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The Types of Plant Growth Regulators on Grain Yield and Yield Components of Barley (*Hordeum vulgare* L.) in Water Stress Condition

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ABSTRACT

Iran is climatically located in semi-arid and arid zones, as stressful environment in the world, Barley is one of the stress-tolerant crops that adapted to salinity and drought simultaneously. In order to evaluate the impacts of different plant growth regulators (PGR) on the grain yield and yield components of irrigated barley crop under water low or deficit irrigation condition, an experiment was conducted as a split plot with three replications in two different experimental fields, namely Abarkuh and Faragheh in 2018-2019 cropping year. Main plots were irrigation after the evaporation from the class A pan, namely control (80 mm) (S1), 100 mm (S2), and 120 mm (S3), and the subplots were the PGR application by spraying water (control) (P1), gibberellic acid (GA_3 at 110 mg/l) (P2), salicylic acid (SA at 1.5 mM) (P3), benzyl adenine (BA_6 at 60 mg/l) (P4), GA_3 (110 mg/l) + SA (1.5 mM) (P5), and superoxide dismutase (SOD at 5 mg/l) (P6) solutions in water. In this experiment the effects of experiment treatments were affected plant height, leaf area index (LAI), the number of tillers per plant, peduncle length, spike length, the number of seed per spike, one thousand grain weight, grain yield, biological yield, harvest index (HI), and grain protein significantly. The highest values of plant height (102.64 cm), leaf area index (3.62), the number of tillers per plant (4.27), peduncle length (26.02 cm), spike length (7.87 cm), the number of seed per spike (33.09), one thousand grain weight (39.86 g), grain yield (3.06 t/ha), biological yield (5.62 t/ha), harvest index (54.53%), and grain protein (11.82%) was related to 80 mm evaporation from the Pan class A and combined application GA_3 and SA. All PGRs, particularly the combined application of SA and GA_3 followed by superoxide dismutase significantly increased nutrient uptake, grain yield, grain protein, and yield components of barley. In conclusion, it is important to use tested PGR to increase barley yield and yield components particularly under drought stress condition.

***Keywords*:** Barley, Benzyl adenine, Drought, Gibberellic acid, Grain protein, Salicylic acid, Superoxide dismutase.

INTRODUTION

Environmental stresses negatively limit plant growth, development and crop yield (Wu *et al*., 2015; Kosova *et al*., 2023). Abscisic acid (ABA) is accumulated in plants under water shortage stress, and decreasing stomatal conductance as well as significant decline in photosynthetic rate with significant decrease of leaf area, shoot fresh weight and final yield of barley (*Hordeum vulgare* L.) (Tachibana *et al*., 2013; Jerbi *et al*., 2022; Ferioun *et al*., 2023; Li and Wang, 2023). Gibberellins (GA_3) are endogenous plant growth regulators, including diterpenoid and tetracyclic compounds which act as promoters of development and growth of many crops (Bradford *et al*., 2008; Khoshkharam *et al*., 2010; Shahrajabian *et al*., 2011; Soleymani *et al*., 2013; Soleymani and Shahrajabian, 2017). As a phytohomone, it has important role in promoting the change from vegetative to reproductive development with important functions in flower development and fertilization (Prakash *et al*., 2022). Othman and Leskovar (2022) reported that application of gibberelic acid (GA_3) at the 8-leaf stage is an appropriate crop management strategy for globe artichoke grown under warm climates. GA_3 has been used extensively to improve seedling growth, germination rate, and consequently yield (Rady *et al*., 2021). It play a significant function in the growth and development of plants by improving cell elongation, cell division, the development of pollen, growth of fruit, growth of the pollen tube, germination and development of seeds (Colak, 2018; Bakeer, 2019), for example tomatoes (Chunthaburee *et al*., 2014). Saleem *et al*. (2020) concluded that application of GA_3 can decrease Cu toxicity in fibrous jute seedlings by increasing biomass, plant growth, photosynthetic pigments, and gaseous exchange attributes as well as positive role in reducing reactive oxygen species (ROS) generation in the plant cells/tissues and increased phytoextraction of Cu in various plant parts. Gundogdu *et al*. (2021) also reported that foliar application of GA_3 treatments caused to significant increase of organic acids, phenolic compounds, vitamin C content, and agro-morphological characteristics of strawberry cultivars. Superoxide dismutase (SOD) is an important antioxidant enzyme which has been widely used as cosmetic additive, therapeutic agent, and food supplement (Sun *et al*., 2021; Sun *et al*., 2022; Sun and Shahrajabian, 2023a,b; Sun *et al*., 2023).

The inducible expression of SOD helps plants respond to abiotic and biotic stresses, such as under cold stress, the ROS content of cold-tolerant tea tree varieties, which can lead to minimum damage to the leaves (Wang *et al*., 2019). Alexopoulos *et al*. (2007) reported that the application of benzyl adenine can increase concentration of sucrose. Biton *et al*. (2014) observed that application of benzyl adenine can increase cell proliferation, reduced fruit cuticle cracking, and delayed chlorophyll degradation in fruits. Salicylic acid is an important regulator of plant growth, in the modulation of biochemical and physiological characteristics under abiotic stress (Osama *et al*., 2019; Min and Aroroa, 2022; Zulfiqar *et al*., 2023). The hormone can decrease the stress by boosting antioxidants, proline, secondary metabolites, heat shock proteins, and sugars responses (Roumani *et al.*, 2022; Turgut and Bezirganoglu, 2022; Rharbi *et al*., 2023). Salicylic acid can also favor plant tolerance mechanisms against physical stresses such as UV radiation, heat, cold, drought, heavy metals and salt (Poursakhi *et al*., 2019; Shohani *et al*., 2023). There are many researches on the effects plant growth regulators (PGR) on different crops, however, there is not much data about the effects of different PGR treatments on yield and yield components of barley under field drought conditions. This article aims to investigate the effects of different PGR including water, gibberellic acid 3 (GA_3), salicylic acid, benzyl adenine and superoxide dismutase on barley yield and yield components under water deficit conditions.

MATERIALS AND METHODS

In order to evaluate the effects of different plant growth regulators under water deficit conditions, a trial was conducted in two different research experimental stations (L) in the towns of Faragheh (northern latitude of $31^{o}3^{/}$, and eastern longitude of $53^{o}0^{/}$, and the latitude of 1713 m), and Abarkuh (northern latitude of $31^{o}7^{/}$, eastern longitude of $53^{o}14^{/}$, and the altitude of 1530 m), Yazd Province, Iran in 2018-2019. The climate of the region is hot with dry summers, and on the basis of report the rate of evapo-transpiration is much higher than the rate of rainfall, with the yearly average of 70 mm and the yearly temperature of 18^{o}C. The maximum temperature is related to the month of July and the lowest temperature occurs at the month of January. The soil physical and chemical properties of the experimental stations are presented in Table 1.

Table 1. The chemical and physical properties of the experimental field (0-30 cm)

Experimental Station	pH	EC (dS/m)	OC (%)	P (mg/kg)	K (mg/kg)	Sand (%)	Silt (%)	Clay (%)
Abarkuh	7.2	0.94	0.79	9.55	398	25.2	40.80	34.0
Faragheh	6.8	0.89	0.74	9.98	410	23.1	43.60	33.3

EC: Electrical conductivity (Salinity), OC: Organic carbon, P: Phosphorous, K: Potassium.

The trial was done on the basis of a split plot, on the basis of completely randomized block design, with three replications. Main plots were the evaporation from the pan class A, namely control (80 mm) (S1), 100 mm (S2), and 120 mm (S3), and the subplots were the PGR treatments including spraying with water (control) (P1), gibberellic acid (GA_3 at 110 mg/l) (P2), salicylic acid (SA at 1.5 mM) (P3), benzyl adenine (BA_6 at 60 mg/l) (P4), GA_3 (110 mg/l) + SA (1.5 mM) (P5), and superoxide dismutase (SOD at 5 mg/l) (P6).

Each plot consisted of 10 rows, and the field was cultivated and smoothed using a disk, and the plantation was done on the 21st of November in 2018. The plots measured 3×4 m, with rows, which were 15 cm apart, and planted at the density of 400 plants/m^2. The control plots were irrigated regularly and were not treated with any type of PGR. The other plots were irrigated until before the stemming stage, and were then irrigated and treated with PGR by using a standard sprayer on the basis of the experimental treatments. In this experiment, the barley genotype which was used for analyzing was *Hordeum vulgare* cv. Nosrat, which is the most common local genotype in the region. The weeds were controlled by using 2,4-D and the pests were also managed by using pesticides. The plant samples were collected by omitting the first 50 cm of each plot and the rows of 3, 4, 5, 6, 7, and 8. The protein content of grain was measured according to the method of ICC (International Association of Cereal Chemistry). Other experimental characteristics in this experiment were plant height (cm), leaf area index (LAI), the number of tillers per plant, peduncle length (cm), spike length (cm), one thousand grain weight, and grain yield (t/ha). The plant height was taken from five randomly selected plants of each plot, and the height of the plant was evaluated from the base of the plant to the tip of the upper most spikelets per spike. Tillers per plant that had at least one visible leaf was counted with considering both non-effective and effective tillers. Spike length was taken from basal node of the rachis to the apex of last grains of each spike. Grain yields were assessed by harvesting crops grown one square meter area at the center of each plot, and the harvested samples were then threshed, dried, weighted and the values expressed in ton/ha. Harvest index calculated according to the following formula, to analysis data of variance, SAS 9.3 was used.

Harvest index (%) = Grain yield/biological yield × 100

RESULTS

On the basis of analysis of variance, the effects of location on plant height, the number of tillers per plant, peduncle length and grain protein was significant, while spike length and grain yield did not significantly influenced by location (Table 2). All experimental characteristics such as plant height, the number of tillers per plant, peduncle length, spike length, grain yield and grain yield did significantly influenced by stress treatments, and plant growth regulators. None of the experimental characteristics significantly influenced by interaction between location and stress treatments, and the interaction between location and plant growth regulators. Similarly, the effects of interaction between location, stress and plant growth regulators were not meaningful on experimental characteristics. The interaction between stress and plant growth regulators treatments had meaningful effects on plant height, the number of tillers per plant, peduncle length, spike length, grain yield, and grain protein. On the basis of analysis of variance results the effect of location was not significant on leaf area index (LAI), however, the effects of stress, PGR, and interaction between stress and PGR on LAI was meaningful. LAI was not significantly affected by interaction between location and stress, and interaction between location and PGR. Although, the number of seed per spike was significantly influenced by location, its effect was not significant on one thousand grain weight. The effect of stress and PGR treatments on both experimental characteristics namely the number of seed per spike and one thousand grain weight was significant. Among all interaction between experimental treatments, the only interaction between stress and PGR treatments had meaningful influence on the number of seed per spike and one thousand grain weight. The effects of location on both biological index and harvest index was not significant, however, both stress treatment and PGR had meaning effects on these two experimental characteristics. Moreover, both biological yield and harvest index significant influenced by interaction between stress treatment and PGR (Table 2).

Table 2. Analysis of variance of the experimental treatments on different parameters.

S.V.	d.f.	Plant height	Leaf area index (LAI)	The number of tillers per plant	Peduncle length	Spike length	The number of seed per spike	One thousand grain weight	Grain yield	Biolgical yield	Harvest index	Grain protein
L	1	3.03*	0.02ns	0.47**	2.54*	0.099ns	3.55*	0.24ns	162.10ns	224.10ns	1.20ns	0.28**
S	2	87.68**	551.04**	6.68**	201.98**	0.770**	124.87**	238.18**	20533.90**	22820.10**	187.08**	9.83**
P	5	150.13**	900.82**	10.78**	93.38**	0.090**	204.16**	391.95**	8992.00**	8950.90**	93.18**	13.24**
L*S	2	0.15ns	0.04ns	0.04ns	0.12ns	0.016ns	0.59	0.07ns	57.80ns	47.80ns	0.92ns	0.02ns
L*P	5	0.07ns	1.44ns	0.01ns	0.08ns	0.008ns	0.57ns	0.02ns	20.20ns	27.70ns	0.38ns	0.02ns
S*P	10	0.80**	8.02**	0.28**	0.32*	0.031*	1.29**	3.52**	184.20**	226.40**	14.81**	0.06**
L*S*P	10	0.07ns	0.45ns	0.01ns	0.09ns	0.013ns	0.08ns	0.07ns	20.00ns	19.10ns	0.79ns	0.03ns

S.V.: Source of variance; d.f.: degree of freedom; L: Location; S: Stress; P: PGR

ns: Non significant; *significant at 0.05 significant in F-tests; **significant at 0.001 significance in F-tests.

The highest value of plant was related to interaction between control treatment (80 mm evaporation from the Pan Class A) and application of GA_3 + SA (102.65 cm), which had meaningful differences with other treatments, and the minimum value of plant height was achieved in application of 120 mm evaporation from the Pan Class A and water (control) treatment (90.5 cm). The highest leaf area index was related to interaction between control treatment (80 mm evaporation from the Pan Class A) and GA_3 + SA (3.62), and the minimum one was obtained for 120 mm evaporation from the Pan Class A and water (control treatment), which had meaning differences with each other's. The number of tillers per plant ranging from 0.97 to 4.27, and the maximum and the minimum value was obtained for control treatment (80 mm evaporation from the Pan Class A), and GA_3 + SA which showed meaningful difference with the minimum which was related to S3P1 (120 mm evaporation from the Pan Class A and water treatment). The highest values of peduncle length and spike length was 26.02 cm, and 7.87 cm, which have been related to S1P5 (80 mm evaporation from the Pan Class A and GA_3 + SA) which had meaningful differences with all treatments. On the other side, the interaction between 120 mm evaporation from the Pan Class A and control treatment (water) (S3P1) has obtained the lowest values of peduncle length (14.60 cm), and spike length (6.991 cm).

The number of seed per spike ranging from 20.76 to 33.09, and the maximum one was related to S1P5, and the minimum one was achieved for S3P1. Like, the number of seer per spike, the highest value of one thousand grain weight was related to S1P5 (39.86 g), and the lowest value was related to S3P1 (21.32 g), which had significant differences with each other's. Grain yield ranging from 1.89 t/ha (S3P1) to 3.06 t/ha (S1P5), which had meaningful differences with each other's. Both treatments namely S3P1 and S1P5 has significant differences with other treatments. Biological yield ranging from 4.59 (t/ha) for S3P1, and 5.62 (t/ha) for S1P5, which had meaningful differences with each other's. The maximum and the minimum harvest index was related to S1P5 (54.53%), and S3P1 (41.13%), respectively. The meaningful difference was found between S1P5 and S3P1. Even though, with increasing the level of stress from control treatment to 120 mm evaporation from the Pan Class A, grain protein reduced, the combined application of GA_3 and SA with single usage of superoxide dismutase significantly increased grain protein under various levels of stress treatments in comparison with control treatments. Grain protein ranging from 8.36% (S3P1) to 11.82% (S1P5) which had significant difference with each other's and other experimental treatments (Table 3).

Table 3. The mean comparison of interactions of stress and PGR on the experimental characteristics.

Treatment	Plant height (cm)	Leaf area index (LAI)	The number of tillers per plant	Peduncle length (cm)	Spike length (cm)	The number of seed per spike	One thousand grain weight (g)	Grain yield (t/ha)	Biolgical yield (t/ha)	Harvest Index (%)	Grain protein (%)
S1P1	94.88j	2.86i	1.33j	18.98h	7.12ijk	24.15i	27.56j	2.46g	4.93j	49.95ef	9.52j
S1P2	96.79fg	3.01g	2.18g	21.51e	7.31fg	26.88g	30.41g	2.71de	5.33e	50.82def	10.32gh
S1P3	98.01e	3.21de	3.03x	23.84bc	7.53cd	30.45d	33.67f	2.77cd	5.43cd	51.09cde	11.37b
S1P4	97.75e	3.07f	2.50ef	22.66d	7.38ef	30.18d	33.30e	2.72de	5.38de	50.55def	10.84d
S1P5	102.65a	3.62a	4.27a	26.02a	7.87a	33.09a	39.86a	3.06a	5.62a	54.53a	11.82a
S1P6	100.26c	3.37b	3.12bc	24.25b	7.65bc	32.27b	37.48b	2.93b	5.52b	53.12b	11.35b
S2P1	92.46l	2.66k	1.27j	17.17j	7.01kl	22.49j	25.98m	2.23i	4.83k	46.17h	8.93l
S2P2	95.30ij	2.90i	1.75i	20.03g	7.16hij	25.94h	28.77i	2.49fg	4.99hi	49.89ef	9.76i
S2P3	96.55gh	3.03fg	2.47g	21.42e	7.26gh	27.93f	30.10h	2.54f	5.10g	49.84f	10.59ef
S2P4	96.18h	2.95h	2.18g	20.48f	7.23ghi	27.84f	29.89h	2.65e	5.05gh	52.49bc	10.45fg
S2P5	100.83b	3.38b	3.25b	23.64c	7.68b	31.30c	37.61b	2.83c	5.48bc	51.70cd	11.26b
S2P6	99.19d	3.25d	2.65e	22.29d	7.52d	30.49d	36.15c	2.66e	5.33e	49.99f	11.07c
S3P1	90.5m	2.46l	0.97k	14.60k	6.99l	20.76k	21.32n	1.89k	4.59m	41.13i	8.36m
S3P2	93.77k	2.66k	1.38j	16.95j	7.08jk	23.04j	26.75l	2.16j	4.72l	45.74h	9.29k
S3P3	95.48i	2.89i	1.90hi	18.66h	7.17hij	25.80h	27.38j	2.33h	4.84k	48.10g	10.19h
S3P4	95.16ij	2.76j	1.98h	18.20i	7.09jk	25.76h	27.05k	2.27hi	4.83k	46.99gh	9.87i
S3P5	99.45d	3.31c	2.81d	20.88f	7.44de	30.39d	35.09d	2.66e	5.18f	51.26def	10.64e
S3P6	97.20f	3.18e	2.23d	19.64g	7.32efg	28.93e	33.88e	2.50fg	5.02i	49.77f	10.59ef

Common letters within each column do not differ significantly ($P < 0.05$).

S: Stress; P: PGR

S1: control (80 mm), S2: 100 mm, and S3: 120 mm evaporation from the Pan Class A; P1: water (control), P2: gibberellic acid (GA_3 at 110 mg/l), P3: salicylic acid (SA at 1.5 mM), P4: benzyl adenine (BA_6 at 60 mg/l), P5: GA_3 + SA, and P6: superoxide dismutase (SOD at 5 mg/l)

DISCUSSION

Plant height is ranging about 90.5 cm to 102.65 cm was the highest under the control level of water stress, however, the application of PGR, especially GA_3 + SA and superoxide dismutase significantly increased plant height under the medium and the high levels of stress. Leaf area index is an important indicator of radiation and precipitation interception, water balance, and energy conversion. In this experiment, LAI varied from 2.46 to 3.62, as the PGR significantly alleviated the stress by improving the index at different levels of the stress. Aminifard *et al*. (2020) reported that the application of benzyl adenine at 250 or 500 ppm and salicylic acid (75-150 μM) can be recommended for the improvement of growth, yield and biochemical indices of coriander. In other studies, the positive effects of salicylic acid and benzyl adenine on yield, fruit set, flowering, growth, and oil production in *Majorana hortensis* (Gharib, 2006), *Cuminum cyminum* (Rahimi *et al*., 2013), *Plukenetia volubilisn* (Fu *et al*., 2014), *Planta goovata* Forssk (Shekofteh *et al*., 2015), and *Digitalis trojana* (Cingoz and Gurel, 2016) have reported. The highest number of tillers per plant and peduncle length ranging from 0.97 to 4.27, and from 14.60 cm to 26.02 cm. Although, with increasing the level of stress both the number of tillers per plant and peduncle length decreased, application of PGR, namely, salicylic acid, gibberellic acid, benzyl adenine, and superoxide dismutase significantly increased these two parameters. Nicholls (1978) reported that application of gibberellic acid improved the growth of the double-ridge meristem (upper ridge only) and this may result in a group of abnormal spikelets being formed on the lower six nodes of the inflorescence. Nicholls (1978) also showed that the usage of gibberellic acid slightly decrease the growth rate of the vegetative barley apex between days 10 and 14. The maximum spike length (7.87 cm), the number of seed per spike (33.09), and one thousand grain weight (39.86 g) were related to S1P5 (80 mm evaporation from the Pan Class A and application of GA_3 + SA). Pirasteh-Anosheh *et al*. (2015) discovered that salicylic acid application in various concentrations could ameliorate the adverse impacts of water shortage on growth, yield and yield components of barley, however, application of salicylic acid at 2.0 mM under non-saline and at 1.41 mM under saline conditions could be considered as the appropriate concentration for increasing barley performance. In agreement with the results of this experiment, Bandurska and Ski (2005), Fayez and bazaid (2014), and Abdelaal *et al*. (2020) also observed that salicylic acid treatment led to increase plant dry weights, stem length, chlorophyll concentration, activity of antioxidant enzymes, relative water content, and grain yield under drought stress. Salicylic acid which is a signaling compound for signal transduction pathways, helps plants in protection against different abiotic and biotic stresses, and regulates seed germination, senescence, photosynthesis, cellular homeostasis, and improve yield of sweet basil (Mirzajani *et al*., 2015), common thyme (Khalil *et al*., 2018), wheat (Sedaghat *et al*., 2017; Kadam *et al*., 2021; Munsif *et al*., 2022; Das *et al*., 2023), pearl millet (Yadav *et al*., 2020), sweet potato (More *et al*., 2023), fragrant rice (Luo *et al*., 2023), spearmint (Shiri *et al*., 2023), chillies (Zahid *et al*., 2023), sesame (Pourghasemian *et al*., 2020), lemon balm (Pirbalouti *et al*., 2019), barley (Djande *et al*., 2023), and potato (Li *et al*., 2019). Grain yield ranging from 1.89 t/ha to 3.06 t/ha. Under the medium and high level of stress, the combination of SA and GA_3 resulted in significant increase in grain yield. The positive effects of gibberellic acid has been reported for date palm (Doaigey *et al*., 2013), cotton (Wang *et al*., 2014), sweet pepper (Perez-Jimenez *et al*., 2015), kenaf (Muniandi *et al*., 2018), pomegranate (Hosein-Beiji *et al*., 2019), wheat (Iftikhar *et al*., 2019; Alharby *et al*., 2021), maize (Tuna *et al*., 2008; Dawar *et al*., 2021; Bijanzadeh *et al*., 2022), garlic (Liu *et al*., 2020), olive tree (Moula *et al*., 2020), coriander (Saleem *et al*., 2021), isabgol (Roumani *et al*., 2022), rice (Zainordin *et al*., 2023), and Strawberry (Kocaman, 2023).

The maximum biological yield (5.62 t/ha), and harvest index (54.53%) was related to S1P5 which was the interaction between 80 mm evaporation from the Pan Class A (control treatment) and application of SA and GA_3. According to the results, the application of PGR significantly alleviated the stress. Gibberellic acid is an effective plant growth regulator, which could speed up barley germination as well as final yield and yield components (Higgins *et al*., 1976; Hamman *et al*., 2003; Sun *et al*., 2020; Allafe and Adam, 2022). Gibberellic acid increase physiological responses in plants and change the source-sink relationship by its impacts on leaf gas exchange such as photosynthesis, stomatal conductance, and sink formation. Gibberellic acids, interact with various environmental parameters such as water, temperature, and light to promote seed germination, and plant transition procedures such as meristem to shoot growth, juvenile to adult leaf stage and vegetative growth to flowering (Shahrajabian and Sun, 2023a,b,c,d,e; Shahrajabian *et al*., 2023a,b; Chandel *et al*., 2023). The positive effects of SOD to improve the production of plants in semi arid regions, promote antioxidant activities, and increase yield and yield components have been already reported in crops such as cowpea (Cavalcanti *et al*., 2004), rice (Wang *et al*., 2005), soybean (Celik *et al*., 2009), tobacco (Park *et al*., 2016), potato (Che *et al*., 2020), tomato (Liu *et al*., 2020), triticale (Saed-Moucheshi *et al*., 2021), barley (Kunos *et al*., 2022), and wheat (Guo *et al*., 2023) have been reported. Grain protein ranging from 8.36% to 11.82%, which has shown that with the increasing the level of stress, grain protein decreased, and the combined application of SA and GA_3 with the single use of superoxide dismutase notably increased grain protein under various levels of stress in compaAcevedo *et al*. (2023) reported that exogenous foliar application of salicylic acid mitigated the oxidative damage, increased synthesis of bioactive components under water deficit stress, and also induced the enzymatic antioxidant protection mechanism of potato. In another experiment, foliar application of salicylic acid at 150 mg L^{-1} suggested when grape tomato is grown under moderate to sufficient soil moisture availability (Chakma *et al*., 2021).

Abhari and Gholinezhad (2019) reported that the foliar application of salicylic acid can mitigate the adverse effects of water deficit which may negatively affect the structure of the cell membrane, increased the permeability of the membrane relative to the ions and macromolecules, and reduced the photosynthesis by decreasing the chlorophyll index, and finally foliar application of salicylic acid can increase grain yield and yield components of barley. In another study, it has been reported that the negative impacts of drought stress on different yield parameters of canola could be reduced by the exogenous application of gibberellic acid via foliar application at a dose of 150 mg L^{-1} as well as positive impacts on quality parameters such as the oleic acid contents (Elahi *et al*., 2023). It has been reported that benzyl adenine can delay cell division and the elongation of aerial parts of plants, and positively influence the peduncle length and final yield of plants (Fraszczak *et al*., 2021). Benzyl adenine application can improve soybean response to abiotic stress, mitigate the negative effects of stress in soybean (Zarain *et al*., 1987; Mangena, 2022). Nayak *et al*. (2020) observed that utilization of benzyl adenine can positively influence total chlorophyll content, yield per clump, yield per hectare, leaf length, the maximum number of tillers per clump, and leaf breadth.

CONCLUSION

Barley is an annual and ancient domesticated plant, and an important model plant to study among different crops because of its high drought adaptation. Like other crops, barley has complex and different responses to drought stress which evolved various strategies to alleviate the negative impacts of harsh environments by changing their cellular, molecular, and physiological functions. GA_3 is one of the most important plant growth regulators in the agricultural practices which is most appropriate for improving and promoting plant-growth of different plants. In this experiment, the tested PGR, particularly the combination of salicylic acid and gibberellins acid as well as superoxide dismutase notably increased nutrient uptake and plant physiology. The combined application of SA and GA_3 may promote plant physiology and nutrient uptake under drought stress by increasing the cross talk between various plant hormones, especially salicylic and gibberellins acid. The combined application of GA_3 and SA followed by superoxide dismutase significantly increased experimental characteristics such as plant height, leaf area index, the number of tillers per plant, peduncle length, spike length, the number of seed per spike, one thousand grain weight, grain yield, biological yield, harvest index and grain protein. The significant function of PGR is to induce the physiological and genetic processes in crops so, that they could be able to act similar to the non-stress conditions. SA can alleviate water stress through increasing stabilization of cellular membrane, leaf potassium and calcium, chlorophyll content and stability, leaf water content, proteins, soluble sugars, the activity of antioxidants, and glycine betaine. The tested PGR can influence barley physiology including nutrient uptake by influencing plant carbohydrate metabolism. On the basis of the results, application of PGR is strongly recommended to improve seed yield and yield components of barley under drought stress conditions, especially in center of Iran.

Disclosure statement

The authors declare that they do not have any conflict of interest

Author contributions

All authors have contributed equally to this manuscript.

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