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SALICYLIC ACID PROMOTES SUNFLOWER PRODUCTION UNDER NORMAL AND WATER DEFICIT CONDITIONS

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Abstract

Water insufficiency affects agriculture productivity and quality of crops. Applying antioxidants such as salicylic acid (SA) can enhance plant resistivity against drought stress. The current experiment was performed to check the concentration and mode of application of salicylic acid (S.A) under normal and drought stress. A completely randomized design (CRD) with factorial arrangement, one factor being the moisture condition (i.e., normal and drought) and the second one being the application method (foliar spray and seed soaking) was used. The treatments included T1 (control), T2-T4 (0.5mM, 1.0mM, and 1.5mM SA by foliar spray) respectively, and T5-T7 (0.5mM, 1.0mM, and 1.5mM SA by seed soaking), respectively). Under the normal irrigation i.e., at 75% of Water Holding Capacity (WHC), T4 had the highest percentage increase in plant height (56.28%), head diameter (45.65%), shoot fresh weight (56.30%), shoot dry weight (164.94%), root fresh weight (184.66%), root dry weight (159.42%), No. of achene/plant (35.74%), thousand grain weight (65.03%) and seed yield/plant (124.15%), NPK concentration (125%, 61.30% and 28.41%), proline contents (59.18%), chlorophyll contents (41.25%) and oil contents (34.88%) compared to T1. Under the drought (40%WHC), T4 performed better and increased plant height (55.67%), head diameter (44.26%), shoot fresh weight (114.87%), shoot dry weight (179.38%), root fresh weight (134.27%), root dry weight (133.90%, No. of achene/plant (20.49%), thousand grain weight (62.58%) and seed yield/plant (96.02%), NPK concentration (221.30%, 78.16% and 11.91%), proline contents (55.43%), chlorophyll contents (43.68%) and oil contents% (35.04%) compared to T1. The electrolyte leakage (EL%) was reduced by 47.18% at 75WHC and 50.41% at 40%WHC. The results predicted that the application of SA at the 1.5mM(T4) concentration in both moisture conditions and drought showed better performance. The agronomic and biochemical parameters were enhanced by foliar application of SA except the electrolyte leakage which reduces significantly by SA foliar spray. Similarly, the macronutrients (NPK) were enhanced by the foliar application of S.A at 1.5mM dose. Therefore, the foliar application of adequate quantity of SA could be a better strategy to cope with water stress in dry areas where rainfall in low.

Key words: Antioxidants, Oil seed crop, Drought, Nutritional status, Growth, Yield components, Physiological properties.

Introduction

Water scarcity threatens agricultural production sustainability (Hussain *et al*., 2008). Adequate soil growth conditions like satisfactory supply of water as well as nutrient, are necessroy for crop growth potential and yield production(Dar *et al*., 2021). At all staeges of growth water is important for plant metabolism. So, one of the main reasons lowering agricultural productivity is water stress. (Askari-Khorasgani *et al*., 2021; Ilyas *et al*., 2021). Water stress diminishes yield through affecting protein and nucleic acid synthesis, respiration and photosynthesis (Hussain *et al*., 2014; Ibrahim and Samiullah, 2010). Previously, it is fact that drought stress reduces the yield of sunflowers (El-Din, 2015).

Water shortage is limiting abiotic factor worldwide, and reduce crop production. Unpredicted global climate with irregular rainfall patterns is among one of the reason for frequentdrought stress globally(Lobell *et al*., 2011). Economic losses from droughts were estimated at nearly $29 billion from 2005 -2015, and are predicted to be more in the future (Trenberth *et al*., 2014). By 2050, nearly 50 percent of arable land is cosideredwater deficit (Kasim *et al*., 2013). Plants generally cope with drought stress through numerousphysiological, morphological, molecular characteristics and biochemical mechanisms. However, impact of stress differs with species, developmental stages, and other abiotic factors (Demirevska *et al*., 2009).

In semi arid regions, sunflower is a considered as drought resistance crop. Sunflower is seen as a promising oilseed and drought resistance crop in dry climatic conditions (Garca-Vila & Fereres, 2012) because of the existence of a compliated branching root structure that allows the plants to easily obtain water under drought stress(Keipp *et al*., 2020).Yet, very dry circumstances have a significantly impact the early blooming and anthesis phases, potentially reducing seed output by up to 80% (Hussain *et al*., 2016; Pekcan *et al*., 2015). Previous researches describedthat sunflower production reduces as there is an increse in drought stress level (Erdem *et al*., 2006; Manivannan *et al*., 2007; Nezami *et al*., 2008; Saudy *et al*., 2020; Siddique *et al*., 2020). Its productivity is regulated by avaliability of water and theproduction reduction in observed when a water deficiency is present. (Yawson *et al*., 2011).

Plants utilise several processes to alleviatewater stress. (Khoyerdi *et al*., 2016). Plants osmotic adaptations, sythesis of biochemical compounds and depostion of low molecular weight organic molecules are critical to preserving osmotic potential during dry circumstances (Chaves *et al*., 2003). It appears that the production and storage of osmolytes like proline contents, sucrose, carbohydratesand phenolic chemicals in the cytoplasm and vacuole plays positiverole to stabilize thecell membrane structure (Molaei *et al*., 2012). Various studies have found that osmotic adjustments improve under stress circumstances such as drought and salinity (Khoyerdi *et al*., 2016; Marcińska *et al*., 2013; Osama *et al*., 2019; Estaji *et al*., 2019; Estaji *et al*., 2018). This increase improves resistance to harsh circumstances among plants. The salicylic acid is classified as a phenolic regulator of growth.It plays apivotal function in the regulation of growth of plant and development (Szepesi, 2008). Salicylic acid is a powerful signalling molecule in plant that aids defence by modulating physiological characters and biochemical attributes. (Gunes *et al*., 2007; Nazar *et al*., 2011). The findings of previous researches has also demonstrated that using SA enhanced plant tolerance to salt stress(Khan *et al*., 2014; Nazar *et al*., 2015)and drought tensions (Hussein *et al*., 2007; Yazdanpanah *et al*., 2011). Noreen *et al*., (2010) discovered that applying SA lowers the negative stress impacts and increases the quantity of oil percentage in seed.

According to Khalili *et al*., (2009), SA treatment may increase antioxidant activity and secondary metabolite buildup. Furthermore, plants that are treated with salicylic acid appeared to be more drouhgttolerant (Al-Hakimi & Hamada, 2001). According to Nazar *et al*., (2015), Salicylic acid treatment boosted water stress tolerance via increasing proline buildup and decreasing the formation of 1-aminocyclopropane carboxylic acid. Brito *et al*., (2019) proposed that applying appropriate SA concentrations is an effective technique for improving homeostasis in cells and growth in plants directed to recurring drought spells.In the current experiment,it was hypothosized that the useof SA helps in the alleviation of drought impactson sunflower growth and development.

Material and Methods

Experimental site/location: A pot experiment was performed in greenhouse conditions at the experimental area of the "Department of Soil Science, Bahauddin Zakariya University", Multan, Pakistan. Thestudy was accompanied to check the impacts of dose and application method of salicylic acid (SA) in mitigating water stress associated damages with sunflowersunder both normal and drought moisture conditions respectively.

Seed sowing and pot preparation: The sunflower (Hysun 33) seeds were treatedwith 1 percent of sodium hypochlorite (NaOCl) for tenminutesthen washed with distilled water prior to sown. Khazaei *et al*., *(*2020) Then seeds were sown in pots filled with 2mm sieved soil of capacity 10kg. Five seeds were placed in each pot, and following full germination, the number of plants were thinned down to one healthy plant per pot.

Irrigation and fertilizer application: A calculation was made and each treatment, including T1 (control), received the recommended dose of nitrogen, phosphorus, and potassium (200: 80: 80 kg ha^{-1}) for optimum soil fertility. By maintaining the weight of each pot at that determined for normal irrigation (75% FC) and drought (40% FC) everyday by the adding of water as necessary, the moisture contents of normal irrigated and drought pots were kept and constantly monitored.

Treatment plan: The experiment was planned into Complete Randomized Block (CRD) two-factorial design. One factor was the application of S.A. by two different modes of application (i.e., foliar sprayatthe stage of vegetation, flowering, andseed soaking at the time of sowing) and the other factor was moisture condition at two levels i.e., 40% WHC and 75% WHC. Water stress were maintained on a pot-plus-soil weight basis in the pots. The three concentrations of S.A were used for foliar as well as for seed soaking method with a control i.e., T1 (control), T2 (0.5mM foliar application), T3 (1.0 mM foliar application), T4 (1.5mM foliar application), T5 (0.5mM seed soaking), T6 (1.0mM seed soaking) and T7 (1.5mM seed soaking).

Plant analysis: In this experiment, 21 sunflower plants were harvested at 85% maturity. Leaf samples were replicated thrice. The fresh sample was then subjected to a laboratory and was analyzed for the determination of biochemical characteristics and other fresh plant analyses. Data for agronomic characteristics like root and shoot fresh weights (gm), plant height, etc. were recorded, and a fresh sample was preserved for further analysis. The dry weights of the roots, shoots, achenes, and thousand achenes were then computed after the plants had been dried for three days in an oven at 60°C.

Table 1. Soil attributes of the experimental area.

Parameter	Unit	Value
pH	—	8.42
$CaCO_3$	%	6.72
Electrical conductivity (EC)	dSm^{-1}	1.35
Organic matter	%	0.63
Nitrogen	$mgKg^{-1}$	0.05
Phosphorous	$mgKg^{-1}$	6.32
Extractable potassium	$mgKg^{-1}$	112
Texture	—	Silt loam

Determination of macronutrient: For the determination of nitrogen, phosphorous, and potassium in plant samples the procedure mentioned at ICARDA manual 3rd edition were followed (Ryan *et al*., 2001).

Electrolyte leakage: To assess plant electrolyte leakage (EL), leaves were incubated in distilled water at 23°C for 24 hours while kept in the dark. The samples were then vortexed, and an electrical conductivity meter was used to determine the initial electrical conductivity. After that, the samples underwent a 15-minute autoclave at 60°C. The samples' final conductivity was assessed after cooling at ambient temperature. The equation below was used to determine electrolyte leakage (Lutts *et al*., 1996).

$$(EL\ \%) = \frac{\text{Initail electrical conductivity}}{\text{Final electrical conductivity}} \times 100$$

Proline concentration: Proline was determined by extracting 0.1g of fresh tissue sample in 5 mL of sulfosalicylic acid (3%) and centrifuging the solution for 15 minutes. After that, a one milliliter aliquot was taken and placed in a test tube with a mixture of 1 mL of acidic ninhydrin and one milliliter of glacial acetic acid. Then, it was cooked for 10 minutes at 100°C, instantly chilled in an ice bath, vortexed for 20 seconds, and allowed to cool to 25°C temperature. The absorption at 520nm were recorded by using spectrophotometer (Bates *et al*., 1973).

$$\text{Proline } g^{-1} \text{ fresh wt. } (\mu mol) = \mu g \text{ proline } mL^{-1} \times mL \text{ of toluene}/115.5/\text{sample wt. (g)}$$

Statistical Analysis

Experimental data was analyzed statistically by using a twofactorialanalysis of variance (ANOVA) (Steel *et al*., 1997). Differencesin treatment mean were analyzed by the least significance difference (LSD) test using statistical software Statistix 8.1and Origin pro-2022 were used for correlation matrix.

Results

Agronomic Attributes: The experimental site soil was alkaline, silty loam, and had low organic matter (Table 1). It has been noted that among all treatments the salicylic acid application at the rate of 1.5 mM (T4) showed a significant increase in all observed growth parameters and concerning drought conditions, all treatments performed well in normal irrigation.

The data regarding the plant height was found statistically significant ($p \leq 0.05$) under the different moisture regimes and applied treatments. Under the normal irrigation where foliar application of SA was applied, the T2 showed an increase of 15.40% followed by 24.53%, 56.28% at T3 and T4 respectively. However, the plant height was also increased by the seed soaking methods but was lower than the foliar spray. The 2.52%, 9.39% and 7.93% increase in the plant height was observed at T5, T6 and T7 treatments respectively as compared to control (T1). Under the drought, the increase in plant height observed from T2 to T4 where foliar application done was 10.93%, 24.99% and 55.67% respectively whereas the seed soaking methods i.e., T5, T6 and T7 the increase was 24.90%, 23.31% and 4.09% respectively (Table 2). The head diameter increased 14.52%, 26.24%, 45.65%, 8.18%, 23.85% at T2, T3, T4, T5 and T6 respectively but the at the T7 the 3.24% reduction was found under the normal irrigation. Similarly, under the drought, 10.53%, 21.07%,44.26%, 13.44%, 19.29% and 11.30% increase was observed from T2 to T7 as compared with the control. The highest values regarding the head diameter were observed by the application of foliar spray of SA under both irrigation conditions (Table 2). Under the normal irrigation, the shoot fresh weight showed an increase of 16.50% at T2 followed by 47.72%, 56.30%, 12.26%, and 13.21% at T3, T4, T6, and T7 respectively expect T5 where 3.11% decrease in shoot fresh weight was observed. Under the drought, the treatments from T2 to T7 showed an increase of 44.67%, 73.31%, 114.87%, 24.91%, 48.91% and 17.97% respectively as compared with the control (T1) (Table 2). Similar findings were obtained for shoot dry weight where under the normal irrigation conditions, the 61.90% increase in the shoot dry weight was recorded at T2 followed by 99.13%, 164.94%, 18.18%, 65.80% and 26.37% at T3 to T7 respectively. Under the drought, the T2 to T7 showed 105%, 143.75%, 179.38%, 13.75%, 98.135 and 17.48% respectively as compared with the control (Table 2). The root fresh weight under the normal irrigation showed an increase of 70.35%, 104.81%, 184.66%, 26.14%, 74.90% and 15.17% from T2 to T7 respectively as compared with control. Under the drought, 65.98% increase was observed at T2 followed by 85.68%, 134.27%, 9.59%, 39.77% and 66.70% at T3 to T7 respectively (Table 2). The data regarding the root dry weight under normal irrigation showed an increase of 120.89% at T2 followed by 131.51%, 159.42%, 102.74%, 118.66% and 7.75% at T3 to T7 respectively. Under the drought, the 113.63% increase in root dry weight was recorded at T2 whereas the T3, T4, T5, T6 and T7 showed 116.68%, 133.90%,96.41%, 121.52% and 1.54% respectively (Table 2). The number of achenes showed an increase by the application of SA treatments. Among the applied treatments, under the normal irrigation, 5.32% increase was observed at T2 followed by 23.14%, 35.7%, 4.91% and 6.15% at T3 to T6 respectively except T7 where reduction of 0.10% was observed. Under the drought, the 5.04%, 11.20%, 20.49%, 3.70%, 6.16% and 6.22% increase was observed from T2 to T7 respectively as compared with the control (T1) (Table 2). Under the normal irrigation, the thousand grain weight showed an increase of 42.06%, 52.68%, 65.03%, 9.98%, 21.58% and 9.56% at T2 to T7 respectively whereas under the drought, T2 to T7 showed increase of 39.35%, 49.78%, 62.58%, 10.41%, 12.40% and 11.59% respectively (Table 2). Data regarding the seed yield/plant showed increase by applying SA to the crop. Under the normal irrigation, 49.67% increase was recorded at T2 followed by 88.07%, 124.15%, 12.32%, 29.05% and 9.56% at T3 to T7 respectively. Under the drought, the T2 to T7 showed 46.53%, 66.55%, 96.02%, 14.56%, 19.49% and 18.43% respectively as compared with the control (T1) (Table 2).

Nutrient concentration in leaves: Like the above parameters, the seed soaking showed lower values of NPK when compared to the same rate of salicylic acid applied with the foliar method regardless of the moisture conditions. The nitrogen, phosphorus, and potassium (NPK) concentrations in the plant were also changed with the salicylic application (Table 3). Overall, concerning the control, the contents of NPK in plants significantly increased with increasing the rates of salicylic application either with foliar or seed soaking method in drought and normal moisture levels. The significantly highest contents of NPK in soil were observed at the rate of 1.5 mM of salicylic (T4), as compared to control (T1), when applied with foliar and seek soaking method in drought and normal moisture levels. Among the macro nutrients (NPK), under the normal irrigation, the N was increased 47.41% at T2 followed by 87.97%, 125%, 35.89%, 60.68% and 19.11% at T3 to T7 respectively. Under the drought, the T2 to T7 showed 91.22%, 195.28%, 221.30%, 45.53%, 145.85% and 10.25% respectively. Similarly, the P concentrations in the plant showed an increase of 17.20%, 48.40%, 61.30%, 6.16%, 10.86% and 10.24% from T2 to T7 under the normal irrigation while under the drought, the T2 to T4 showed 24.89%, 53.16%, 78.16% respectively. The T5 showed a decrease of 4.95% whereas T6 and T7 showed 27.47% and 13.63% respectively as compared with the control. The K increased 10.20% at T2 followed by 20.75%, 28.41%, 4.99%, 10.84% and 5.86% at T3 to T7 respectively under the normal irrigation. Under the drought, the increase of 7.51%, 12.63%, 11.91%, 0.89%, 1% and 10.08% in the K concentration was observed at T2 to T7 respectively as compared with the control (Table 3).

Table 2. Effect of salicylic acid on growth parameter of Sunflower under normal and drought moisture conditions.

Methods of application	Treatments	Moisture conditions	Plant height (cm)	Head diameter (cm)	Shoot Fresh wt. (g)	Shoot dry wt. (g)	Root fresh wt.t (g)	Root dry wt. (g)	No. of achenes per head	1000 achene wt. (g)	Yield (g) plant^{-1}
Control	T1		68.73^{e}	9.14^{d}	6.378^{e}	0.33^{d}	1.30^{d}	0.093^{e}	310.17^{d}	29.98^{g}	9.308 ^{f}
Foliar spray	T2		77.85^{d}	10.29^{c}	8.12^{d}	0.59^{c}	2.18^{c}	0.206^{c}	326.25^{c}	42.20^{c}	13.797^{c}
	T3		85.75^{b}	11.31^{b}	10.04^{b}	0.71$_{b}$	2.53^{b}	0.213^{bc}	364.17^{b}	45.36^{b}	16.581^{b}
	T4		107.21^{a}	13.25^{a}	11.39^{a}	0.88$_{a}$	3.35^{a}	0.235^{a}	398.33^{a}	49.12^{a}	19.65 ^{a}
Seed soaking	T5		77.85^{d}	10.12^{c}	6.86^{e}	0.38$_{d}$	1.53^{d}	0.190^{d}	323.58^{cd}	32.57^{f}	10.551^{e}
	T6		79.78^{cd}	11.12^{b}	8.05^{d}	0.58$_{c}$	2.04^{c}	0.210^{c}	329.25^{c}	35.12^{e}	11.601^{d}
	T7		84.55^{bc}	11.52^{b}	9.29^{c}	0.71$_{b}$	2.81^{b}	0.220^{b}	338.92^{c}	38.81^{d}	13.166^{c}
	LSD <0.05		**5.04**	**0.40**	**0.57**	**0.06**	**0.29**	**8.1e-03**	**15.55**	**0.93**	**0.77**
		Normal	84.31^{a}	11.34^{a}	9.66^{a}	0.67^{a}	2.31^{a}	0.204^{a}	360.14^{a}	40.88^{a}	14.948^{a}
		Drought	81.89^{a}	10.58^{b}	7.52^{b}	0.52^{b}	2.18^{a}	0.187^{b}	322.90^{b}	37.17^{b}	12.097^{b}
	LSD<0.05		**2.69**	**0.22**	**0.31**	**0.03**	**0.15**	**4.31e-03**	**8.31**	**0.50**	**0.42**
Control	T1	Normal	71.43^{ef}	9.47^{j}	7.89^{d-f}	0.39^{gh}	1.29^{h}	0.097^{h}	331.00^{d-f}	31.05^{h}	10.016^{h}
		Drought	66.03^{f}	8.81^{kb}	4.87^{i}	0.27^{i}	1.31^{h}	0.090^{h}	297.67^{h}	28.9^{1i}	8.600 ^{i}
Foliar spray	T2	Normal	82.44^{cd}	10.85^{ef}	9.19^{c}	0.63^{cd}	2.18^{d-f}	0.217^{cd}	339.83^{cd}	44.11^{c}	14.992^{d}
		Drought	73.25^{e}	9.73^{ij}	7.04^{g}	0.55^{de}	2.17^{ef}	0.197^{f}	312.6^{f-h}	40.29^{d}	12.601^{e}
	T3	Normal	88.96^{c}	11.96^{c}	11.65^{a}	0.77^{b}	2.63^{c}	0.223^{bc}	397.33^{b}	47.41^{b}	18.838^{b}
		Drought	82.53^{cd}	10.66^{fg}	8.43^{c-e}	0.65^{c}	2.42^{c-e}	0.203^{ef}	331.0^{d-f}	43.30^{c}	14.323^{d}
	T4	Normal	111.64^{a}	13.80^{a}	12.33^{a}	1.02^{a}	3.65^{a}	0.253^{a}	438.00 ^{a}	51.24^{a}	22.451^{a}
		Drought	102.79^{b}	12.70^{b}	10.45^{b}	0.75^{b}	3.06^{b}	0.217^{cd}	358.67^{c}	47.00^{b}	16.858^{c}
Seed soaking	T5	Normal	73.23^{e}	10.25^{g-i}	7.65^{e-g}	0.46^{fg}	1.62^{gh}	0.197^{f}	338.50^{cd}	33.22^{g}	11.250^{fg}
		Drought	82.47^{cd}	9.99^{h-j}	6.08^{h}	0.31^{hi}	1.43^{gh}	0.183^{g}	312.7^{f-h}	31.92^{gh}	9.852^{h}
	T6	Normal	78.15^{de}	11.73^{cd}	8.85^{c}	0.64^{c}	2.24^{c-e}	0.21^{c-e}	342.50^{cd}	37.75^{e}	12.926^{e}
		Drought	81.42^{d}	10.50^{f-h}	7.24^{fg}	0.52^{ef}	1.83^{fg}	0.21^{d-f}	316.0^{e-h}	32.49^{g}	10.276^{gh}
	T7	Normal	84.34^{cd}	11.35^{de}	10.02^{b}	0.81^{b}	2.58^{cd}	0.230^{b}	342.17^{cd}	41.36^{d}	14.162^{d}
		Drought	84.75^{cd}	11.69^{cd}	8.55^{cd}	0.61^{cd}	3.04^{b}	0.210^{de}	335.67^{de}	36.26^{f}	12.170^{ef}
	LSD<0.05		**7.12**	**0.57**	**0.81**	**0.09**	**0.40**	**0.011**	**21.10**	**1.31**	**1.10**

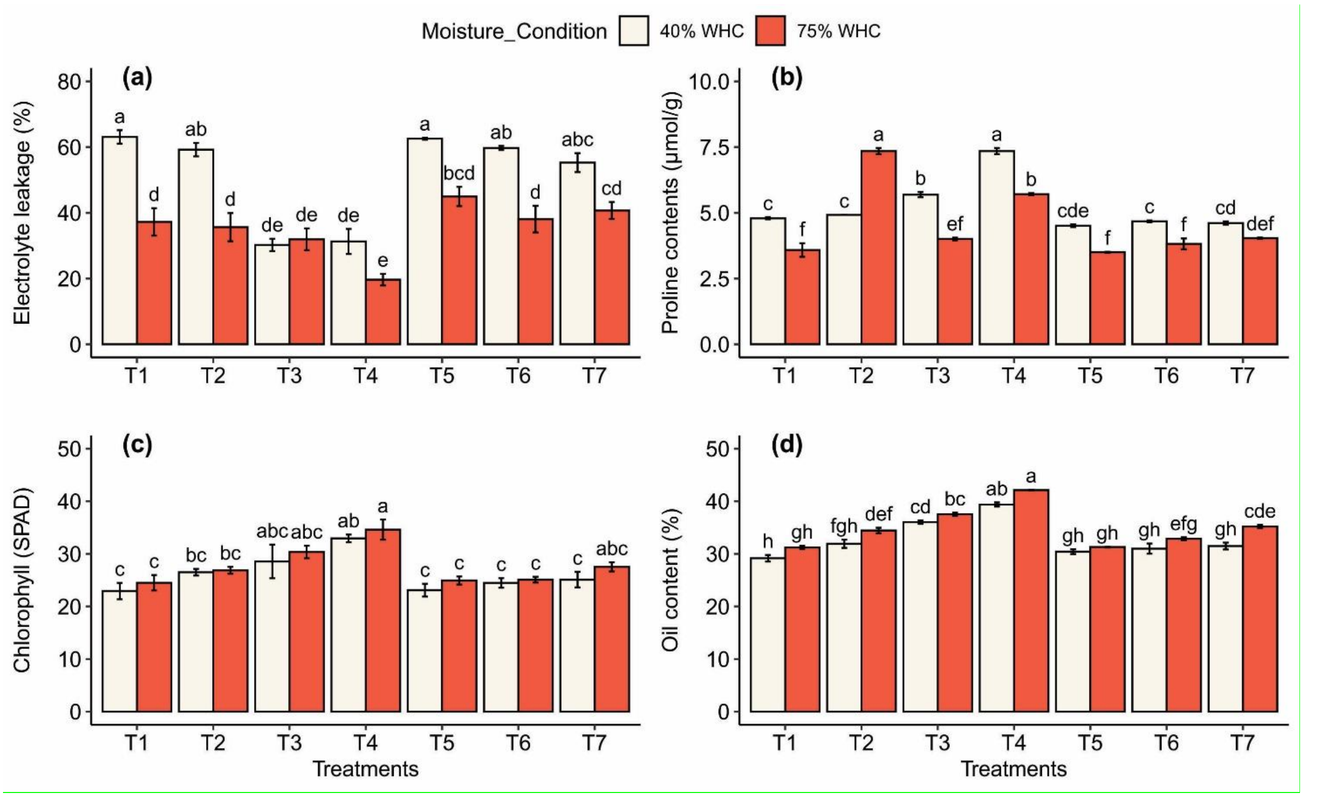

Fig. 1. Effect of salicylic acid electrolyte leakage (a), proline contents (b), chlorophyll (c) and oil content (d) of Sunflower under normal and drought moisture conditions.

Biochemical characteristics: The biochemical attributes showed significant differences by the application of SA treatments under different moisture conditions. The electrolyte leakage % reduced by the foliar spray of SA from T2 to T4 where the reduction was 4.32%, 14.21% and 47.18% respectively under the normal irrigation. However, the seed soaking application from T5 to T6 did not prove better as compared to foliar SA application as the increase of 20.74%, 2.25% and 6.91% in the EL% was observed at T5, T6 and T7 respectively as compared with control. Under the drought conditions, a reduction of 6.12%, 52.09%, 50.41%, 0.82%, 5.35% and 7.43% were found at T2 to T7 respectively when compared to control (T1) (Fig. 1). Similarly, the proline content was improved by the foliar spray of SA. Under the normal irrigation, the 104.93% increase was observed at T2 followed by 11.67% and 59.18% at T3 and T4 respectively while the T 5 showed reduction of 2.46% and T6 and T7 showed an increase of 6.51% and 5.63% respectively. Under the drought, the foliar application of SA from T2 to T4 showed an increase of 2.75%, 18.83% and 53.43% respectively. However, the seed soaking method did not prove better, the treatments included seed soaking methods i.e., T6 to T7 showed decrease of 5.81%, 2.37% and 1.46% respectively (Fig. 1). The statistical analysis showed that the chlorophyll contents were improved by the application of SA in both methods of application. Under the normal irrigation, the T2 showed an increase of 9.68% followed by 23.91%, 41.25%, 1.75%, 2.42% and 9.71% from T3 to T7 respectively as compared to control. Under the drought conditions, the alike results were obtained where the T2 showed 15.66% increase followed by 24.62%, 43.68%, 0.76%, 6.78% and 2.59% from T3 to T6 respectively (Fig. 1). Like the yield of the crop, the oil content is also important. The statistical analysis of the current experiment also suggests that the oil content % was improved by the application of SA under different methods of application and different moisture conditions. However, the results of foliar SA spray were highest as compared to the seed soaking application of SA. Among the applied treatments, under the normal irrigation, the 10.25%, 20.12%, 34.88%, 0.18%, 5.27% and 7.03% increase in oil content was observed from T2 to T7 respectively. Under the drought conditions, T2 to T7 showed an increase of 9.42%, 23.50%, 35.04%, 4.29%, 6.25% and 1.61% respectively when compared to control (T1) (Fig. 1).

Pearson correlation: Results of Pearson correlation coefficient (r) among the agronomic, nutritional, and biochemical attributes of sunflower under normal and drought moisture conditions were summarized in (Fig. 2). All these attributes are positively associated with each other under both moisture regimes except electrolyte leakage which is negatively correlative with the other parameter. The most important analysed variable, thousand achenes weight and oil content of the plant showed that it is significantly ($p=0.05, 0.01$) and positively correlated to all parameters except electrolyte leakage percentage which has a significant ($p=0.05,0.01$). Except for electrolyte leakage percentage, all observed parameters of this research were positively and significantly ($p=0.01$) correlated to each other. The electrolyte leakage has a negative and significant correlation with all other parameters.

Table 3. Effect of Salicylic acid on nutrients concentration in plants under normal and drought moisture conditions.

Methods of application	Treatments	Moisture conditions	N	P	K
			%		
Control	T1		1.32 ^{f}	0.35^{e}	2.94^{d}
Foliar spray	T2		2.17^{d}	0.42^{d}	3.20$^{b\text{-}d}$
	T3		3.03^{b}	0.52^{b}	3.43^{ab}
	T4		3.46^{a}	0.59^{a}	3.52^{a}
Seed soaking	T5		1.84^{e}	0.35^{e}	3.02^{d}
	T6		2.55^{c}	0.41^{d}	3.11^{cd}
	T7		2.93^{b}	0.46^{c}	3.36$^{a\text{-}c}$
LSD<0.05			**0.15**	**0.03**	**0.27**
		Normal	2.64^{a}	0.47^{a}	3.26^{a}
		Drought	2.30^{b}	0.42^{b}	3.19^{a}
LSD<0.05			**0.08**	**0.01**	**0.14**
Control	T1	Normal	1.61^{i}	0.38^{g}	2.88^{e}
		Drought	1.03^{j}	0.32^{h}	2.99^{de}
Foliar spray	T2	Normal	2.37^{fg}	0.44^{de}	3.17$^{b\text{-}e}$
		Drought	1.96^{h}	0.40^{fg}	3.22$^{b\text{-}e}$
	T3	Normal	3.02^{c}	0.56^{b}	3.48^{ab}
		Drought	3.03^{c}	0.49^{c}	3.38$^{a\text{-}c}$
	T4	Normal	3.62^{a}	0.61^{a}	3.69^{a}
		Drought	3.30^{b}	0.56^{b}	3.35$^{a\text{-}d}$
Seed soaking	T5	Normal	2.19^{g}	0.40^{fg}	3.02$^{c\text{-}e}$
		Drought	1.50^{i}	0.30^{h}	3.02$^{c\text{-}e}$
	T6	Normal	2.58^{de}	0.42^{ef}	3.19$^{b\text{-}e}$
		Drought	2.52^{ef}	0.40$^{e\text{-}g}$	3.03$^{c\text{-}e}$
	T7	Normal	3.08^{c}	0.46^{cd}	3.38$^{a\text{-}c}$
		Drought	2.78^{d}	0.46 ^{cd}	3.33$^{a\text{-}d}$
LSD<0.05			**0.21**	**0.04**	**0.38**

The significant difference in the mean value of each treatment group is indicated by different lowercase letters based on the LSD test ($p<0.05$). T1 (control), T2 (0.5mM foliar application), T3 (1.0 mM foliar application), T4 (1.5mM foliar application), T5 (0.5mM seed soaking), T6 (1.0mM seed soaking) and T7 (1.5mM seed soaking)

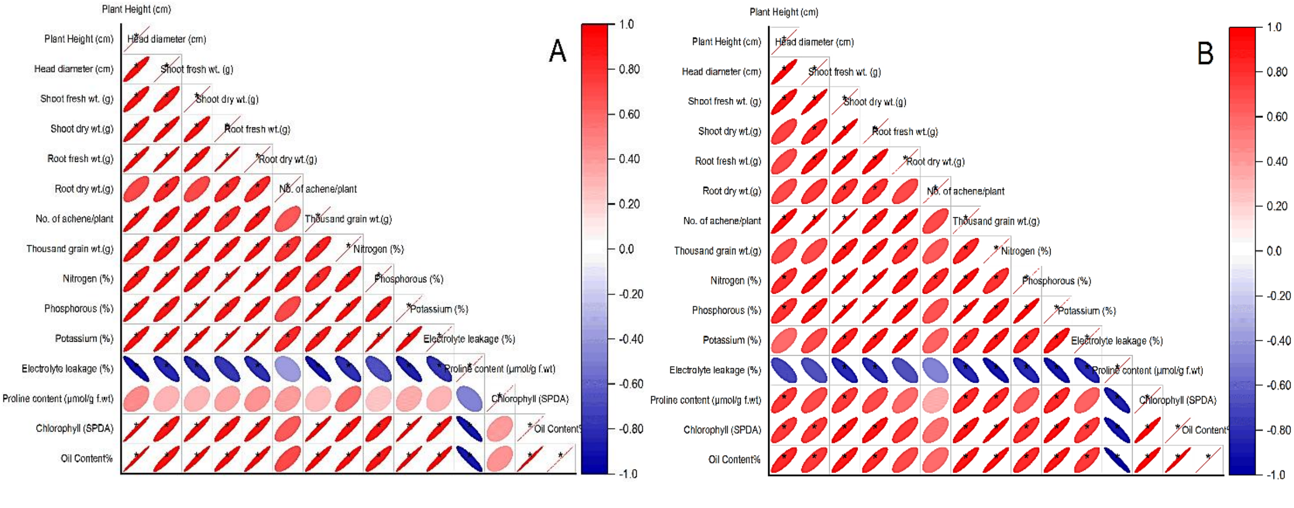

Fig. 2. Pearson correlation for sunflower growth, nutritional and biochemical attributes affected by different application rates of SA under normal and drought moisture conditions. (A= Normal, B= Drought).

Discussion

Sunflower is an important crop, especially for their use as edible oil. The proper moisture conditions are necessary for its growth and development as many other crops need. The water deficiency limits the productivity of crop as well as its growth. According to the study's findings, S.A. application significantly and favorably affected growth parameters including plant height, shoot and root fresh and dry weight, thousand achenes weight, etc. When S.A at 1.5mM (T4) was used as foliar treatments, these components performed better than the control. The current study results showed a significant negative relation among growth and yield parameters and water stress. The results are found in combination with the previous research that reported that water stress reduces plant growth. It has been reported that deficient water causes a significant decrease in the vital parameters of sunflower, safflower as well as sesame crop (Ebrahimian *et al*., 2019) and decreases their growth and production. While foliar spray of salicylic acid application increases growth variables like height, weight of dry shoot/root, diameter of the head, etc. It is observed that the foliar application of SA gradually decreasesthe harmful effects of drought stress. Previous investigation also showed that SA improves the safflower, *Ammi visnaga* L. and *Egletesviscosa* L. growth under water stress (Shaki*et al*., 2018; Osama *et al*., 2019; Batista *et al*., 2019).

Hussain *et al*., (2008) found that applying SA to sunflower plants increased their growth and yield under water-stressed situations. Water scarcity affects turgor pressure (Khoyerdi *et al*., 2016), which modifies physiological and morphological characteristics and decreasesplant development (Selvakumar *et al*., 2012). Salicylic acid favorable effects on growth may influence both physiological and metabolic systems. According to previous investigations the SA can boost development of roots under water stress, prevent cytokinin and auxin from reducing, also affects cell extension and cell differentiation and uptake of ion (Shakirova *et al*., 2003; Miura *et al*., 2010; Batista *et al*., 2019; Brito *et al*., 2019). Our findings suggest that SA's growth-promoting properties may be conditioned by enhanced water relationships and osmolytes buildup, for example proline, which mitigate the detrimental impacts of water decline. As discussed in Figure 1, a significant (p<0.01 & 0.05) and positive correlation was foundamong plant growth attributes and yield attributes. According to Hoekstra *et al*., (2001), the accumulation of osmotic adaptations has a substantial association with drought stress tolerance. According to Loutfy *et al*., (2012), SA treatment increased the resilience of certain molecules in stress circumstances that promote plant development. Proline is an osmotic adjustment that helps plants maintain their osmotic potential under water deficiency situations (Li *et al*., 2014). Khan *et al*., (2015) emphasised proline's advantageous role in controlling turgor pressure during drought stress without interfering with other metabolic processes.In this situation, boosting the activity of the enzymes responsible for producing defensive proteins to cope with stress may cause a buildup of proline contents in plants (Khedr *et al*., 2003). Proline content production serves as an energy source to control redox potential. (Hong-Bo *et al*., 2006). Khedr *et al*., (2003) claim that proline content lessens the free radical impact on plant. Ourstudy results indicated that proline concentration was increased under water deficiency (Fig. 1). These findings contrast with those of Li *et al*., (2014), who discovered that using SA lessens the negative impact of water stress by raising proline content. SA treatment may also increase proline content biosynthesis by boosting ABA and stress protein synthesis (Pál *et al*., 2018). Previously it was noted that application of 0.5 and 1mM concentration can activate proline content biosynthesis enzymes (Khan *et al*., 2015). El-Tayeb & Ahmed (2010), as well as Ghafiyehsanj *et al*., (2013), reported an increase in proline contents because of the salicylic acid, which is in line with our investigations. Kordi *et al*., (2013) found that the 1.5mM SA concentraion to plants under drought stress had the greatest proline level in their leaves. As for as the plant nutritional uptake is concerned, the macro-nutrient concentration in the plant was higher in T4 treatment where the foliar application of S.A at 1.5mM was used. The study results were incomparison with the findings of Karlidag *et al*., (2009) that salicylic acid application increases the uptake of macronutrients.

Conclusion

The present investigation results revealed that the foliar use of salicylic acid (S.A) has greater potential to enhance growth and nutrition of the sunflower crop. The experimental study concludes that the foliar application of S.A at 1.5mM in both normal and drought conditions could prove a better strategy for the optimum production of sunflowers. The world is facing a water shortage problem severely and agriculture is affected badly. The foliar application of S.A. could be a solution for optimum productivity of sunflower crops in the area where drought is a threat to this crop.

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