 and ir150, most plants treated with AA and SA had higher forage yield than the control. In ir75, the highest forage yield was obtained from the plants treated with SA1 and AA1, but it was not significantly different from some PGR levels. In ir150, the highest forage yield was produced by the plants treated with SA2, which increased dry forage yield by 14.6% in the first year and 20.8% in the second year *versus* the control (Table 3).

The analysis of variance indicates that the interaction of irrigation and PGRs was significant for the ear/forage ratio. In both years, water deficit increased this ratio in most treatments. Among the PGR levels, the highest ear/forage ratio was obtained from the plants treated with AA3 in ir150 and those treated with SA1 in ir75. The lowest ratio was 34%, observed in AA3-treated plants in ir75 (Table 3).

Forage quality. Variance analysis shows that irrigation and PGRs' interactive effect was significant on WDC, CRUF, ADF, and DMD in both years and on NDF only in the second year (Table 4). In both experimental years, ir150 reduced WDC and DMD and increased CRUF, ADF, and NDF in all treatments. The treated plants had lower ADF, NDF, and CRUF than the control but did not show statistically significant differences. The plants treated with SA, especially SA2, mainly exhibited lower ADF, NDF, and CRUF than those treated with AA.

PGRs increased WDC *versus* the control by 6.5–25.4% in the first year and 11.4–13.5% in the second year in ir75 and by 7.3–19.4% in the first year and 18.7–22.1% in the second year in ir150. Although AA and SA levels did not differ significantly, their difference was significant in ir150. SA1 had the highest WDC in both years (Table 4).

Dry matter and protein digestibility. The interaction of irrigation × PGRs was significant for DMD in both years (Table 4) and protein digestibility (Table 5) only in the first year. Based on the comparison of the means, ir150 in all treatments decreased DMD by 30.5–35.8% in the first year and 28.1–34.4% in the second year. The lowest and highest decreases were related to the plants treated with SA2 and AA1, respectively. The highest DMD was observed in SA1-treated plants in ir75 and SA3-treated plants in ir150 (Table 4). However, protein digestibility was changed by 4.17–5.05% in response to the experimental treatments. Indeed, the treatments could influence it slightly in both ir75 and ir150. The highest protein digestibility (5.05%) was observed in the plants treated with AA3 in ir150 (Table 5).

Content and yield of protein. In both years, the interaction of irrigation × PGRs was significant in the content and yield of protein (Table 5). As the results of the comparison of the means reflect, the plants exposed to ir150 had higher protein content than the plants in ir75. Although the treated plants exhibited higher protein content than the control, they did not differ significantly. The highest protein yield was obtained from the SA1 treatment in the ir75 (1 670 kg/ha in the first year and 1 550 kg/ha in the second year) and from the SA2 treatment in the ir150 (1 243 kg/ha in the first year and 1 339 kg/ha in the second year) (Table 5).

Also, the protein yield of the stem was influenced by the interaction of irrigation × PGRs. The highest protein yield of the stem was obtained from the SA1 in the first year (737 kg/ha) and AA3 in the second year (722 kg/ha) in the ir75 and from the SA2 treatment in the ir150 (586 kg/ha in the first year and 572 kg/ha in the second year) (Table 5).

DISCUSSION

A key function of water is cell turgor, which plays an essential role in stomatal enlargement, photosynthesis increase, plant growth, and the activity of other specialised organs of the plants (Arefi et al. 2016). Water deficit reduces cell turgor and cell growth and development, especially in stems and leaves, resulting in organ size reduction due to the loss of cell growth. Therefore, the first visible symptom of water deficit in plants emerges as a decline in plant height or smaller size of the leaves (Khodadadi et al. 2020). Research shows that drought stress reduces the height of maize plants by reducing cell growth (the reduction of cell division and size) at the vegetative growth stage (Saedpanah et al. 2016, Jones et al. 2017). Our results reveal that water deficit reduced plant

https://doi.org/10.17221/181/2023-PSE

Table 4. ANOVA and mean comparison of salicylic acid (SA) and ascorbic acid (AA) effect on chlorophyll content and forage quality under water deficit conditions in two years

Source of variance	*df*	Chl *a* (mg/g FW)	WDC	CRUF	ADF	NDF	DMD
					(%)		
2013							
R	3	0.839**	2.974^{ns}	2.58^{ns}	1.09^{ns}	4.46**	14.0^{ns}
I	1	12.5**	327**	143.8**	76.1**	0.97^{ns}	270.1**
PGR	6	0.223^{ns}	181**	3.68^{ns}	12.6**	0.11^{ns}	12.18^{ns}
I × PGR	6	0.147^{ns}	70.54^{ns}	88.3**	11.33**	1.14^{ns}	164.8**
2014							
R	3	1.043**	76.27**	6.35**	12.8^{ns}	6.00**	34.7**
I	1	101.5**	3 776.9**	156.0**	34.2**	21.7**	313.5**
PGR	6	0.254*	100.0**	1.4838^{ns}	21.28**	2.19*	13.7**
I × PGR	6	0.326**	70.05**	13.01**	3.71**	1.719*	22.78**
Irrigation	PGRS			2013			
	AA1	11.13 ± 0.21	10.12 ± 0.34^{b}	33.1 ± 0.83^{e}	25.0 ± 0.89^{de}	33.03 ± 0.57	64.1 ± 0.1^{ab}
	AA2	11.60 ± 0.08	11.20 ± 0.46^{ab}	33.4 ± 0.21^{e}	22.9 ± 0.29^{fg}	33.10 ± 0.05	63.3 ± 3.2^{ab}
	AA3	11.53 ± 0.21	11.92 ± 0.49^{a}	33.9 ± 0.94^{de}	23.9 ± 0.76$^{e–g}$	32.58 ± 0.09	63.7 ± 2.022^{ab}
Ir75	SA1	11.32 ± 0.12	12.00 ± 0.566^{a}	33.5 ± 3.63^{e}	22.3 ± 1.37^{g}	32.47 ± 0.32	65.2 ± 1.61^{a}
	SA2	11.38 ± 0.07	12.35 ± 0.473^{a}	34.5 ± 0.66$^{b–e}$	20.4 ± 0.47^{h}	32.50 ± 0.55	62.8 ± 1.33^{bc}
	SA3	11.22 ± 0.31	12.20 ± 0.38^{a}	34.3 ± 2.37^{cd}	25.9 ± 0.66^{cd}	32.80 ± 1.00	62.3 ± 2.923^{bc}
	control	11.60 ± 0.22	9.47 ± 0.862^{c}	36.0 ± 4.46$^{a–e}$	24.2 ± 1.32$^{d–f}$	32.65 ± 0.66	60.7 ± 4.59^{c}
	AA1	8.59 ± 0.77	6.07 ± 0.050^{d}	37.2 ± 3.10$^{a–c}$	30.3 ± 0.44^{a}	34.00 ± 0.19	42.1 ± 1.31^{f}
	AA2	8.79 ± 0.18	7.17 ± 0.189^{de}	38.3 ± 0.76^{a}	31.1 ± 1.59^{a}	33.90 ± 0.32^{ab}	40.5 ± 2.122^{f}
	AA3	9.04 ± 0.12	7.42 ± 0.126^{de}	37.2 ± 1.99$^{a–c}$	30.0 ± 1.81^{a}	32.83 ± 0.57	41.7 ± 5.47^{f}
Ir150	SA1	8.98 ± 0.14	8.25 ± 0.332^{d}	35.9 ± 1.41$^{a–e}$	28.3 ± 0.85^{b}	33.78 ± 0.09	42.7 ± 1.258^{de}
	SA2	8.99 ± 0.07^{d}	7.17 ± 0.150^{de}	36.9 ± 1.15$^{a–d}$	27.2 ± 0.82^{bc}	33.73 ± 0.21	43.7 ± 3.51^{d}
	SA3	9.00 ± 0.10	7.30 ± 0.082^{de}	38.1 ± 0.88	31.7 ± 1.59^{a}	32.98 ± 0.66	40.1 ± 0.987^{f}
	control	8.70 ± 0.22	6.65 ± 0.173^{e}	37.6 ± 2.68^{ab}	30.9 ± 1.89^{a}	34.28 ± 0.71	40.6 ± 4.73^{ef}
				2014			
	AA1	11.13 ± 0.25^{c}	10.13 ± 0.096^{a}	34.77 ± 0.76^{d}	23.83 ± 2.59^{e}	33.13 ± 0.83$^{b–e}$	62.5 ± 3.636^{ab}
	AA2	11.65 ± 0.30^{a}	10.18 ± 0.096^{a}	34.93 ± 0.59^{d}	23.68 ± 1.70^{e}	33.30 ± 1.00$^{b–d}$	63.2 ± 1.25^{ab}
	AA3	11.73 ± 0.34^{a}	10.15 ± 0.100^{a}	34.75 ± 1.06^{d}	23.63 ± 3.73^{e}	32.48 ± 0.34^{de}	63.2 ± 2.263^{ab}
Ir75l	SA1	11.10 ± 0.12^{c}	10.13 ± 0.096^{a}	34.59 ± 1.59^{d}	25.58 ± 4.30^{de}	32.23 ± 0.78^{de}	62.2 ± 1.7^{ab}
	SA2	11.08 ± 0.15^{c}	10.13 ± 0.096^{a}	34.43 ± 0.66^{d}	22.65 ± 2.64^{e}	31.95 ± 0.44^{e}	64.23 ± 1.357^{a}
	SA3	11.23 ± 0.15^{bc}	10.08 ± 0.050^{a}	34.84 ± 1.83^{d}	23.78 ± 1.27^{e}	32.88 ± 1.18$^{c–e}$	63.2 ± 0.7^{ab}
	control	11.58 ± 0.51^{ab}	8.90 ± 0.200^{b}	35.64 ± 1.23^{d}	27.78 ± 3.21^{cd}	32.25 ± 1.55^{de}	61.2 ± 3.703^{b}
	AA1	8.35 ± 0.66^{e}	8.13 ± 0.096^{de}	38.26 ± 1.38$^{a–c}$	32.03 ± 1.38^{ab}	34.25 ± 0.89^{ab}	41.0 ± 0.83^{d}
	AA2	8.58 ± 0.47^{de}	8.15 ± 0.058$^{c–e}$	38.68 ± 1.31^{ab}	29.1 ± 1.21^{bc}	34.30 ± 1.41^{ab}	43.6 ± 3.77^{cd}
	AA3	8.90 ± 0.42^{d}	8.28 ± 0.150^{c}	38.89 ± 0.41^{a}	27.33 ± 0.57^{cd}	32.63 ± 0.35^{de}	42.3 ± 1.24^{d}
Ir150	SA1	8.78 ± 0.37^{d}	8.20 ± 0.082^{cd}	38.59 ± 0.63^{ab}	31.33 ± 2.75^{ab}	33.98 ± 0.67$^{a–c}$	42.1 ± 0.419^{d}
	SA2	8.85 ± 0.23^{d}	8.05 ± 0.058^{e}	37.49 ± 1.09^{bc}	31.23 ± 2.37^{ab}	34.03 ± 0.68$^{a–c}$	45.2 ± 1.46^{c}
	SA3	8.88 ± 0.40^{d}	8.08 ± 0.096^{d}	37.00 ± 0.82^{c}	29.80 ± 1.43$^{a–c}$	32.78 ± 1.55^{de}	45.5 ± 2.234^{c}
	control	8.30 ± 0.22^{e}	6.63 ± 0.050^{f}	38.42 ± 0.98^{ab}	32.48 ± 1.79^{a}	34.98 ± 1.51^{a}	41.8 ± 0.1^{d}

*P < 0.05; **P < 0.01; R – replication; I – irrigation; PGRS – plant growth regulators. Means within a column followed by the same letter are not significantly (P < 0.05) different according to the *LSD* test (mean + standard deviation, n = 3). Chl *a* – chlorophyll *a*; WDC – water-dissolved carbohydrate content; CRUF – crude fibre; ADF – acid detergent fibre; NDF – neutral detergent fibre; DMD – dry matter digestibility

https://doi.org/10.17221/181/2023-PSE

Table 4. ANOVA and mean comparison of salicylic acid (SA) and ascorbic acid (AA) effect on protein content, digestibility of protein, total protein yield, and protein of stem and leaves under water deficit conditions in two years

Source of variance	*df*	PC	DP	PY	PS
		(%)		(kg/ha)	
2013					
R	3	0.176**	0.221**	72 189**	13 232*
I	1	2.280**	0.996**	1 382 382**	347 049**
PGR	6	0.235**	0.187**	52 783**	14 173**
I × PGR	6	0.220**	0.0747**	18 847**	15 989**
2014					
R	3	0.866**	0.303**	169 754**	25 977**
I	1	0.951**	3.52**	947 773**	275 287**
PGR	6	0.403**	0.107^{ns}	68 368**	12 917**
I × PGR	6	0.134*	0.0954^{ns}	13 321*	7 305*
Irrigation	PGRS	2013			
	AA1	8.72 ± 0.350^{h}	4.28 ± 0.27^{e}	1 441 ± 250$^{b–d}$	719 ± 58.83^{ab}
	AA2	9.14 ± 0.033^{g}	4.70 ± 0.05$^{b–d}$	1 412 ± 164.4^{cd}	691 ± 37.84$^{a–c}$
	AA3	9.21 ± 0.082^{g}	4.77 ± 0.09^{cd}	1 468 ± 177^{bc}	716 ± 105.19^{ab}
Ir75	SA1	9.04 ± 0.163^{g}	4.67 ± 0.16$^{b–d}$	1 670 ± 151^{a}	737 ± 76.24^{a}
	SA2	9.10 ± 0.271^{g}	4.67 ± 0.27$^{b–d}$	1 595 ± 58.7^{ab}	643 ± 133.02$^{b–d}$
	SA3	9.07 ± 0.299$^{e–g}$	4.69 ± 0.27$^{b–d}$	1 512 ± 116$^{a–c}$	606 ± 116.57$^{c–e}$
	control	8.65 ± 0.173^{h}	4.17 ± 0.01^{e}	1 358 ± 88.7$^{c–e}$	608 ± 34.26$^{c–e}$
	AA1	10.27 ± 0.150$^{b–e}$	4.78 ± 0.21^{bc}	1 178 ± 176$^{f–h}$	533 ± 48.83$^{e–g}$
	AA2	11.32 ± 0.050$^{b–d}$	4.87 ± 0.09^{ab}	1 168 ± 88.4$^{f–h}$	510 ± 52.84^{fg}
	AA3	10.42 ± 0.050^{a-c}	5.05 ± 0.05^{a}	1 197 ± 29.4$^{e–gh}$	475 ± 9.37^{g}
Ir150	SA1	10.25 ± 0.058$^{c–f}$	4.71 ± 0.10$^{b–d}$	1 243 ± 81.6$^{e–g}$	553 ± 21.17$^{d–f}$
	SA2	10.50 ± 0.082^{ab}	4.80 ± 0.32^{b}	1 299 ± 85.2$^{d–f}$	586 ± 43.67$^{d–g}$
	SA3	10.57 ± 0.330^{a}	4.73 ± 0.30$^{b–d}$	1 103 ± 130^{gh}	465 ± 59.58^{g}
	control	10.02 ± 0.096^{f}	4.55 ± 0.05^{d}	1 069 ± 43.0^{h}	497 ± 12.50^{fg}
		2014			
	AA1	8.85 ± 0.25^{d}	4.38 ± 0.08	1464.23 ± 129.0^{ab}	668.44 ± 34.56$^{a–c}$
	AA2	9.25 ± 0.52^{c}	4.57 ± 0.12	1 434.11 ± 209.6^{ab}	692.34 ± 45.96^{ab}
	AA3	9.25 ± 0.37^{c}	4.61 ± 0.10	1 427.19 ± 192.3^{ab}	722.30 ± 82.72^{a}
Ir75	SA1	8.93 ± 0.55^{cd}	4.60 ± 0.04	1 550.61 ± 168.7^{a}	635.37 ± 87.70^{bc}
	SA2	8.88 ± 0.47^{d}	4.55 ± 0.17	1 478.91 ± 141.6^{a}	636.81 ± 124.7^{bc}
	SA3	9.13 ± 0.62$^{a–d}$	4.55 ± 0.08	1 477.24 ± 163.3^{a}	653.91 ± 73.44$^{a–c}$
	control	8.38 ± 0.13^{e}	4.32 ± 0.20	1 237.69 ± 135.6^{cd}	552.19 ± 62.22^{cd}
	AA1	10.28 ± 0.19^{ac}	4.60 ± 0.017	1 126.84 ± 64.2^{de}	503.98 ± 41.94^{e}
	AA2	10.13 ± 0.10^{b}	4.63 ± 0.12	1 190.24 ± 128.9^{d}	521.76 ± 52.65^{de}
	AA3	10.48 ± 0.05^{a}	4.70 ± 0.14	1 190.08 ± 82.0^{d}	478.43 ± 27.50$^{c–e}$
Ir150	SA1	10.25 ± 0.24^{ab}	4.60 ± 0.03	1 226.40 ± 52.0^{cd}	544.12 ± 30.51^{de}
	SA2	10.40 ± 0.24^{ab}	4.68 ± 0.16	1 339.23 ± 93.2^{bc}	572.15 ± 54.84^{de}
	SA3	10.08 ± 0.15^{b}	4.64 ± 0.12	1 202.37 ± 203.5^{d}	534.77 ± 86.82^{de}
	control	9.88 ± 0.25^{d}	4.44 ± 0.19	993.50 ± 110.4^{e}	438.56 ± 44.16^{f}

*P < 0.05; **P < 0.01; R – replication; I – irrigation; PGRS – plant growth regulators. Means within a column followed by the same letter are not significantly (P < 0.05) different according to the *LSD* test (mean + standard deviation, n = 3). PC – protein content; DP – digestibility of protein; PY – protein yield; PS – protein of stem

https://doi.org/10.17221/181/2023-PSE

height in both years. The highest plant height was obtained from the SA1 treatment in normal irrigation conditions, but there was no significant difference between SA and AA levels in water deficit conditions. SA seems to increase the number of internodes on the main stem by influencing vegetative meristems, but its precise mechanism is unclear. SA is likely to be involved in regulating cell elongation and division, like auxin (Wang and Ruan 2013). A study on the foliar application of SA to maize found that 300 mg/L SA had a positive effect on morpho-physiological traits (Tayyab et al. 2020). It was concluded that SA regulates physiological processes, like growth and development, and effectively increases plant dry weight, plant height, and protein yield by synthesising specific kinase proteins responsible for cell division, differentiation, and morphogenesis. Also, it reportedly increased cell division in the vegetative meristems of wheat seedlings (Arfan et al. 2007), maize (Zamaninejad et al. 2013), and soybean and increased shoot growth of these plants under water deficit conditions (Razmi et al. 2017).

Furthermore, the role of SA has been reported to enhance the fresh and dry plant weight of maize and sorghum, which corroborates our findings as we observed that the plants treated with SA and AA increased stem and leaf weight significantly. The highest stem fresh weight (8.21 t/ha) and leaf fresh weight (36.4 t/ha) were obtained from the plants treated with SA1 and SA2, respectively. The results as to the ear weight also show that lower rates of SA and AA were more effective than their higher rate (300 ppm) in increasing ear weight so that in both years, the maximum ear weight was obtained from the treatments of SA1 and AA1 in both normal and water deficit conditions.

While the maximum dry forage yield in normal conditions was observed in the plants treated with SA1 and AA1, it was obtained from the plants treated with SA2 in water deficit conditions. Thus, in water deficit conditions, SA levels had a more positive effect on increasing the forage yield of maize than AA levels. In this regard, researchers argue that in water deficit conditions, SA increases the growth and yield of plants by affecting photosynthesis processes and enzymes and accelerating the translocation of assimilates from the source to the consumption point (Keshavarz and Modarres Sanavy 2014). In addition, Idrees et al. (2010) suggest that SA contributes to preserving forage yield by modulating the detrimental effects of the stress. Additionally, AA can influence cell cycle or cell division and elongation and is a key metabolite involved in many cell processes, including cell division (De Gara et al. 2003). Exogenous application of AA induces mitosis activity in forage maize (Kerk and Feldman 1995), possibly by developing cell division from G1 to S (Zhang et al. 2017).

Water deficit in all treatments reduced some qualitative forage components, such as WDC and DMD, and increased CRUF, ADF, and NDF. However, treating the plants with the PGRs reduced ADF, NDF, and CRUF *versus* the control. The plants treated with SA, especially SA2, had mostly lower ADF, NDF, and CRUF than AA-treated plants. It seems that the PGRs influence polysaccharide hydrolysing enzymes in stressful conditions, resulting in the enhancement of the plant's dissolved carbohydrates, and the accumulation of these carbohydrates increases osmotic pressure and enhances the plant's capability of taking up water and nutrients from the soil (Zhang et al. 2017). Drought stress impacts plant growth by influencing the plant's physiological conditions, water status, enzymatic activity, and carbohydrate reserves (Jaleel et al. 2007). It reduces forage quality by increasing the precipitation of cellulose compounds. In contrast, in limited water availability, AA and SA cope with the trend of the severe decline in yield and increase chlorophyll concentration (Habibi 2012), thereby contributing to photosynthesis stability and increasing plant growth, which finally increases its dry matter yield.

We observed that water deficit reduced chlorophyll content in all treatments by 20.9–28.7%, but the treatments increased this trait *versus* the control significantly except for AA1 and AA2. Chlorophyll content in plants is a major factor involved in preserving their photosynthesis capacity. In drought conditions, chlorophyll is degraded due to various factors, such as the loss of carbon assimilation and an increase in reactive oxygen species (ROS) (Lawlor and Cornic 2002). SA increases the chlorophyll content of the plants by increasing the activity of the enzymes involved in photosynthesis and reducing the accumulation of ROS by influencing biochemical processes and the activity of antioxidant enzymes (Razmi et al. 2017). Reporting similar results, Saedpanah et al. (2016) found that the foliar application of SA significantly increased total carbohydrates in wheat grains and leaves *versus* the control and AA and had similar effects on leaf nitrogen, phosphorus, and potassium contents up to 200 ppm. Still, the higher levels brought about insignificant differences *versus* the control. However, compounds with antioxidant

https://doi.org/10.17221/181/2023-PSE

properties, such as ascorbate (Miguel et al. 2006), can alleviate the damages of drought stress by improving the plant's antioxidant capacity.

Membrane lipid peroxidation is a symptom of oxidative stress and is regarded as an index of the extent of damage to membranes in stress-exposed plants (Khan and Panda 2008). Our results reveal that MDA content increased over the plant's growth period in both years, but water deficit increased MDA to 109.6 nmol/g FW in the first year and 87.4 nmol/g FW in the second year (in the control plants). The PGR levels reduced MDA content, but SA was more effective than AA. Various studies have shown an increasing rate of MDA content in drought stress (Zabet et al. 2003), which agrees with our findings. An increase in MDA content under stress reflects an increase in membrane lipid peroxidation by ROS (Zeinali Yadeghari et al. 2007). The application of SA to plants can be a proper response to the reduction of membrane lipid peroxidation by inhibiting the activity of lipoxygenase and reducing H_2O_2 content to protect cell membranes in drought stress (Janda et al. 2007), which will hinder the accumulation of MDA (Noctor and Foyer 1998). Similar to our findings, it has been reported that SA application reduces MDA content in drought stress significantly (Yazdanpanah et al. 2011). The antioxidant defensive system, the reduction of oxidative stress and electrolyte leakage, an increase in the coherence of biomembranes, nitrogen metabolism, and mineral nutrition of the plants can be mentioned as has been reported in various studies (Popova et al. 2009). Therefore, as antioxidants, SA and AA activate and increase antioxidant enzymes, thereby scavenging ROS resulting from oxidative stress and improving the plant status under stress (Mutlu et al. 2009).

Phenolic compounds, e.g., salicylites, and antioxidant compounds, e.g., ascorbate, are involved in translocating photosynthates to the sink. Furthermore, increasing fresh and dry weight has also been attributed to an increase in net photosynthesis rate and carboxylation and an increase in the activity of the nitrate reductase and carbonic anhydrase (*versus* the control plants). On the other hand, phenolic compounds prevent auxin oxidation, affecting plant growth (Fariduddin et al. 2003). So, it can be concluded from the results that compounds with antioxidant activities like ascorbate (Miguel et al. 2006) and SA (Avaccini et al. 2003) reinforce plants' antioxidant potential and protect them against oxidative stress, so they improve plant growth and drought resistance.

REFERENCES

AOAC (2002): Official Method of Analysis. 17th Edition. Arlington, Association of Official Analytical Chemists.

Arefi F., Ganjali H.R., Rad M.R.N. (2016): Influence of drought stress and ascorbic acid on some characteristics of sorghum. International Journal of Agriculture and Biosciences, 5: 113–115.

Arfan M., Athar H.R., Ashraf M. (2007): Does exogenous application of salicylic acid through the rooting medium modulate growth and photosynthetic capacity in two differently adapted spring wheat cultivars under salt stress? Journal of Plant Physiology, 164: 685–694.

Arnon A.N. (1967): Method of extraction of chlorophyll in the plants. Agronomy Journal, 23: 112–121.

Avancini G., Abreu I.N., Saldana M.D.A., Mohamed R.S., Mazzafera P. (2003): Induction of pilocarpine formation in jaborandi leaves by salicylic acid and methyl jasmonate. Photochemistry, 63: 171–175.

Bakry B.A., Elewa T.A., El-Kramany M.F., Wali A.M. (2013): Effect of humic and ascorbic acids foliar application on yield and yield components of two wheat cultivars grown under newly reclaimed sandy soil. International Journal of Agronomy and Plant Production, 4: 1125–1133.

Bijani M., Hayati D., Azadi H., Tanaskovik V., Witlox F. (2020): Causes and consequences of the conflict among agricultural water beneficiaries in Iran. Sustainability, 12: 6630.

Buysse J., Merckx R. (1993): An improved colorimetric method to quantify sugar content of plant tissue. Journal of Experimental Botany, 44: 1627–1629.

De Gara L., De Pinto M.C.V., Moliterni M.C., d'Egidio M.G. (2003): Redox regulation and storage processes during maturation in kernels of *Triticum durum*. Journal of Experimental Botany, 54: 249–258.

Del Rio D., Stewart A.J., Pellegrini N. (2005): A review of recent studies on malondialdehyde as toxic molecule and biological marker of oxidative stress. Nutrition, Metabolism and Cardiovascular Diseases, 15: 316–328.

Dijkman T.J., Birkved M., Saxe H., Wenzel H., Hauschild M.Z. (2017): Environmental impacts of barley cultivation under current and future climatic conditions. Journal of Cleaner Production, 140: 644–653.

Fariduddin Q., Hayat S., Ahmad A. (2003): Salicylic acid influences net photosynthetic rate, carboxylation efficiency, nitrate reductase activity and seed yield in *Brassica juncea*. Photosynthetica, 41: 281–284.

Habibi G. (2012): Exogenous salicylic acid alleviates oxidative damage of barley plants under drought stress. Acta Biologica Szegediensis, 56: 57–63.

Hamada A. (2000): Amelioration of drought stress by ascorbic acid, thiamin or aspirin in wheat plants. Indian Journal of Plant Physiology, 5: 358–364.

https://doi.org/10.17221/181/2023-PSE

Hayat S., Hayat Q., Alyemeni M.N., Wani A.S., Pichtel J., Ahmad A. (2012): Role of proline under changing environments. Plant Signaling and Behavior, 7: 1456–1466.

Idrees M., Masroor Khan M.A., Aftab T., Naeem M., Hashmi N. (2010): Salicylic acid-induced physiological and biochemical changes in lemongrass varieties under water stress. Journal of Plant Interactions, 5: 293–303.

Jaleel C.A., Manivannan P., Sankar B., Kishorekumar A., Gopi R., Somasundaram R. (2007): Induction of drought stress tolerance by ketoconazole in *Catharanthus roseus* is mediated by enhanced antioxidant potentials and secondary metabolite accumulation. Colloids and Surfaces B: Biointerfaces, 60: 201–206.

Janda T., Horvath G., Szalai G., Paldi E. (2007): Role of salicylic acid in the induction of abiotic stress tolerance. In: Hayat S., Ahmad A. (eds.): Salicylic Acid – A Plant Hormone. Dordrecht, Springer Publishers. ISBN: 101-4020-5183-2

Jones R.A., Forero-Vargas M., Withers S.P., Smith R.S., Traas J., Dewitte W., Murray J.A.H. (2017): Cell-size dependent progression of the cell cycle creates homeostasis and flexibility of plant cell size. Nature Communications, 8: 15060.

Kerk N.M., Feldman L.J.A. (1995): A biochemical model for the initiation and maintenance of quiescent center, implications for organization of root meristems. Development, 121: 2825–2833.

Keshavarz H., Modarres Sanavy S.A.M. (2014): Effect of salicylic acid on chlorophyll, some growth characteristics and yield of two canola varieties. Crop Production, 7: 167–178.

Khalid Hussein Z., Qader Khursheed M. (2014): Effect of foliar application of ascorbic acid on growth, yield components and some chemical constituents of wheat under water deficit conditions. Jordan Journal of Agricultural Sciences, 10: 1–15.

Khan M.H., Panda S.K. (2008): Alterations in root lipid peroxidation and antioxidative responses in two rice cultivars under NaCl-salinity stress. Acta Physiologiae Plantarum, 30: 89–91.

Kheiri M., Soufizadeh S., Ghaffari A., Agha Alikhani M., Eskandari A. (2017): Association between temperature and precipitation with dryland wheat yield in northwest of Iran. Climatic Change, 141: 703–717.

Khodadadi S., Chegini M.A., Soltani A., Ajam Norouzi H., Sadeghzadeh Hemayati S. (2020): Influence of foliar-applied humic acid and some key growth regulators on sugar beet (*Beta vulgaris* L.) under drought stress: antioxidant defense system, photosynthetic characteristics and sugar yield. Sugar Tech, 22: 765–772.

Kolupaev Y., Yastreb T., Karpets Y.V., Miroshnichenko N. (2011): Influence of salicylic and succinic acid on antioxidant enzymes activity, heat resistance and productivity of *Panicum miliaceum* L. Journal of Stress Physiology and Biochemistry, 7: 154–163.

Kumar S., Sieverding H., Lai L., Thandiwe N., Wienhold B., Redfearn D., Jin V. (2019): Facilitating crop-livestock reintegration in the northern great plains. Agronomy Journal, 111: 2141–2156.

Lawlor D.W., Cornic G. (2002): Photosynthtic carbon assimilation and associated metabolism in relation to water deficits in higher plant. Plant, Cell and Environment, 25: 275–249.

Maghsoudi K., Arvin M. (2010): Salicylic acid and osmotic stress effects on seed germination and seedling growth of wheat (*Triticum aestivum* L.) cultivars. Journal of Plant Ecophysiology, 2: 7–11.

Maghsoudi K., Emam Y., Ashraf M., Arvin M.J. (2019): Alleviation of field water deficit in wheat cultivars by using silicon and salicylic acid applied separately or in combination. Crop Pasture Science, 70: 36–43.

Miguel A.J., Rosales M., Ruiz Hernandez J., Soriano T., Castilla N., Romero L. (2006): Antioxidant content and ascorbate metabolism in cherry tomato exocarp in relation to temperature and solar radiation. Journal of Science and Food Agriculture, 86: 1545–1551.

Miron J., Ephraim Z., Dgnit S., Gabriel A. (2005): Yield, composition, *in vitro* digestibility of new forage sorghum varieties and their ensilage characteristics. Animal Feed Science and Technology, 120: 17–32.

Mohamed H.I., Akladious S.A. (2014): Influence of garlic extract on enzymatic and non enzymatic antioxidants in soybean plants (*Glycine max*) grown under drought stress. Life Science Journal, 11: 46–58.

Muhammad Q., Mudassir A., Fahim N., Muhammad A. (2019): Role of salicylic acid and ascorbic acid in alleviating the harmful effects of water deficit in maize (*Zea mays* L.). Asian Journal of Agriculture and Biology, 7: 442–449.

Mutlu S., Atici O., Nalbantoglu B. (2009): Effects of salicylic acid and salinity on apoplectic antioxidant enzymes in two wheat cultivars differing in salt tolerance. Biologia Plantarum, 53: 334–338.

Noctor G., Foyer C.H. (1998): Ascorbate and glutathione: keeping active oxygen under control. Annual Review of Plant Physiology and Plant Molecular Biology, 49: 249–279.

Oddy V.H., Robars G.E., Low S.G. (1983): Pre-diction of *in vivo* dry matter digestibility from the fiber nitrogen content of a feed. In: Robards G.E., Packham R.G. (eds.): Feed Information and Animal Production. Farnham Royal, Commonwealth Agriculture Bureaux, 395–398.

Popova L.P., Maslenkova L.T., Yordanova R.Y., Ivanova A.P., Krantev A.P., Szalai G., Janda T. (2009): Exogenous treatment with salicylic acid attenuates cadmium toxicity in pea seedlings. Plant Physiology and Biochemistry, 47: 224–231.

Razmi N., Ebadi A., Daneshian J., Jahanbakhsh S. (2017): Salicylic acid induced changes on antioxidant capacity, pigments and grain yield of soybean genotypes in water deficit condition. Journal of Plant Interactions, 12: 457–464.

Saedpanah P., Mohammadi K., Fayaz F. (2016): Agronomic traits of forage maize (*Zea mays* L.) in response to spraying of nanofertilizers, ascorbic and salicylic acid. Journal of Research in Ecology, 4: 359–365.

Savari M., Eskandari Damaneh H., Damaneh H.E. (2020): Factors influencing farmers' management behaviors toward coping with

https://doi.org/10.17221/181/2023-PSE

drought: evidence from Iran. Journal of Environmental Planning and Management, 64: 2021–2046.

Schoppach R., Soltani A., Sinclair T.R., Sadok W. (2017): Yield comparison of simulated rainfed wheat and barley across Middle-East. Agricultural Systems, 153: 101–108.

Schyns J.F., Hoekstra A.Y., Booij M.J., Hogeboom R.J., Mekonnen M.M. (2019): Limits to the world's green water resources for food, feed, fiber, timber, and bioenergy. Proceedings of the National Academy of Sciences, 116: 4893–4898.

Tayyab N., Naz R., Yasmin H., Nosheen A., Keyani R., Sajjad M., Roberts T.H. (2020): Combined seed and foliar pre-treatments with exogenous methyl jasmonate and salicylic acid mitigate drought-induced stress in maize. Plos One, 15: e0232269.

Ullah H., Santiago-Arenas R., Ferdous Z., Attia A., Datta A. (2019): Improving water use efficiency, nitrogen use efficiency, and radiation use efficiency in field crops under drought stress: a review. Advances in Agronomy, 156: 109–157.

Van Soest P.J., Robertson J.B., Lewis B.A. (1991): Method for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. Journal of Dairy Science, 74: 3583–3597.

Wang L., Ruan Y.L. (2013): Regulation of cell division and expansion by sugar and auxin signaling. Frontiers in Plant Science, 4: 163.

Wang L.J., Fan L., Loescher W., Duan W., Liu G.J., Chen J.S., Luo H.B., Li S.H. (2010): Salicylic acid alleviates decreases in photosynthesis under heat stress and accelerates recovery in grapevine leaves. BMC Plant Biology, 10: 34–41.

Yazdanpanah S., Abasi F., Baghzadeh A. (2011): Effect of salicylic acid and ascorbic acid on proline, sugar and protein content in *Satureja hortensis* L. under aridity stress. In: Proceeding of the First National Conference of Environmental Stress in Agricultural Science 28–29 Juan 2010. The University of Birjand, Iran.

Zabet M., Hossainzadeh A., Ahmadi A., Khialparast F. (2003): Effects of drought on growth characters and determine index of resistance to drought in mungbean. Iranian Journal of Agricultural Science, 34: 889–898.

Zamaninejad M., Khorasani S.K., Moeini M.J., Heidarian A.R. (2013): Effect of salicylic acid on morphological characteristics, yield and yield componenjts of corn (*Zea mays* L.) under drought condition. European Journal of Experimental Biology, 3: 153–161.

Zeinali Yadegari L., Heidari R., Carapetian J. (2007): The influence of cold acclimatiom on proline, malondialdehyde (MDA), total protein and pigments in soybean (*Glycine max*) seedlings. Journal of Biological Sciences, 7: 1436–1441.

Zhang C.X., Feng B.H., Chen T.T., Zhang X.F., Tao L.X., Fu G.F. (2017): Sugars, antioxidant enzymes and IAA mediate salicylic acid to prevent rice spikelet degeneration caused by heat stress. Plant Growth Regulation, 83: 313–323.

Zhang Y. (ed.) (2013): Ascorbic Acid in Plants: Biosynthesis, Regulation and Enhancement. Springer Science & Business Media, 123. ISBN: 1461441277

Received: May 4, 2023
Accepted: January 5, 2024
Published online: February 19, 2024