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Survey on the Impacts of Different Plant Growth Regulators on Wheat Growth Stages under Water Shortage Treatments

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ABSTRACT
Wheat (*Triticum aestivum* L.) is one of the main crops which occupies an important part in agricultural production and water shortages, drought stress and low precipitation happen regularly during wheat growing periods in semi-arid and arid regions, which can significantly alter physiological processes such as respiration and photosynthesis as well as wheat production. Water deficit is widely reported for global wheat production, and it is the main constrains influencing wheat production in semiarid regions of Iran. Plant growth regulators (PGRs) can bring the most benefits to winter wheat crop to reduce plant height, increase stem thickness, reduces the risk of lodging, making managing and harvesting a tall winter wheat crop easier. Gibberelic acid can elongate plant cells and encourage cell division. In this trial, the highest number of days from seed plantation until seed germination, seed plantation until double ridge stage, seed plantation until terminal spikelet stage, seed plantation until swelling of stem stage, seed plantation until flowering stage, seed plantation until grain filling stage, and seed plantation until grain ripening stage was obtained in interaction between 120 mm evaporation from pan class A and control treatment (water treatment), and the minimum data also was belonged to interaction between 80 mm evaporation from pan class A and superoxide dismutase in both Abarkuh and Faragheh experimental research stations. Different stages of winter wheat showed different sensitivity to water deficit at various different growth periods. Water shortage is the major limiting parameter which can negatively influence plant growth and development of wheat plants.

Keywords: Benzyl adenine, Gibberellic acid, Grain protein, Irrigation, Salicylic acid, Superoxide dismutase, Wheat.

INTRODUCTION

Gibberellic acid (GA_3) are known as important plant growth regulators which are also considered to induce various physiological responses in plants (Azizi *et al*., 2023), which is unduly suited for improving and stimulating, photosynthetic activity, and plant growth (Shayanfar *et al*., 2011; Soleymani *et al*., 2013; Soleymani and Shahrajabia, 2017). GA_3 is a biologically active form of gibberellins (GAs) (Srivastava and Handa, 2005), and GAs promote cell numbers, and increase cell elongation, which has shown in importance in stem elongation (Hedden and Thomas, 2012; Shen *et al*., 2020). GAs can stimulate root and stem elongation, flowering, leaf expansion, seed germination, fruit senescence, and seed dormancy (Hooley, 1994; Kato *et al*., 2011; Hedden and Sponsel, 2015; Cui *et al*., 2023), as they can lead to better cell division, and cell elongation during growth, and improve the expression of hydrolytic enzymes which have function in the conversion of starch into sugar (Broumand *et al*., 2010; Khoshkharam *et al*., 2010; Riaziat *et al*., 2012; Sayed *et al*., 2020; Aliahmadi *et al*., 2021). It has been reported that GA_3 has significant ability to reduce the adverse impacts of salinity by promoting accumulation of osmolytes, antioxidant enzyme activity, and boosting vigor (Shahrajabian *et al*., 2011; Seo *et al*., 2019). GA_3 can significantly promote the stimulation of various non-enzymatic and enzymatic antioxidants, and the accumulation of osmolytes in plants (Jaleel *et al*., 2007; Misratia *et al*., 2015; Shahrajabian *et al*., 2021). Gibberellins are important endogenous hormones produced by fungi and plants which control plant development through triggering different physiological mechanisms (Gupta and Chakrabarty, 2013; Shahrajabian *et al*., 2023). Its application can boost the development of plant by revealing the fact that they improve the amino acid concentration in embryo and promote the syntheses of hydrolytic enzyme needed for digestion of endospermic starch when renew growth at seed germination (Soleymani *et al*., 2010; Soleymani *et al*., 2011; Sun and Shahrajabian, 2023; Sun *et al*., 2023). Pan *et al*. (2017) showed that exogenous application of GA_3 ca improve seed germination and promote vigorous respiratory metabolism as well as increase metabolism time, relative germination time, and critical oxygen pressure. Its application can reduce the negative impacts of phytotoxic impacts, as it can restored the mobilization of starch and protein reserves from the endosperm to seedling roots during germination of barley plants (Amri *et al*., 2016). Salicylic acid which is an important component can reduce the sensitivity of plants to environmental stresses through modulation the antioxidant defense system, regulation of transpiration rates, photosynthetic rate, and stomatal movement (Shakirova *et al*., 2003; Agarwal *et al*., 2005; Sahu *et al*., 2010; Ding *et al*., 2016; Akbulut *et al*., 2018). Superoxide dismutase (SOD) are defence-related proteins which are active in detoxifying reactive oxygen species (ROS) which can enhance grain yield and yield components of wheat (Tyagi *et al*., 2017), and improve tolerance of crops to different stresses such as salt and drought stress (Barra *et al*., 2016; Shen *et al*., 2018). Wheat growth and development are all affected by different parameters, and according to the physiological parameters, wheat development are usually distinguished as germination, emergence, tillering, floral initiation or double ridge, terminal spikelet, first node or beginning of stem elongation, boot, spike emergence, anthesis, and maturity. It has been reported that the foliar application of GA can significantly influence both wheat physiology and morphology, and foliar application of GA increased wheat growth and nutritional quality with positive impact on wheat irrespective of nanoparticles (NPs) combinations or alone supply (Al-Huqail *et al*., 2023). This article aimed to assess the impacts of different plant growth regulators and irrigation treatments on different growth and development of winter wheat.

MATERIALS AND METHODS

In order to experiment the effects of different types of plant growth regulators and irrigation treatments on the number of days from seed plantation until different growth stages at two research experimental station, namely Abarkuh and Faragheh research stations, an experimented was conducted. Two experimental research stations were Abarkuh (E53^{o} 14′ and N31^{o}7′) with altitude of 1530 m, and Faragheh (E53^{o}14′ and N31^{o}3′) with altitude of 1713 m. The climate of experimental station is dry and hot with the annual rainfall of 75 mm, and the soil physical and chemical properties of two experimental research stations are as follow: pH, EC, OC, P, K, Sand, Sily, and Clay in Abarkuh was 7.2, 0.94 dSm^{-1}, 0.79%, 9.5, 398, 25.2%, 40.80%, and 34.0%, respectively, and these amounts for Faragheh was 6.8, 0.89dSm^{-1}, 0.74%, 9.98, 410, 23.1%, 43.60%, and 33.3%. The trial was done according to split plot, on the basis of a complete randomized block design with three replications, and Sistan was the name of wheat cultivar which was used in this experiment. Main plots were drought stress at three levels (80, 100 and 120 mm evaporation from pan class A), and subplots were foliar application of plant growth regulators (PGRs) at six levels of control treatment (water), foliar application of gibberellic acid (GA_3 at 100 mgL^{-1}), salicylic acid (SA at 1.5 mM), benzyl adenine (BA at 60 mgL^{-1}), GA_3+SA, as well as superoxide dismutase (SOD at g gL^{-1}). The plots (including a non-treated plot as control) measuring 3 × 4 m with the plant density of 400 were established in the fields (cultivated and disked), with a 2.5 m distance from the irrigation canals. The plots were irrigated until the tillering stage and were then treated according to the experimental treatments including spraying with the PGRs at two different stages of tillering and heading. Weeds were controlled by using 2,4-Dichlorophenoxyacetic acid (2,4-D), and the plants were harvested at the physiological maturity when 50% of the plots were matured, and plants were sampled by collecting 10 plants from each plot. In the experiment the number of days from seed plantation until seed germination, the number of days from seed plantation until double ridge stage, the number of days from seed plantation until swelling of stem stage, the number of days from seed plantation until swelling of stem stage, the number of seed plantation until flowering stage, the number of days from seed plantation until grain filling stage, and the number of days from seed plantation until grain ripening stage was measured. The data of experimental parameters analyzed by SAS 9.3. The climatic data of the experimental stations at Abarkuh, and Faragheh are shown in Table 1 and Table 2, respectively.

Table 1. The meteorological data of the experimental station at Abarkuh.

Month	Max Temperature (^oC)	Min Temperature (^oC)	Average Temperature (^oC)	Humidity (%)	Monthly Rainfall (mm)
Nov	27.2	7.8	13.8	48	2
Dec	21.6	2.3	9.5	42	4.7
Jan	22.6	1.1	8.3	40	5.1
Feb	21.5	1.8	8.3	44	26
Mar	22.3	3.4	9.9	37	4.6
Apr	28	9.6	16.2	42	16
May	32.1	13.8	20.70	29	28.4
Jun	39.3	19.9	27.5	21	0.1

Table 2. The meteorological data of the experimental station at Faragheh.

Month	Max Temperature (^oC)	Min Temperature (^oC)	Average Temperature (^oC)	Humidity (%)	Monthly Rainfall (mm)
Nov	25.9	6.9	12.7	51	2.2
Dec	20.9	1.2	9.1	46	4.8
Jan	21.4	1	7.9	42	4.9
Feb	20.4	1.5	8	45	26.8
Mar	21.7	3.2	9.7	39	5.2
Apr	27.6	8.9	15.4	40	17.1
May	30.10	12.8	19.5	39	29.6
Jun	34.4	18.7	25.6	26	0.15

RESULTS AND DISCUSSION

The effects of different irrigation treatments and foliar application of PGRs were significant on all experimental characteristics, namely seed plantation until seed germination seed plantation until double ridge stage, seed plantation until terminal spiekelt stage, seed plantation until swelling of stem stage, seed plantation until grain filling stage, and seed plantation until grain ripening stage at both experimental stations, namely, Abarkuh and Faragheh (Table 3). The highest number of days from seed plantation until seed germination were 21 days which were related to interaction between 120 mm evaporation from pan class A and control treatment, while the minimum one was obtained for interaction between 80 mm evaporation from pan class A and superoxide dismutase (15 days). Bekaardt *et al*. (2004) reported that application of GA_3 can result in the highest seed germination in guayule, and Araujo *et al*. (2009) also showed that GA_3 application can increase the emergence of seeds of Jua tree. The maximum and the minimum days from seed plantation until double ridge stage was related to interaction between 120 mm evaporation from pan class A and control treatment (74 days), and interaction between 80 mm evaporation from pan class A and superoxide dismutase (68 days). Interaction between control treatment and 120 mm evaporation from pan class A had obtained the highest number of days from seed plantation until terminal spikelet stage (86 days), and the minimum number was related to interaction between interaction between 80 mm evaporation from pan class A and superoxide dismutase (80 days). The maximum days from seed plantation until swelling of stem stage, seed plantation until flowering stage, seed plantation until grain filling stage, and seed plantation until grain ripening stage were 119, 133, 149, and 180 days, respectively, which have obtained from interaction between 120 mm evaporation from pan class A and control treatment that they showed significant differences with other interactions. Interaction between 80 mm evaporation from pan class A and superoxide dismutase has obtained the lowest days from seed plantation until swelling of stem stage (113 days), seed plantation until flowering stage (127 days), seed plantation until grain filling stage (143 days), and seed plantation until grain ripening stage (174 days) (Table 3). In many experiments, it has been reported that GA_3 treatment can increase stem elongation through changing the orientation of cellulose microfibrils, regulate cambial cell division, promote xylem differentiation, and lead to formation of secondary xylem fibers (Sauter and Kende, 1993; Bjorklund *et al*., 2007; Hamayun *et al*., 2010; Yazdpour *et al*., 2012; Cuiying *et al*., 2013; Ogbaji *et al*., 2013; Wang *et al*., 2015). GA_3 application can delay ripening stage and increase shelf life of sweet cherry (Kondo and Danjo (2001), and it can also improve and stimulate both bolting and flowering stage (Jung *et al*. 2020).

Table 3. The number of days from seed plantation until different growth stages under different irrigation treatments and various foliar applications of PGRs at Abarkuh research station.

Treatment								
Irrigation	Foliar application of PGRs	Seed plantation until seed germination	Seed plantation until double ridge stage	Seed plantation until terminal spikelet stage	Seed plantation until swelling of stem stage	Seed plantation until flowering stage	Seed plantation until grain filling stage	Seed plantation until grain ripening stage
80 mm evaporation from pan class A	Control treatment (Water treatment)	17	70	82	115	129	145	176
80 mm evaporation from pan class A	Salicylic acid (SA)	17	70	82	115	129	145	176
80 mm evaporation from pan class A	Benzyl adenine (BA)	18	71	83	116	130	146	177
80 mm evaporation from pan class A	Gibberellic acid (GA_3)	17	70	82	115	129	145	176
80 mm evaporation from pan class A	GA_3 + SA	16	69	81	114	128	144	175
80 mm evaporation from pan class A	Superoxide dismutase (SOD)	15	68	80	113	127	143	174
100 mm evaporation from pan class A	Control treatment (Water treatment)	18	71	83	116	130	146	177
100 mm evaporation from pan class A	Salicylic acid (SA)	18	71	83	116	130	146	177
100 mm	Benzyl	18	71	83	116	130	146	177

evaporation from pan class A	adenine (BA)							
100 mm evaporation from pan class A	Gibberellic acid (GA_3)	18	71	83	116	130	146	177
100 mm evaporation from pan class A	GA_3 + SA	18	71	83	116	130	146	177
100 mm evaporation from pan class A	Superoxide dismutase (SOD)	18	71	83	116	130	146	177
120 mm evaporation from pan class A	Control treatment (Water treatment)	21	74	86	119	133	149	180
120 mm evaporation from pan class A	Salicylic acid (SA)	20	73	85	118	132	148	179
120 mm evaporation from pan class A	Benzyl adenine (BA)	18	71	83	116	130	146	177
120 mm evaporation from pan class A	Gibberellic acid (GA_3)	17	70	82	115	129	145	176
120 mm evaporation from pan class A	GA_3 + SA	20	73	85	118	132	148	179
120 mm evaporation from pan class A	Superoxide dismutase (SOD)	19	72	84	117	131	147	178

Mean values followed by the same letters are not significantly different at $P < 0.05$ using least significant difference (LSD).

Its application meaningfully boost the length of internodes and overall height of plants, and decrease internode mechanically strength (Peng *et al*., 2014; Zhang *et al*., 2018) as the stimulatory influence of GAs on plant internode length is closely associated to the endogenous levels of GAs (Ingram *et al*., 1986). PGRs contain a stress-signal molecule which can activate abiotic stress-responsive gene expression, which can induce the expression of biosynthetic enzymes and proteins in plants under environmental stresses.

The maximum days from seed plantation until seed germination (26 days), seed plantation until double ridge stage (79 days), seed plantation until terminal spikelet stage (91 days), seed plantation until swelling of stem stage (124 days), seed plantation until flowering stage (146 days), seed plantation until grain filling stage (153 days), and seed plantation until grain ripening stage (184 days) was achieved in interaction between 120 mm evaporation from pan class A and control treatment (Table 4). Interaction between 80 mm evaporation from pan class A and superoxide dismutase had obtained the highest seed plantation until germination (20 days), seed plantation until double ridge stage (73 days), seed plantation until terminal spikelet stage (85 days), seed plantation until swelling of stem stage (118 days), seed plantation until flowering stage (140 days), seed plantation until grain filling stage (147 days), and seed plantation until grain ripening stage (178 days) (Table 4). They were significant differences between all treatments. GA_3 application can increase and its concentration in stems is the major parameter for the change in internode diameter and length of soybean (Zhang *et al*., 2011; Zhang *et al*., 2020; Bawa *et al*., 2020). The usage of GA3 is effective in increasing seedling growth and length (Shahrajabian *et al*., 2021; Sun and Shahrajabian, 2024; Sun *et al*., 2024). PGRs can induce to elongation of wheat coleoptile sections and its connection with endogenous indoce acetic acid; PGRs can also stimulate various physiological processes and plant development, which consists of cell division and maturity, and enhance tolerance to different stresses. Salicylic acid which is known for its defensive role can significantly influence plant growth and development as well as reduce the negative effects of stresses (Singh and Usha, 2003; Sakhabutdinova *et al*., 2003; Hara *et al*., 2012; Sun *et al*., 2024;).

Table 4. The number of days from seed plantation until different growth stages under different irrigation treatments and various foliar applications of PGRs at Faragheh research station.

Treatment								
Irrigation	Foliar application of PGRs	Seed plantation until seed germination	Seed plantation until double ridge stage	Seed plantation until terminal spikelet stage	Seed plantation until swelling of stem stage	Seed plantation until flowering stage	Seed plantation until grain filling stage	Seed plantation until grain ripening stage
80 mm evaporation from pan class A	Control treatment (Water treatment)	22	75	87	120	142	149	180
80 mm evaporation from pan class A	Salicylic acid (SA)	22	75	87	120	142	149	180
80 mm evaporation from pan class A	Benzyl adenine (BA)	23	76	88	121	143	150	181
80 mm evaporation from pan class A	Gibberellic acid (GA_3)	22	75	87	120	142	149	180
80 mm evaporation from pan class A	GA_3 + SA	21	74	86	119	141	148	179
80 mm evaporation from pan class A	Superoxide dismutase (SOD)	20	73	85	118	140	147	178
100 mm evaporation from pan class A	Control treatment (Water treatment)	23	76	88	121	143	150	181
100 mm evaporation from pan class A	Salicylic acid (SA)	23	76	88	121	143	150	181
100 mm	Benzyl	23	76	88	121	143	150	181

evaporation from pan class A	adenine (BA)							
100 mm evaporation from pan class A	Gibberellic acid (GA_3)	23	76	88	121	143	150	181
100 mm evaporation from pan class A	GA_3 + SA	23	76	88	121	143	150	181
100 mm evaporation from pan class A	Superoxide dismutase (SOD)	23	76	88	121	143	150	181
120 mm evaporation from pan class A	Control treatment (Water treatment)	26	79	91	124	146	153	184
120 mm evaporation from pan class A	Salicylic acid (SA)	25	78	90	123	145	152	183
120 mm evaporation from pan class A	Benzyl adenine (BA)	23	76	88	121	143	150	181
120 mm evaporation from pan class A	Gibberellic acid (GA_3)	22	75	87	120	142	149	180
120 mm evaporation from pan class A	GA_3 + SA	25	78	90	123	145	152	183
120 mm evaporation from pan class A	Superoxide dismutase (SOD)	24	77	89	122	144	151	182

Mean values followed by the same letters are not significantly different at $P < 0.05$ using least significant difference (LSD).

CONCLUSION

Unlike, hormones which are produced naturally by plants, plant growth regulators are applied to plants by humans, and plant growth regulators are chemical that significantly affect flowering, aging, root growth, distortion and killing of organs, promotion or prevention of stem elongation, color enhancement of fruit, prevention of leafing and leaf fall, etc. GA_3 can significantly stimulate cell division and elongation, breaks seed dormancy, and increase speed of germination. Benzyl adenine is a synthetic cytokinin which stimulates cell division in crops. Supplementation of optimum ration of hormones for directing the growth of root, shoot can result in proliferation of specified cells. Supplementation of PGRs for different crops can also lead to the expression of different genes such as transcription factors which can further regulates the different development phases in plants. Studying of different growth stages are important to identify and assign different actions on the basis of the occurrence of key developmental events such as flowering, leaf and head emergence, and tillering. The number of leaves present on the first shoot on main stem can be designated with a decimal, and a tiller is a shoot which originates at the coleoptilar node. Tillers share the same root mass with the main stem, and the major management of tillering should be considered on the basis of whether they are enough to achieve yield goals. Winter wheat can continue to tiller for several weeks, although it depends on different agronomical factors such as using PGRs. Most tillers have been formed at the beginning of erect growth. At the boot stage, the head is completely developed and can be easily found in the swollen section of the leaf sheath below the flag leaf. Flowering is usually marked by the extrusion of anthers from florets in the center of the spike. In studies of the influence of PGRs influence wheat plant and growth development, wheat morphological terms such as an anther, awn, coleoptile, flag leaf, floret, spike, spikelet, stigma, and tiller should be considered. In this experiment, the maximum days from seed plantation until seed germination, seed plantation until double ridge stage, seed plantation until terminal spikelet stage, seed plantation until swelling of stem stage, seed plantation until flowering stage, seed plantation until grain filling stage, and seed plantation until grain ripening stage was achieved in interaction between 120 mm evaporation from pan class A and control treatment (water treatment), and the minimum data also was belonged to interaction between 80 mm evaporation from pan class A and superoxide dismutase in both Abarkuh and Faragheh experimental research stations. Water shortage is an important water-saving activity in irrigated agriculture, and the deficit irrigation impacts on growth and development of plants should be more studied. Appropriate irrigation programming of irrigation is important to promote crop yield, as balancing the relationship between reproductive and vegetative growth stages are very important. Irrigation strategy during periods of high wheat demand for water has significant impacts on grain yield, wheat growth, and soil water status at various growth stages have numerous impacts on grain yield, physiological characteristics, and photosynthetic parameters.

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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REFERENCES

Agarwal S, Sairam RK, Srivastava GC, Tyagi A, Meena RC. 2005. Role of ABA, salicylic acid, calcium and hydrogen peroxide on antioxidant enzymes induction in wheat seedlings. Plant Science, 169(3):559-570.

Akblut GB, Yigit E, Kaya A, Aktas A. 2018. Effects of salicylic acid and organic selenium on wheat (*Triticum aestivum* L.) exposed to fenoxaprop-p-ethyl. Ecotoxicology and Environmental Safety, 148:901-909.

Aliahmadi Z, Mohadesi A, Ranjbar M, Javanshah A. 2021. Preparation and evaluation of Ca/Mg-layered double hydroxide as a novel modifier for electrochemical determination of gibberellic acid. Journal of Molecular Structure, 1246:131200.

Amri B, Khamassi K, Ali MB, Silva JATD, Kaab LBB. 2016. Effects of gibberellic acid on the process of organic reserve mobilization in barley grains germinated in the presence of cadmium and molybdenum. South African Journal of Botany, 106:35-40.

Araujo PC, Freitas RMOD, Praxedes SC, Ribeiro MCC. 2009. Gibberellic acid enhances the emergence of *Zizyphus joazeiro* seeds. Journal of New Seeds. 10(4):277-281.

Azizi MH, Soleymani A, Javanmard HR. 2023. Wheat (*Triticum aestivum* L.) biochemical and nutritional properties affected by plant growth regulators under field conditions. Cereal Research Communications. https://doi.org/10.1007/s42976-023-0041401

Barra PJ, Inostroza NG, Acuna JJ, Mora ML, Crowley DE, Jorquera MA. 2016. Formulation of bacterial consortia from avocado (*Persea americana* Mill.) and their effect on growth, biomass, and superoxide dismutase activity of wheat seedlings under salt stress. Applied Soil Ecology, 102:80-91.

Bawa G, Feng L, Chen G, Chen H, Hu Y, Pu T, Cheng YJ, Shi Y, Xiao T, Zhou WG, Yong T, Sun X, Yang F, Yang W, Wang X. Gibberellins and auxin regulate soybean hypocotyl elongation under low light and high-temperature interaction. Physiologia Plantarum, 170:345-356.

Bekaardt CR, Pieterse PJ, Coetzee JH, Agenbag GA. 2004. The breaking of seed dormancy of guayule (*Parthenium argentatum* Gray). By treatment with gibberellic acid and smoke water solution. South of African Journal of Plant and Soil, 21(2):114-116.

Bjorklund S, Antti H, Uddestrand I, Mortiz T, Sundberg B. 2007. Cross-talk between gibberellin and auxin in development of *Populus* wood: Gibberellin stimulates polar auxin transport and has a common transriptome with auxin. The Plant Journal, 52:499-511.

Broumand P, Rezaei A, Soleymani A, Shahrajabian MH, Noory A. 2010. Influence of forage clipping and top dressing of nitrogen fertilizer on grain yield of cereal crops in dual purpose cultivation system. Research on Crops, 11(3):603-613.

Cui H, Shahrajabian MH, Kuang Y, Zhang H, Sun W. 2023. Heterologous expression and function of cholesterol oxidase: A review. Protein and Peptide Letters, 30(7):531-540.

Cuiying W, Bao Y, Wang QQ, Zhang HX. Introduction of the rice CYP714D1 gene into *Populus* inhibits expression of its homologous genes and promotes growth, biomass production and xylem fibre length in transgenic tress. Journal of Experimental Botany, 64:2847-2857.

Ding LN, Yang GX, Yang RY, Cao J, Zhou Y. 2016. Investigating interactions of salicylic acid and jasmonic acid signaling pathways in monocots wheat. Physiological and Molecular Plant Pathology, 93:67-74.

Kato F, Araki M, Miyazawa Y, Fujii N, Takeda K, Suge H, Takahashi H. 2011. Factors responsible for deep-sowing tolerance in wheat seedlings: varietal differences in cell proliferation and the co-ordinated synchronization of epidermal cell expansion and cortical cell division for the gibberellin-mediated elongation of first internodes. Annals of Botany, 108:439-447.

Gupta R, Chakrabarty SK. 2013. Gibberellic acid in plant: Still a mystery unresolved. Plant Signaling and Behavior, 8: e25504.

Hamayun M, Khan SA, Khan AL, Shin JH, Ahmad B, Shin DH, Lee IJ. 2010. Exogenous gibberellic acid reprogras soybean to higher growth and salt stress tolerance. Journal of Agricultural and Food Chemistry, 58:7226-7232.

Hara M, Furukawa J, Sato A, Mizoguchi T. 2012. Abiotic stress and role of salicylic acid in plants. In Abiotic Stress Responses in Plants, 235-251. Springer, New York, NY.

Hedden P, Thomas SG. 2012. Gibberellin biosynthesis and its regulation. Biochemical Journal, 444:11-25.

Hedden P, Sponsel V. 2015. A century of gibberellin research. Journal of Plant Growth Regulation, 34:740-760.

Hooley R. 1994. Gibberellins: Perception, transduction and responses. Plant Molecular Biology, 26:1529-1555.

Ingram TJ, Reid JB, Macmillan J. 1986. The quantitative relationship between gibberellin A1 and internode growth in *Pisum sativum* L. Planta, 168:414-420.

Jaleel CA, Gopi R, Manivannan P, Sankar B, Kishorekumar A, Panneerselvam R. 2007. Antioxidant potentials and ajmalicine accumulation in *Catharanthus roseus* after treatmentwith gibberellic acid. Colloids and Surfaces B: Biointerfaces, 60:195-200.

Jung H, Jo SH, Jung WY, Park HJ, Lee A, Moon JS, Seong SY, Kim JK, Kim YS, Cho HS. 2020. Gibberellin promotes bolting and flowering via the floral integrators RsFT and RsSOC1-1 under marginal vernalization in radish. Plants. 9:594.

Khoshkharam M, Rezaei A, Soleymani A, Shahrajabian MH. 2010. Effects of tillage and residue management on yield components and yield of maize in second cropping after barley. Research on Crops, 11(3):659-666.

Kondo S, Danjo C. 2001. Cell wall polysaccharide metabolism during fruit development in sweet cherry Satohnishiki as affected by gibberellic acid. Journal of the Japanese Society for Horticultural Science, 70(2),178-184.

Misratia KM, Islam MR, Ismail MR, Oad FC, Hanafi MM, Puteh A. Interactive effects of gibberellic acid (GA_3) and salt stress on growth and ion accumulation of two rice (*Oryza sativa* L.) varieties differing in salt tolerance. Journal of Food, Agriclture and Environment, 13:66-70.

Ogbaji PO, Shahrajabian MH, Xue X. 2013. Changes in germination and primarily growth of three cultivars of tomato under diatomite and soil materials in auto-irrigation system. International Journal of Biology, 5(3):80-84.

Pan B, Zhong T, Zhao G. 2017. Promoting deep-sowing germinability of corn (*Zea mays* L.) by seed soaking with gibberellic acid. Archives of Agronomy and Soil Science, 63(9):1314-1323.

Peng D, Chen X, Yin Y, Lu KL, Yang WB, Tang YH, Wang ZL. 2014. Lodging resistance of winter wheat (*Triticum aestivum* L.): ligning accumulation and its related enzymes activities due to the application of paclobutrazol or gibberellin acid. Field Crops Research, 157:1-7.

Riaziat A, Soleymani A, Shahrajabian MH. 2012. Changes in seed yield and biological yield of six wheat cultivars on the basis of different sowing dates. Journal of Food, Agriculture and Environment, 10(1):467-469.

Sahu GK, Kar M, Sabat SC. 2010. Alteration in phosphate uptake potential of what plants co-cultivated with salicylic acid. Journal of Plant Physiology, 167(4):326-328.

Sakhabutdinova AR, Fatkhutdinova DR, Bezrukova MV, Shakirova FM. 2003. Salicylic acid prevent the damaging action of stress factors on wheat plants. Bulg J Plant Physiol, 21:314-319.

Sauter M, Kende H. 1993. Internodal elongaton and orientation of cellulose mirofibrils and microtubules in deepwater rice. Planta, 190:354-362.

Sayed AEDH, AbdAllah EA, Hamed M, Soiliman HAM. 2020. Hepatonephrotoxicity in late juvenile of *Oreochromis niloticus* exposed to gibberellic acid: Ameliorative effects of *Spirulina platensis*. Pesticide Biochemistry and Physiology, 167:104600.

Seo Y, Gudz A, Lowe JM, Gagne MR. 2019. Selective deoxygenation of gibberellic acid with fluoroarylborane catalysts. Tetrahedron, 75(49):130712.

Shahrajabian MH, Soleymani A, Naranjani L. 2011. Grain yield and forage characteristics of forage sorghum under different plant densities and nitrogen levels in second cropping after barley in Isfahan, Iran. Research on Crops, 12(1):68-78.

Shahrajabian MH, Chaski C, Polyzos N, Petropoulos SA. 2021. Biostimulants application: A low input cropping management tool for sustainable farming of vegetables. Biomolecules, 11(5):698.

Shahrajabian MH, Chaski C, Polyzos N, Tzortzakis N, Petropoulos SA. 2021. Sustainable agriculture systems in vegetable production using chitin and chitosan as plant biostimulants. Biomolecules, 11(6):819.

Shahrajabian MH, Petropoulos SA, Sun W. 2023. Survey of the influences of microbial biostimulants on horticultural crops: Case studies and successful paradigms. Horticulturae, 9(193):1-24.

Shakirova FM, Sakhabutadinova AR, Bezrukova MV, Fatkhutdinova RA, Fatkhutdinova DR. 2003. Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. Plant Science, 164(3):317-322.

Shayanfar M, Soleymani A, Shahajabian MH. 2011. Effect of plant densities on solar radiation absorption and depreciation, leaf area index and crop growth rate of different cultivars of sunflower. Research on Crops, 12(3):728-730.

Shen Y, Li J, Gu R, Yue L, Wang H, Zhan X, Xing B. 2018. Carotenoid and superoxide dismutase are the most effective antioxidants participating in ROS scavenging in phenanthrene accumulated wheat leaf. Chemosphere, 197:513-525.

Shen C, Wang XJ, Guo FT, Zhou WQ, Wang GL. 2020. Gibberellin and the plant growth retardant Paclobutrazol altered fruit shape and ripening in tomato. Protoplasma, 257:853-861.

Singh B, Usha K. 2003. Salicylic acid induced physiological and biochemical changes in wheat seedlings under water stress. Plant Growth Reg, 39:137-141.

Soleymani A, Shahri MM, Shahrajabian MH, Naranjani L. 2010. Responses of cultivars of canola to sulfur fertilizer and plant densities under climatic condition of Gorgan region, Iran. Journal of Food, Agriculture and Environment, 8(3&4):298-304.

Soleymani A, Shahrajabian MH, Naranjani L. 2011. The effects of nitrogen as starter fertilizer on ash percentage, important elements and solar radiation absorption of berseem clover cultivars intercropped by corn. Journal of Food, Agriculture and Environment, 9(1):342-344.

Soleymani A, Shahrajabian MH, Naranjani L. 2013. Effect of planting dates and different levels of nitrogen seed yield and yield components of nuts sunflower (*Helianthus annuus* L.). African Journal of Agricultural Research, 8(46):5802-5805.

Soleymani A, Shahrajabian MH. 2017. Effects of planting dates and row distance on sugar content, root yield, and solar radiation absorption in sugar beet at different plant densities. Romanian Agricultural Research, 34(34):1-11.

Srivastava A, Handa AK. 2005. Hormonal regulation of tomato fruit development: A molecular perspective. Journal of Plant Growth Regulation, 24:67-82.

Sun W, Shahrajabian MH. 2023. The application of arbuscular mycorrhizal fungi as microbial biostimulant, sustainable approachesin modern agriculture. Plants, 12(17):3101.

Sun W, Shahrajabin MH, Petropoulos SA, Shahrajabian N. 2023. Developing sustainable agriculture systems in medicinal and aromatic plant production by using chtiosan and chitin-based biostimulants. Plants, 12(13):2469.

Sun W, Shahrajabian MH. 2024. Survey on nitrogenase evolution by considering the importance of nitrogenase, its structure, and mechanism of nitrogenase. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 52(1):13157.

Sun W, Shahrajabian MH, Kuang Y, Wang N. 2024. Amino acids biostimulants and protein hydrolysates in agricultural sciences. Plants, 13(210):1-22.

Sun W, Shahrajabian MH, Soleymani A. 2024. The roles of plant-growth-promoting rhizobacteria (PGPR)-based biostimulants for agricultural production systems. Plants, 13(613):1-38.

Taygi S, Sharma S, Taneja M, Shumayla, Kumar R, Sembi JK, Upadhyay SK. 2017. Superoxide dismutase in bread wheat (*Triticum aestivum* L.): Comprehensive characterization and expression analysis during development and biotic and abiotic stresses. Agri Gene, 6:1-13.

Wang GL, Que F, Xu ZS, Wang F, Xiong AS. 2015. Exogenous gibberellin altered morphology, anatomic and transcriptional regulatory networds of hormones in carrot root and shoot. BMC Plant Biology, 15:290-302.

Yazdpour H, Shahri MM, Soleymani A, Shahrajabian MH. 2012. Effects of harvesting time and harvesting height on grain yield and agronomical characters in rice ratoon (*Oryza sativa* L.). Journal of Food, Agriculture and Environment, 10(1):438-440.

Zhang J, Smith DL, Liu W. 2011. Effecs of shade and drought stress on soybean hormones an yield of main-stem and branch. African Journal of Biotechnology, 10:14392-14398.

Zhang HX, Wang HH, Zhu Q, Gao YB, Wang HY, Zhao LZ, Wang, YS, Xi FH, Wang WF, Yang YQ, Lin C, Gu L. 2018. Transcriptome characterization of moso bamboo (*Phyllostachy edulis*) seedlings in response to exogenous gibberellin applications. BMC Plant Biology, 18:125-140.

Zhang R, Shan FX, Wang C, Yan C, Dong SK, Xu Y, Gong ZP, Ma CM. 2020. Internode elongation pattern, internode diameter and hormone changes in soybean (*Glycine max*) under different shading conditions. Crop and Pasture Science, 7:679-688.