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Assessment of Salicylic Acid Application in Enhancing Quantitative and Qualitative Improvement of Wheat (*Tiriticum aestivum* L.) under End-Season Moisture Stress Conditions

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ABSTRACT

BACKGROUND: In drought stress conditions, the use of plant growth regulators such as salicylic acid can be considered as a strategy to mitigate the adverse effects of drought stress on plants.

OBJECTIVES: This study aims to investigate the biochemical effect of growth regulator on the quantitative and qualitative yield of two wheat varieties, bread and rainfed, in Khuzestan province under end-of-season drought stress conditions.

METHODS: Current research was done via factorial experiment according complete randomized block design with three replications in the greenhouse of Islamic Azad University, Ahvaz branch, in 2018. The treatment included two levels of salicylic acid [control (zero application) and 1 mM foliar spray], two irrigation regimes [watering until the end of the season and cessation of watering at the seed filling stage (Zadox stage 69)]; and two drought-resistant wheat varieties: Chamran 2 and Karkheh.

RESULT: The results showed that end-season drought stress significantly affected the studied traits. The cessation of irrigation at the seed filling stage led to a significant increase in catalase, proline, protein, remobilization, and a decrease in chlorophyll index and stomatal conductance. However, the application of salicylic acid regulated these traits and positively influenced both the quantity (seed yield) and quality (gluten) of the seed, increasing them by 7.30% and 8.05%, respectively.

CONCLUSION: The findings of this study suggest that salicylic acid application can mitigate the adverse effects of drought stress and enhance growth and yield under favorable conditions while reducing decline under stress conditions. Therefore, the use of salicylic acid as a growth regulator is recommended in the Chamran 2 variety.

KEYWORDS: *Chlorophyll, Growth regulator, Protein, Proline, Gluten.*

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1. BACKGROUND

Cereal seeds are among the largest sources of energy from foodstuffs worldwide. It is estimated that by the year 2050, the global population will reach around 10 billion people. The primary responsibility of agricultural science, especially in crop production, is to produce more and better-quality crops to meet the needs of this increasing population (Siadat *et al*., 2020). Wheat, with an approximate cultivation area of 225 million hectares and an annual production of nearly 740 million tons, is one of the world's most important cereals. In Iran, the wheat production is about 12.7 million tons on 6.5 million hectares, two-thirds of which are rainfed, often facing water scarcity during part of the growing season (FAO, 2020). Drought is one of the most critical environmental stress factors affecting agricultural production in arid and semi-arid regions, leading to reduced yields (Karimzadeh Soureshjani *et al*., 2012). In drought stress conditions, the use of plant growth regulators such as salicylic acid can be considered as a strategy to mitigate the adverse effects of drought stress on plants (Madadi and Fallah, 2018). These substances, including plant hormones, play a significant role in the plant's response to abiotic stresses such as drought, cold, toxic heavy metals, heat, and osmotic stress (Rivas-San Vicente and Plasencia, 2011). Salicylic acid exhibits its properties by affecting the expression of certain genes and the production of inhibitors like ethylene (Enteshari and Jafari, 2013; Wang *et al*., 2020). Drought is the most serious and common challenge for global wheat producers. Various studies have shown that the lack of sufficient water supply to wheat, especially during the anthesis period, affects agronomic and physiological traits, leading to reduced leaf photosynthesis and subsequently lower assimilate availability for developing seeds, ultimately decreasing wheat yield both quantitatively and qualitatively (Khatiwada *et al*., 2020; Behdad *et al*., 2022; Qaseem *et al*., 2019; Mehraban *et al*., 2019). Vahabi *et al*. (2017) in evaluating the application of salicylic acid on the growth and yield of wheat under drought stress conditions reported that moisture stress and its increased severity reduced flag leaf area, spike length, seed number per spike, biological yield, and seed yield. However, the application of growth regulator improved all seed yield components, resulting in a 12.2% increase in seed yield. This study indicated that although moisture stress reduced wheat seed yield, growth regulators could compensate for some of this yield loss. Mousavi Ouri *et al*. (2021) in assessing the effect of salicylic acid on yield and yield components of marigold reported that the application of this substance reduced the negative impacts of stress. For instance, a concentration of 25 $mg.l^{-1}$ of salicylic acid led to a 20% increase in yield under non-stress conditions compared to the control and decreased by 86% under drought stress conditions, improving both quantitative and qualitative characteristics of marigold under stress. Considering the crucial and fundamental role of growth regulators, especially salicylic acid, which at low concentrations and when applied foliar in agricultural plants, particularly cereals, reduces the effect of drought stress.

2. OBJECTIVES

This study aims to investigate the biochemical effect of growth regulator on the quantitative and qualitative yield of two wheat varieties, bread and rainfed, in Khuzestan province under end-of-season drought stress conditions.

3. MATERIALS AND METHODS

3.1. *Field and Treatments Information*

The effect of salicylic acid application on the quantitative and qualitative improvement of two wheat varieties under end-of-season drought stress was investigated in 2018. This study was conducted via factorial experiment based on complete randomized block design with three replications in the research greenhouse of the Islamic Azad University, Ahvaz branch. The experimental factors included two levels of growth regulator salicylic acid; control (without any growth regulator) and foliar application of 1 mM salicylic acid, two watering regimes; full irrigation until the end of the season and irrigation cessation at the seed filling stage (Zadox stage 69), and two drought-resistant wheat varieties: Chamran 2 and Karkheh.

3.2 .*Farm Management*

Wheat seeds, after sterilization with Benomyl fungicide for two minutes and drying at room temperature (25°C), were planted in 50-liter pots containing an equal mixture of field soil and sand. One week after germination, the seedlings were thinned to 15 per pot and after full growth; the pots were maintained under normal full irrigation (100% field capacity). The moisture content for the pot soil was calculated at 22% by weight using a pressure plate device. The amount and type of chemical fertilizers used were determined and applied based on the common practices in Khuzestan province (70 and 50 $kg.ha^{-1}$ of nitrogen and phosphate, respectively). The growth regulator was applied in two stages; the first at the beginning of the flowering stage (double ridge) and the second coinciding with the initiation of drought stress at the beginning of seed filling. In each stage, the wheat plants were treated with the growth regulator solution in the early morning through foliar application. The salicylic acid solution was prepared with warm water. During the solution spraying, the surface of the pots was covered with polyethylene plastic to prevent soil absorption. Harvesting was done after full maturity and in the form of spike cutting for each pot. The treatments were selected based on the methods and recommendations of studies by Maleki *et al*. (2007).

3.3. *Measured Traits*

3.3.1. *Seed Yield*

To determine seed yield, all spikes were harvested at the maturity stage. After weighing and drying in an oven at 75 degrees Celsius for 24 hours, the seeds were separated from the spikes. The seed yield was then calculated in grams per square meter (Modhej *et al*., 2011).

3.3.2. *Chlorophyll Index Calculation*

The chlorophyll index (SPAD value) was measured one week after the application of the growth regulator using the method of Jiriaie *et al*. (2014) with a SPAD meter, model SPAD-502, made in Japan.

3.3.3. *Proline Content Measurement*

The free proline content in the leaves during the flowering stage was measured using the method of Bates *et al*. (1973) with a spectrophotometer (Spectrophotometer), model Shimadzu UV-120-02, at a wavelength of 520 nanometers.

3.3.4. *Catalase Enzyme Activity Assay*

To assess the activity of the antioxidant enzyme catalase at the full flowering stage (Zadox stage 59), the method of Boominathan and Doran (2002) was employed using a spectrophotometer (Spectrophotometer), model Shimadzu UV-120-02, at a wavelength of 240 nanometers.

3.3.5. *Stomatal Conductance Measurement*

The measurement of stomatal conductance of the flag leaf, as an indicator, was carried out following the recommendations of Mirzadeh and Emam (2007) using a leaf porometer, model Decagon Devices INV. Version 1.06.

3.3.6. *Calculation of Seed Protein and Wet Gluten Content*

The seed protein test was conducted using the three-stage Kjeldahl method and was calculated by multiplying the Kjeldahl nitrogen value by 5.7. The wet gluten content was determined using the Iranian National Standard method number 9639-2 (Nasehi, 2015).

3.3.7. *Calculation of Remobilization Amount*

At the end of the growth period, the dry weight of the vegetative parts (the difference between the dry matter yield and seed yield) was calculated. To investigate the remobilization of dry matter, the amount and proportion of remobilization from vegetative parts and the amount and proportion of current photosynthesis were calculated using the relationships proposed by Papakosta and Gayianas (1991). The fresh weight measurements were carried out using a digital scale, and for measuring the dry weight, samples were placed in an oven at 70 C for 48 hours and then reweighed using the scale.

3.4. *Statistical Analysis*

Analysis of variance and mean comparisons were done via MSTAT-C software and LSD test at 5% probability level.

4. RESULT AND DISCUSSION

4.1. *Analysis of Variance*

In this study, the effects of growth regulators (hormones), wheat cultivars, drought stress, and the interaction effects of cultivar with drought stress and cultivar with growth regulator showed significant differences at 1% and 5% levels in all the traits studied (Table 1). The most significant differences among the factors used in this study were, in order, due to the single effects of growth regulators, drought stress, and cultivar. The least significant impact was related to the three-way interaction factor, indicating that this low impact was due to the incoherent combination of factors in this experiment, or that the response of wheat cultivars in this experiment was uniform in the presence of both other factors combined.

4.2. *Chlorophyll Index*

The results indicated that the chlorophyll index was significantly affected by end-of-season drought stress, growth regulator, and the interaction of end-of-season drought stress with the growth regulator (Table 1). The highest chlorophyll index (31.51) was obtained from the fully irrigated treatment, showing an approximately 13% increase compared to the treatment with irrigation cutoff during the seed-filling stage (Table 2). The chlorophyll index showed a positive and significant correlation with seed yield. As the chlorophyll level increased (up to a certain threshold), the plant's photosynthesis rate also increased (Table 3). The application of salicylic acid increased the chlorophyll index by about 20% compared to the control treatment. Additionally, it led to 16% improvement in index under conditions of irrigation cutoff during the seed-filling stage.

Table 1. Result analysis of variance of measured traits

S.O.V	df	Stomatal conductance	Remobilization	Seed yield	Seed protein
Growth regulator (G)	1	0.03^{ns}	8071.9**	267531**	291.7**
Variety (V)	1	0.17^{ns}	11348.2**	316450*	518.3*
V × G	1	1.75^{ns}	12.43^{ns}	282.2^{ns}	0.74^{ns}
Irrigation regime	1	2248.1*	9841.2*	409251*	631.1*
I × G	1	0.12^{ns}	50.14^{ns}	825709**	102.2**
V × I	1	0.05^{ns}	13.67^{ns}	93^{ns}	1.44^{ns}
V × I × G	1	3.14^{ns}	20.51^{ns}	109631**	0.66^{ns}
Error	24	16.08	128.40	6500.00	4.81
CV (%)	32	6.01	11.33	18.13	17.85

ns, * and **: no significant, significant at 5% and 1% of probability level, respectively.

Continue table 1.

S.O.V	df	Gluten	Catalase	Proline	Chlorophyll
Growth regulator (G)	1	7602.1**	5129.7**	267.1**	1025.3**
Variety (V)	1	634.2*	3.1^{ns}	425.2**	559.2**
V × G	1	12.2^{ns}	2.65^{ns}	0.02^{ns}	0.3^{ns}
Irrigation regime	1	7402.1*	7501.2**	603*	866.3*
I × G	1	1002.3**	6008.2**	0.031^{ns}	922.4**
V × I	1	43.7^{ns}	15.4^{ns}	198.2*	0.05^{ns}
V × I × G	1	51.27^{ns}	20.4^{ns}	0.003^{ns}	27.2^{ns}
Error	24	35.14	85.09	0.12	40.11
CV (%)	32	17.40	8.53	17.40	13.19

ns, * and **: no significant, significant at 5% and 1% of probability level, respectively.

Observations indicated reason for this improvement was the increased longevity and durability of leaves with the use of hormone, consistent with the results of Mirzadeh and Doran (2007).

4.3. *Catalase Activity*

According to the results, the impact of end-of-season drought stress, wheat varieties, and growth regulator, as well as the interaction of end-of-season drought stress with the growth regulator on catalase activity, was significant. The highest catalase activity (52.126 µmol) was observed in the treatment with irrigation cutoff during the seed-filling stage, showing an approximately 28.5% increase compared to the fully irrigated conditions (Table 2). Among wheat varieties, Chamran2 exhibited the highest catalase activity with an average of 26.109 µmol, while the lowest activity was associated with the Durum variety, although there was no statistically significant difference. The application of salicylic acid increased catalase activity (16.117 µmol) by about 24% compared to the control treatment (Table 2).

Table 2. Mean comparison effect of treatment on measured traits

Treatment	Stomatal conductance (mol $H_2O.m^{-2}.S^{-1}$)	Remobilization ($gr.m^{-2}$)	Seed yield ($kg.ha^{-1}$)	Seed protein (%)
Irrigation				
I_1	37.11a	85.24b	4903a	10.83b
I_2	31.02b	115.07a	3987b	13.73a
Variety				
V_1	35.1a	108.8a	4728a	13.9a
V_2	33.03b	91.51b	4163b	10.65b
Growth regulator				
Control	30.00b	112.01a	3800b	11.00b
Salicylic acid	38.03a	93.4b	4880a	13.98a

*Similar letters in each column show non-significant difference at 5% probability level.
I_1: Full irrigation, I_2: Cut irrigation at grain filling period, V_1: Chamran 2, V_2: Karkheh.

Continue **table 2.**

Treatment	Gluten (%)	Catalase ($Unit.mg^{-1}.protein$)	Proline ($mg.g^{-1}$ FW)	Chlorophyll (Spad)
Irrigation				
I_1	31.54a	90.63b	430.01a	82.63a
I_2	32.16a	126.52a	425.3a	71.15b
Variety				
V_1	32.10a	109.26a	442.12a	77a
V_2	32.23a	107.74a	413.18b	78.02a
Growth regulator				
Control	29.5b	89.08b	402.58b	70.53b
Salicylic acid	33.0a	117.16a	460.20a	80.87a

*Similar letters in each column show non-significant difference at 5% probability level.
I_1: Full irrigation, I_2: Cut irrigation at grain filling period, V_1: Chamran 2, V_2: Karkheh.

Furthermore, the interaction effect of end-of-season drought stress with the growth regulator showed that the highest catalase activity (01.121 µmol) was achieved under conditions of irrigation cutoff during the seed-filling stage and the application of salicylic acid. This represented an approximately 25% increase compared to the fully irrigated treatment without the application of the growth regulator (Table 1). Agarwal *et al*. (2005) suggested that catalase activity likely plays a role in maintaining peroxidase activity under severe stress. They also demonstrated that the application of salicylic acid in wheat under drought stress conditions led to a 17% increase in the activities of ascorbic peroxidase and catalase compared to the control treatment, aligning with the findings of this study.

4.4. *Proline*

The results indicated that proline was significantly affected by end-of-season drought stress, wheat varieties, the growth regulator, and the interaction of end-of-season drought stress with the growth regulator (Table 1).

Table 3. The simple correlation coefficient of the studied traits

Treatment	A	B	C	D	E	F	G	H
A	1							
B	-0.582*	1						
C	0.862**	-0.917**	1					
D	0.362ns	0.643*	0.823**	1				
E	0.313ns	0.401*	0.709**	0.918**	1			
F	0.422*	0.398ns	0.455*	0.687*	0.556*	1		
G	-0.439*	0.456*	-0.746**	-0.784**	0.802**	0.689*	1	
H	0.861**	0.211ns	0.934**	0.792**	0.635*	-0.584*	-0.733**	1

1: Stomatal conductance**, 2:** Remobilization, **3:** Seed yield, **4**: Seed protein, **5**: Gluten, **6**: Catalase, **7**: Proline, **8**: Chlorophyll.

ns, * and **: no significant, significant at 5% and 1% of probability level, respectively.

The correlation analysis of the evaluated traits revealed a significant negative correlation between leaf proline content and all the investigated traits (Table 3). The highest proline content (35.2 $mg.g^{-1}$) was obtained in the treatment with irrigation cutoff during the seed-filling stage, showing an approximately 31% increase compared to fully irrigated conditions (Table 2). Among the wheat varieties, Chamran2 and Karkheh exhibited the highest and lowest proline content, with averages of 17.2 and 8.1 $mg.g^{-1}$, respectively. The application of salicylic acid led to an increase in proline content by 37.2 $mg.g^{-1}$, representing a 5.37% increase compared to the control treatment. The results also demonstrated that drought stress significantly increased proline content in both studied varieties. Chamran2 had the highest proline content (31.2 $mg.g^{-1}$) during the seed-filling stage, while Karkheh exhibited the lowest content (5.8 $mg.g^{-1}$) under fully irrigated conditions. These findings align with the results of Anjum *et al*. (2011), indicating an increase in amino acid accumulation with improved drought tolerance in wheat varieties. It appears that the increase in proline during stress is a result of protein breakdown and a reduction in their utilization due to decreased plant growth.

4.5. *Stomatal Conductance*

The results demonstrated that the end-of-season drought stress treatment had a significant effect on the stomatal conductance of the plant, with a five percent probability level (Table 1). The fully irrigated treatment had the highest stomatal conductance, with 11.75 mol, while the drought stress treatment during the seed-filling stage had the lowest stomatal conductance, with 3.69 mol (Table 2). The trend of stomatal conductance changes indicates a reduction in stomatal conductance with the onset of water stress. Stomatal closure is one of the plant's initial responses to drought stress, and it appears to be a major reason for the decrease in photosynthesis due to water stress. Gudarzian *et al*. (2018) demonstrated that plants under non-stress conditions (control treatment) exhibit the least stomatal resistance compared to other treatments. Therefore, stomatal conductance under stress conditions is expected to be lower than in the control treatment, which aligns with the results of this study.

4.6. *Seed Protein Percentage*

The results indicated that the end-of-season drought stress treatments, wheat varieties, and growth regulator interactions had a significant effect on the seed protein percentage (Table 1).

In this study, the highest and lowest seed protein percentages, with averages of 13.73% and 10.83%, respectively, were associated with the treatments of water cessation during the seed-filling stage and complete irrigation (Table 2). Among the wheat varieties, Chamran2 had the highest seed protein percentage with an average of 13.9%, which was 24% higher than the protein percentage of the Dourm Karkheh variety. Additionally, the application of salicylic acid had an enhancing effect on the seed protein percentage (13.68%), and the lowest seed protein percentage was obtained from the control treatment (11%). Furthermore, the interaction effect of end-of-season drought stress on the growth regulator showed that the highest seed protein percentage (14.13%) was achieved under conditions of water cessation during the seed-filling stage and the application of salicylic acid. This represented an approximately 23% increase compared to complete irrigation and the absence of growth regulator application. Daniel and Triboi (2008) reported similar findings in separate experiments on corn and wheat, indicating that drought stress led to an increase in seed protein percentage compared to optimal irrigation conditions. They attributed this increase to the relative reduction in the transfer of photosynthetic materials to the seed compared to seed protein.

4.7. *Seed Yield*

In this study, it was observed that seed yield was significantly affected by end-of-season drought stress treatments, wheat varieties, growth regulator, and the interaction of end-of-season drought stress in the growth regulator, as well as the three-way interaction of end-of-season drought stress in wheat varieties in the growth regulator (Table 1). The comparison of average end-of-season drought stress conditions showed that the highest seed yield (with an average of 490.33 $g.m^{-2}$) was obtained under normal irrigation conditions until the end of the season, resulting in a 19% increase in seed yield compared to water cessation during the seed-filling stage (Table 2). Among the wheat varieties, Chamran2 had the highest seed yield, with an average of 472.8 $g.m^{-2}$, which was 12% higher than the seed yield of the Durum Karkheh variety. The application of salicylic acid had an enhancing effect on seed yield (488.01 $g.m^{-2}$), attributed to its role in protecting the photosynthetic apparatus, increasing stomatal conductance, and enhancing the activity of antioxidant enzymes (Popova *et al*., 2009). On the other hand, the lowest seed yield was obtained from the control treatment (380.02 $g.m^{-2}$). The interaction effect of irrigation on the growth regulator showed that the highest seed yield (478.18 $g.m^{-2}$) was achieved under complete irrigation conditions until the end of the season with the application of salicylic acid, resulting in approximately a 16% increase compared to water cessation during the seed-filling stage and the absence of growth regulator application. Furthermore, the three-way interaction of end-of-season drought stress treatments, growth regulator, and wheat varieties indicated that the highest seed yield (480.3 $g.m^{-2}$) was obtained under complete irrigation conditions until the end of the season with the application of salicylic acid in the Chamran2 variety. Important reasons for the reduction in plant yield during drought stress may include a decrease in translocation due to reduced water potential in the phloem, reduced leaf photosynthesis, and consequently reduced assimilate supply to growing seeds (Khatiwada *et al*., 2020), or due to the sterility of pollen seeds during stress (Mollasadeghi and Dadbakhsh, 2011). These factors, consistent with the results of this study, collectively contribute to a decrease in seed weight and yield.

4.8. *Translocation Rate*

The results demonstrated that the translocation rate of dry matter was significantly affected by end-of-season drought stress, wheat varieties, and growth regulator (Table 1). In this study, end-of-season drought stress increased the translocation rate in different parts of the plant. Therefore, the highest translocation rate (115.07 $g.m^{-2}$) was observed in the water cessation treatment during the seed-filling stage, showing an approximately 26% increase compared to the complete irrigation treatment until the end of the season (85.24 $g.m^{-2}$) (Table 2). In the absence of salicylic acid application, the highest translocation rate (112.01 $g.m^{-2}$) was recorded, while the lowest translocation rate (93.04 $g.m^{-2}$) was observed with its application. The results also indicated that Chamran2, with an average of 108.8 $g.m^{-2}$, had the highest translocation rate, showing an approximately 16% increase compared to the Durum Karkheh variety. This increase in translocation rate can be attributed to the different efficiency of wheat genotypes in terms of translocation, which is consistent with the findings of Xu *et al*. (2006). Seed yield in cereals is supplied from three sources: current photosynthesis, translocation of assimilates stored before heading to the seed and temporarily stored assimilates in the stem after heading. In this study, it appears that moisture limitation during seed filling leads to a reduction in seed yield through a decrease in current photosynthesis. Therefore, the requirement for seed filling is more likely met through the translocation of stored photosynthetic materials (Mousavi Ouri *et al*., 2011). Salicylic acid, under end-of-season moisture limitation, seems to increase current photosynthesis while relatively reducing the contribution of translocation to seeds, which is in line with the results of this study (Sajedi, 2017).

4.9. *Gluten Content of Seeds*

The results indicate that both drought stress and foliar application of salicylic acid had a significant impact on the moisture gluten content in both wheat varieties (Tables 1 and 2). Foliar application of salicylic acid led to the highest gluten content (33%) while the lowest gluten content (29.5%) was associated with the control treatment. According to previous research (Mujtaba *et al*., 2021), this increase is likely due to the elevation in seed protein content, as the relationship between protein and gluten content is positive, and gluten comprises 80-85% of wheat protein. Different wheat varieties have diverse gluten protein compositions, and wheat varieties with lower protein content may not have the necessary qualities for producing high-quality bread flour, and they tend to deteriorate very quickly (Nasehi, 2015). Therefore, maintaining or improving quality under stress conditions is crucial. It appears that salicylic acid plays a role in stimulating enzymes and increasing the formation of amino acids, the main building blocks of proteins, which positively reflects in increasing the gluten ratio. Similar to the findings of this study, Sajedi's research in 2017 also demonstrated that the application of salicylic acid, besides increasing wheat yield under drought stress conditions, resulted in the improvement of wheat seed quality, particularly the gluten content, by approximately 8.5%. In light of the recurrent droughts and the limited water resources in the country, strategies to cope with double the impact of drought on the efficiency of chemical fertilizer application and, consequently, the quantity and quality of agricultural products have become essential (Charlang Badil *et al*., 2023). One of these strategies involves the application of the plant growth regulator salicylic acid, which, as demonstrated by the results obtained in this study, actively participates in the defense mechanisms of plants under both living and non-living stress conditions, preserving vital plant processes, including water and nutrient absorption, ion transport, and photosynthesis (Mujtaba *et al*., 2021; Azmat *et al*., 2020). The growth regulator contributed to the improvement of both quantitative and qualitative aspects of seed yield under full irrigation and end-of-season drought conditions. In scenarios of water scarcity due to irrigation cut-off, salicylic acid application enhanced seed yield by improving stomatal conductance and photosynthesis in wheat varieties. The highest seed yield (3.480 $g.m^{-2}$) was achieved under complete irrigation until the end of the season with the application of salicylic acid in the Chaman 2 cultivar. This represented an approximately 15% increase compared to the treatment with irrigation cut-off during the seed filling stage and the non-application of the growth regulator in the Karkeh cultivar. End-of-season drought stress generally increased respiratory intensity, reduced material absorption, and, consequently, led to a relative decrease in stored carbon hydrates. As a result, higher protein content was observed. The impact of the growth regulator on the qualitative traits of wheat was also significant, with the highest percentages of protein and gluten in seeds resulting from salicylic acid application, and the lowest from the control treatment. This research revealed a meaningful effect of end-of-season drought stress on the physiological traits of wheat. Irrigation cut-off during the seed filling stage led to a significant increase in catalase enzyme activity, proline amino acid, and a decrease in chlorophyll index and stomatal conductance. However, the application of salicylic acid, while regulating the performance of these traits, had a beneficial effect on their impact on seed quantity and quality. The use of salicylic acid can mitigate the adverse effects of drought stress and enhance growth and yield under favorable conditions, reducing declines in stressful conditions. Therefore, the application of salicylic acid as a growth regulator in the Chaman 2 cultivar is recommended. It is suggested that under drought stress conditions, to preserve agricultural soil, chemical fertilizers be used sparingly, and the efficacy of salicylic acid be increased by substituting half of the chemical fertilizers with organic fertilizers (Charlang Badil *et al*., 2023). Additionally, for further improvement in wheat seed quality, the concurrent use of salicylic acid and amino acid compounds such as tryptophan is recommended (Mujtaba *et al*., 2021).

5. CONCLUSION

The findings of this study suggest that salicylic acid application can mitigate the adverse effects of drought stress and enhance growth and yield under favorable conditions while reducing decline under stress conditions. Therefore, the use of salicylic acid as a growth regulator is recommended in the Chamran 2 variety.

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FOOTNOTES

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