Salicylic Acid with Humic Acid Addition as Potential Hallmarks for Alleviating Drought Stress in Maize Crop and Enhancing Soil Health

ABSTRACT

Climate change is the biggest concern to the human kind and threat to agri-food security. Deficiency of water in soil and the ability of plants to uptake water is slowed down due rising temperature and microbial imbalance in soil. Salicylicacid plays an important role in mitigating drought stress and improves the overall production of crop. Humic acid is another amendment to cope against water stress and optimizes the yield. Apart from that, there is little known about their impact on soil geochemistry and that how soil health is altered.

To investigate the effect of salicylic acid and humic acid on the drought experiment was conducted at University Research Farm (URF), PMAS Arid Agriculture University, Rawalpindi during summer 2023. The experiment was set up in randomized complete block designin two factorial arrangements with four replications. The first factor was comprised of mitigation strategies;salicylic acid, humic acid and chemical fertilizer, while second factor was water regimes; water stressand irrigation maintaining 60% field capacity.

Plant attributes including chlorophyll content (SPAD value), total soluble protein content (mg/g), total free amino acid (mg/g), K^+ content (mg/g), Na^+ content (mg/g), 1000 grain weight (g) and grain yield (kg/ha) were measured and reported. On the other hand, soil parameters that were estimated are: soil pH, soil organic matter content (%), available N (ppm), available P (ppm), available K (ppm) and cation exchange capacity (cmol/kg).

According to the data analysis,all of the features under study had a substantial impact from the mitigation approaches.The increased value of chlorophyll content (49.11 mg/g) was obtained in water stressed condition by the application of salicylic acid. Under water stressed regime and salicylic acid boosted the total soluble protein content (1.67 mg/g) and total free amino acid (31.93 mg/g) while grain yield (9451.7 kg/ha) was also boosted up by the amendment salicylic acid in maize. There was also increase in the values of soil pH (6.78), CEC (54.37cmol/kg), SOM content (0.87%), available N (3.24 ppm), available P (26.14 ppm) and available K (211.23 ppm) drought conditions with the implementation of salicylic acid.

Humic acid also positively impacted the drought stress and improved the maize yield (8436.2 kg/ha) under drought condition. Similarly, soil nutrient retention is also improved to large extent under water stress state; SOM content (0.49%), available N (2.36 ppm), available P (15.67 ppm) and available K (171.94 ppm).

Overall, the study showed that amendment of salicylic acid andhumic acid, is the greatest strategy to increase crop production and quality while also improving the health of the soil.

Keywords*: Drought Stress, Salicylic Acid, Humic Acid, Plant Health, Soil Health, Plant-Soil Interaction.*

INTRODUCTION

The most detrimental factor affecting production globally to a greater extent is water stress brought on by either salinity or drought (Abbaszadeh et al., 2020).Depletion of water in the rooting zone and an increase in the atmospheric vapor pressure deficit exacerbate the effects of water stress (Yang et al., 2022). When water supplies are scarce, crop plant productivity can drop by anywhere between 50% and 73%(Habibi, 2012). In dry and semi-arid locations, evaporation is thought to lose between 30 and 60 percent of the total water supplied to the land (Ilyas et al., 2017). Due to their immobility in the natural world, plants must adapt through a variety of physiological, morphological, biochemical, and molecular processes in order to cope with environmental challenges. By overproducing scavenging phyto-hormones (Németh., 2001) activating the antioxidant battery system (Ilyas et al., 2017), upregulating osmotic adjustment (Shemi et al., 2021) and undergoing anatomical modifications, plants attempt to lessen the impacts of water stress(Chavoushi et al., 2002).

Globally, maize (*Zea mays*), a primary cereal food, is extensively farmed. Due to a roughage scarcity, substantial emphasis has been dedicated to its feeding value in recent years. Maize can produce massive amounts of energy-rich forage for animal diets, and its fodder may be fed safely at all phases of growth without the risk of oxalic acid or prussic acid toxicity that sorghum does (Hayat et al., 2008). But its greatest disadvantage is its minimum crude protein content, ranging normally between 70 and 80 g/kg dry matter (DM) (Kang et al., 2012). The productivity of maize is extremely susceptible to changes in the environment, especially drought and temperature stressors, which often result in a 40–50% loss in yield. Maize grain output is impacted by unfavorable impacts on cell development, physiological and biochemical characteristics, metabolic functions, and enzymatic dysfunction at various plant system levels (Tiwari et al., 2020).

Salicylic acid treatment increased wheat crop productivity by 70% (Damalas, 2019). In tomato,during drought conditions, foliar spraying of salicylic acid at a rate of 100 mg/L significantly decreased the accumulation of salt and chloride (Khatun et al., 2016). Crop types, the timing of application, the stage of crop growth, the level of water stress, and environmental factors all affect how effective is the application of salicylic acid.

Numerous biological effects of humic acid have been documented, including increased permeability of cell membranes, potassium uptake, rates of photosynthesis and respiration, and elongation of root cells (Kovács et al., 2014; Patel et al., 2018). Furthermore, HA functions as a growth regulator to boost stress tolerance, promote plant development, and control the levels of other hormones. By applying 20 mg/l HA, A significant increase in corn vegetative development characteristics, such as plant height and leaf chlorophyll a and b level (Zahra et al., 2022). Humic acid strengthened corn's tolerance to drought stress and lessened the negative impacts of water deficiency stress(Antonić et al., 2020).

A field experiment was conducted in order to determine the effectiveness of different mitigation strategies that includes salicylic acid, humic acid as a remedy to maintain maize output during a drought.

MATERIAL AND METHODS

The research was conducted at University Research Farm, PMAS Arid Agriculture University, Rawalpindi, Punjab, Pakistan in summer 2023 from 28 February to 17 August. A research study was steered to measure the effects of different mitigation approaches on the biochemical and nutritional composition, as well as the growth and yield, of maize crop during drought conditions. A randomized complete block design (RCBD) with four replications was used to arrange the two factors that made up the treatments: (a) two water regimes; water stress (WS), irrigation with field capacity maintained at 60 % (IR) (b) mitigation treatments; salicylic acid (SA), humic acid (HA) and urea + DAP as chemical fertilizer (CF).

Experimental Set-up

Plot Size: 4m × 6m = 24 m^2

Design: RCBD two factorials

Replications: 4

Number of Rows: 5

Row Spacing: 75 cm

Plant Spacing:28 cm

Land is prepared with help of simple cultivator as recommended. Seeds were pre-soaked for 5 minutes with 5 g/L of sodium hypochlorite before sowing and dried them up. After that, seeds were sown with the aid of hand drill in the arranged plots. Row to row distance was maintained 75 cm while plant to plant was 28 cm. All the mitigation treatments; salicylic acid (SA), humic acid (HA) and chemical fertilizer(CF) were dissolved in distilled water. Solutions were prepared with the surfactant Tween-80 (polyoxyethylene sorbitol monolaurate) to ensure fair absorption and penetration by the roots and soil surface. After 35 days of germination of maize, it was subjected to water stress and after 45days of germination, application of salicylic acid (SA), humic acid (HA) and chemical fertilizer (CF) was applied into their respective plots through flooding.

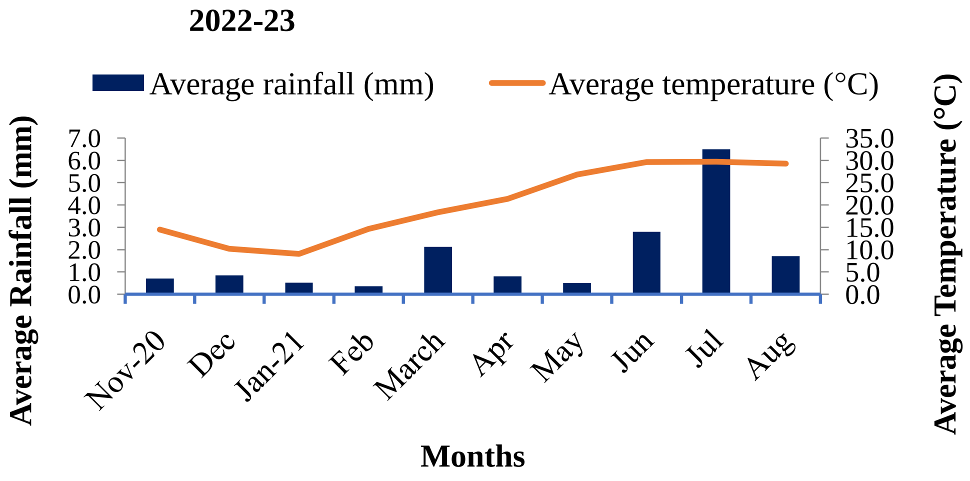

Figure 1. Average temperature and rainfall in the experimental site (University Research Farm, Rawalpindi) in 2022- 2023. (Source: Climate Observatory at University Research Farm, 350 m away from experimental location)

Table 1. Crop husbandry utilized for estimating the effect of mitigation approaches on drought stressed maize.

Crop	Sowing Date	Variety	Seed Rate (kg/ha)	P-P (cm)	R-R (cm)	Harvest Time	Harvest Method
Maize	28 February	YS-16	35	28	75	17August	Manual

Data Collection

Plant Parameters

Data were gathered ten days following the flood application of salicylic acid (SA), humic acid (HA) and Urea + DAP (CF). In the morning, chlorophyll content (SPAD) was measuredfrom each treated plot using a portable chlorophyll meter (Minolta Camera Co., Japan) after 55 days of germination. The 10 random plants were taken out of each plot together with the roots after the data had been recorded and then plant material was cleaned, blotted. The total soluble protein content and free amino acids of these samples were measured using the techniques of Bradford(1976)respectively.

The plants were permitted to develop until they attained physiological maturity. At maturity, data on yield components were recorded which included 1000 grain weight and grain yield. We used the Ryan et al. (2001) approach to identify the ionic components of $K^+$and Na^+ from the plants**.**

Soil Parameters

Composite soil samples (0–15 cm depth) were obtained from each experimental unit for post-harvest soil analysis of pH. cation exchange capacity (CEC), soil organic content (SOM), Available N, P and K. Glass electrode pH meter was used to measure the pH value. CEC was calculated by mean of NH_4OH extraction method. To find out the value of soil organic matter content we will multiply organic carbon (OC) by 1.73 while Walkley and Black method was followed to determine OC titrimetrically. Kjeldahl technique was used to calculate available nitrogen. To find the available phosphorus content, soil was agitated with a 0.03 M NH4F—0.025 M HCl solution at a pH of less than 7.0. By employing the ammonium bicarbonate-DTPA method (AB-DTPA), the value of available K was evaluated.

Statistical Analysis

Utilizing Statistical Software, Statitistixv8.1 and IBM SPSS, data were statistically examined in order to identify substantial variability among various parameters.The least significant difference test was used to compare the means.

RESULTS

Plant Parameters

An essential pigment for photosynthetic processes in plants, chlorophyll affects photosynthetic capacity and, consequently, plant growth. The effects of mitigation treatments on maize under drought stress were seen to cause a notable variation in the amount of chlorophyll content (SPAD value) (Table 2). The range of mean values for several treatments forwater stressed (WS) maize was between 35.43 to 49.11 SPAD value. The water stressed maize under salicylic acid (SA) treatment, had the highest chlorophyll content (49.11 SPAD), whereas the chemical fertilizer, Urea + DAP (CF) treatment had the lowest chlorophyll content (35.43SPAD).In contrast, the value of chlorophyll content has also been altered significantly for irrigated maize but varies between 38.32 to 44.35 SPAD value (Table 2). The maximum chlorophyll content (44.35 SPAD) was observed by the application of salicylic acid (SA) and least value (38.32 SPAD) was estimated for chemical fertilizer, Urea + DAP (CF). By comparing both water regimes; water stress (WS) and irrigated (IR), it has been observed that water stressed maize (WS) with salicylic acid (SA) application achieved optimum increase of 9.69% in chlorophyll content followed by humic acid (HA) with about 7% while chemical fertilizer (CF) has negatively affected the water stressed maizewhich decrease the chlorophyll content to8.15% (Table 2).

Different variables led to substantial differences in total soluble proteins. The total soluble protein content of both water stress (WS) and irrigated (IR) water regimes was between 1.15to 1.67 mg/g. The water stress (WS) maintained a greater concentration of total soluble proteins with the application of salicylic acid (SA) by 1.67 mg/g over irrigated crop (IR), while, lowest soluble protein content of 1.15 mg/g was calculated for urea + DAP (CF). On the other hand, irrigated maize (IR) haslower soluble protein content as compared to water stressed maize (WS). In irrigated (IR) water regime, the detected value of soluble protein content with the application of salicylic acid (SA) was 1.54 mg/g followed by humic acid (HA) and urea + DAP (CF) with 1.32 mg/gand 1.29mg/g, respectively. The application of salicylic acid (SA) increased total soluble protein by 7.78% inwater stressed (WS) maize (Table 2).

Mean square values for total free amino acid (mg/g) showed significant variability among both water stress (WS) and irrigated (IR) maize genotype under the effect of mitigation approaches (Table 2). The means for various treatments for water stressed (WS) maize ranged from 1.26 to 0.82 mg/g (Table 2). Water stressed (WS) maize with salicylic acid (SA) and humic acid (HA) treatments had highest total free amino acidof 0.72 to 1.26 mg/g, respectively while lowest total free amino acid (0.82 mg/g) was obtained by urea + DAP (CF). On the other hand, the means for various treatments for total free amino acid in irrigated (IR) maize ranged from 0.84 to 1.13mg/g (Table 2). Maximum total free amino acid (1.13 mg/g) was observed by the amendment of salicylicacid (SA) treatmentwhile minimum protein content (0.84 mg/g) was present in chemical fertilizer, urea + DAP (CF). Application of salicylic acid (SA) and humic acid (HA) increased the total free amino acid in water stressed (WS) regime by 10.32 and 6.86%, respectively (Table 2).

Significant variations in water regimes and mitigation approaches were all present in the K^+ content in the plant. The K^+ content of both water stress (WS) and irrigated (IR) water regimes was between 13.39 to 24.56 mg/g. The water stress (WS) maintained a greater concentration of K^+ content with the application of salicylic acid (SA) by 24.56 mg/g over completely irrigated maize (IR) while, lowest K^+ content of 13.39 mg/g was calculated for urea + DAP (CF). On the other hand, irrigated maize (IR) has overall lowK^+ content as compared to water stressed maize (WS). In irrigated (IR) water regime, the detected value of K^+ content with the application of salicylic acid (SA) was 21.16 mg/g followed by humic acid (HA) and urea + DAP (CF) with 17.64 mg/g and 15.43 mg/g, respectively. The application of salicylic acid (SA) increased the K^+ content by 13.84% in water stressed (WS) maize (Table 2).

In the present experiment mean square values for Na^+ content (mg/g) showed significant variations in both water regimes; water stressed (WS) and irrigated (IR) under the effect of mitigation approaches. The means for various mitigation treatments for water stressed (WS) maize ranged from 19.76 to 31.93 mg/g (Table 2). Water stressed (WS) maize with amendment of salicylic acid (SA) had given maximum Na^+ (31.93 mg/g) while minimum Na^+ (19.76 mg/g) was obtained for water stressed (WS) maize with accumulation of urea + DAP (CF). Apart from this, the means for various treatments for irrigated (IR)maize ranged from 23.64 to 28.43 mg/g (Table 2). Increase in the value of Na^+content (28.43 mg/g) for irrigated maize (IR) was observed in salicylic acid (SA). followed by humic acid (HA) with value of 25.76 mg/g despite this, minimum Na^+ content (23.64 mg/g) was experienced inCF.

The range of mean values for several treatments for irrigated maize was between 26.37 to 34.98 g of 1000 grain weight. The irrigated maize under salicylic acid (SA) treatment, had the highest 1000 grain weight (34.98 g), whereas the chemical fertilizer, Urea + DAP (CF) treatment had the 1000 grain weight (26.98g). In contrast, the value of 1000 grain weightwas altered significantly for water stressed (WS) maize but varies between 13.46 to 28.76 g (Table 3). The maximum 1000 grain weight (28.76 g) was observed by the application of salicylic acid (SA) and least value (13.46 g) was estimated for chemical fertilizer, Urea + DAP (CF). It has been observed that water stressed maize (WS) with salicylic acid (SA) application achieved an increase of 53.19% in 1000 grain weight followed by humic acid (HA) with 43.14% in comparison to chemical fertilizer (CF) (Table 3).

Grain yield is a crucial plant characteristic because, by excluding water content-induced changes, it offers a more accurate assessment of output. Due to a variety of factors, including nutrition, environment, photosynthetic ability, and other factors, plant performance and grain output of crops are closely correlated. According to the analysis of variance, significant variation was found in the grain yield (kg/ha) of maize combined by different mitigation treatments (Table 3). The means for various treatments for water stressed (WS) maize ranged from 6724.3 to 9451.7kg/ha. Water stressed (WS) maize under salicylic acid (SA) treatment displayed maximum grain yield (8436.2 kg/ha) followed by humic acid (HA) (8754.1 kg/ha), minimum grain yield (6724.3 kg/ha) was seen in urea + DAP (CF) treatment. On the other hand, the means for various treatments for irrigated (IR) maize ranged from 7929.4to 10614.8 kg/ha (Table 3). Irrigated (IR) maizeby applying salicylic acid (SA) demonstrated maximum grain yield (9451.7 kg/ha) whereas minimum grain yield (7175.2 kg/ha) was produced by chemical fertilize, urea + DAP (CF).Application of salicylic acid (SA) improved the grain yield in WS water regime by 28.85% as compared to CF.

Soil Parameters

The application of mitigatio1n techniques together with the adoption of drought conditions has significantly enhanced the characteristics and fertility of soil (Table 4). The use of these techniques in both water regime (WS) has dramatically changed the SOM content, which ranged from 0.15 to 0.87%. The maximum SOM content (0.87%) was found by the application ofsalicylic acid (SA) in water stressed (WS) soil; the lowest value (0.15%) was calculated forchemical fertilizer (CF) treatmentin water stressed (WS) soil (Table 4) followed by chemical fertilizer, urea + DAP (CF) (0.23%) of irrigated (IR) regime. In the same way, available N varied in all mitigation strategies and water regimes used in this experiment, ranging from 1.02 to 3.24 ppm. The available nitrogen value decreased to 1.02ppm in the water stressed (WS) regime under the implementation of chemical fertilizer (CF) treatment. However, the use of salicylic acid (SA) significantly increased the available nitrogen value to 2.95 ppm and 3.24 ppm in irrigated (IR) andwater stressed (WS) soils, respectively (Table 4).

After using mitigation approachesunder drought and irrigated soil conditions, the pH of the soil was raised between4.26 to 6.78. Although water stressed (WS) soil with salicylic acid (SA) raised available P content to 6.78 and irrigated (IR) with salicylic acid (SA) to 6.44, pH declined to 4.26 in the water stressed (WS) treatment of chemical fertilizer (CF), followed by irrigated (IR) treatment (CF) (4.43) with chemical fertilizer (CF)(Table 4). The use of mitigation strategies with both water regimes greatly influenced available P, which varied between6.34 to 26.14 ppm. The highest available P, 26.14 ppm, was observed in water stressed (WS) soil when salicylic acid (SA) was added followed by irrigated (IR) regime of salicylic acid (SA) (23.58 ppm). The lowest value, 6.34 ppm, was in water stressed (WS) treated with urea + DAP (CF) (Table 4).

Available K ranged from 134.76. to 211.23 ppm in both water regimes and mitigation strategies. The highest value (211.23 ppm) was found in the water stressed (WS) regime with the application salicylic acid (SA), followed by salicylic acid (SA) treated to irrigated (IR) soil (193.87 ppm). Water stressed (WS) regime with amendment of chemical fertilizer, urea + DAP (CF) had the lowest value (134.76 ppm) (Table 4).

In CEC of the soil there was significant change was observed from 38.14 to 54.37cmol/kg in both water regimes and mitigation practices in this experiment. In water stressed (WS) regime with addition of salicylic acid (SA), soil CEC increased to 54.37cmol/kg in contrast to the chemical fertilizer (CF) of water stressed (WS) regimewhich has minimum value of CEC (38.14cmol/kg) (Table 3) which was followed by irrigated (IR) regime treated with chemical fertilizer, urea + DAP (CF) (41.56 cmol/g) (Table 4).

Table 2: Effect of different mitigation approaches under different water regimes nutrient on the plant growth parameters.

MS	**Chlorophyll content (SPAD value)**		**Soluble Protein content (mg/g)**		**Total free amino acid (mg/g)**		**K^+ content (mg/g)**		**Na^+ content (mg/g)**	
	WS	**IR**	**WS**	**IR**	**WS**	**IR**	**WS**	**IR**	**WS**	**IR**
CF	35.43c	38.32bc	1.15d	1.29cd	19.76c	23.64bc	13.29c	15.43bc	19.76c	23.64bc
HA	43.32b	40.26bc	1.43bc	1.32c	26.11b	25.76b	18.98b	17.64b	26.11b	25.76b
SA	49.11a	44.35b	1.67a	1.54b	31.93a	28.43b	24.56a	21.16ab	31.93a	28.43b
SE	0.4		0.02		0.01		0.2		0.2	
CV (%)	4.26		1.18		2.76		5.02		4.67	

Figures in a column having common letters differ significantly at 5% level of significance. SE = Standard error of means; CV (%) = Coefficient of variation; MS = Management strategies; WS = Water stress; IR = Irrigated; CF = Chemical fertilizer, HA = Humic acid; SA = Salicylic acid

Table 3: Effect of different mitigation approaches under different water regimes nutrient on the yield parameters.

MS	**1000 grain weight (g)**		**Grain yield (kg/ha)**	
	WS	**IR**	**WS**	**IR**
CF	13.46d	26.37b	6724.3d	7929.4c
HA	23.71c	31.43ab	8436.2bc	8764.6bc
SA	28.76ab	34.98a	9451.7b	10.614.8a
SE	0.1		43.76	
CV (%)	9.21		8.45	

Figures in a column having common letters differ significantly at 5% level of significance. SE = Standard error of means; CV (%) = Coefficient of variation; MS = Management strategies; WS = Water stress; IR = Irrigated; CF = Chemical fertilizer, HA = Humic acid; SA = Salicylic acid

Table 4: Effect of different mitigation approaches under different water regimes nutrient on the soil properties.

MS	**pH**		**CEC (cmol/g)**		**SOM content (%)**		**Available N (ppm)**		**Available P (ppm)**		**Available K (ppm)**	
	WS	**IR**	**WS**	**IR**	**WS**	**IR**	**WS**	**IR**	**WS**	**IR**	**WS**	**IR**
CF	4.26d	4.43cd	38.14d	41.56c	0.15d	0.23cd	1.02c	1.32bc	6.34c	10.76bc	134.76c	145.86bc
HA	5.87b	5.03c	47.67b	42.16bc	0.49bc	0.35c	2.36ab	1.87b	15.67b	12.03b	171.94b	163.77bc
SA	6.78a	6.44ab	54.37a	50.28b	0..87a	0.61b	3.24a	2.95ab	26.14a	23.58ab	211.23a	192.87b
SE	0.01		0.2		0.02		0.01		0.1		3.4	
CV (%)	3.32		2.14		2.65		1.18		4.73		3.26	

Figures in a column having common letters differ significantly at 5% level of significance. SE = Standard error of means; CV (%) = Coefficient of variation; MS = Management strategies; WS = Water stress; IR = Irrigated; CF = Chemical fertilizer, HA = Humic acid; SA = Salicylic acid

DISCUSSION

As an endogenous hormone, salicylic acid and humic acids regulate several physiological and biochemical processes, including progressive growth, seed development, productivity per unit land area, and flower production; they also lessen the production of reactive oxygen species (ROS) and upregulates the defense system to maintain osmotic adjustment in stressful environments (Ryan et al., 2001; Moghadam et al., 2014; Khan et al., 2019). Similarly, when salicylic and humic acid were added under stressful conditions, the quantity and proportional quantities of nutritional ions were also changed (Estefan & Rashid, 2001). According to a number of studies, raising the amount of salicylic acid in the plant system might reduce oxidative stress brought on by the production of reactive oxidative species (ROS) pursuant to drought stress (Johnson & Bhattacharyya, 2019). In a recent study that the negative effects of environmental stressors were lessened by the salicylic acid-induced antioxidative system(Khan et al., 2019).

The current findings showed that the effects of drought stress were more pronounced in relation to growth, development, and other physiological processes, including photosynthetic activity. Reduced biological yield generation followed by a drop in photosynthetic capacity ultimately resulted in yield loss (Zhang et al., 1998;Hasanuzzaman et al., 2014). Numerous studies (Eyidogan et al., 2012; Ashraf et al., 2012) also discovered a strong relationship between photosynthetic capacity and increasing plant growth. Exogenous salicylic acid application improved the growth and development of both maize crop varieties while reducing the negative effects of drought stress. The findings support those of (Chaves et al., 2011;Farooq et al., 2013; Kong et al., 2016) which found that decreasing the detrimental effects of drought stress on the growth and development of different crop species could be achieved by increasing the level of salicylic acid through foliar spraying or by an excess of organic osmolytes in the plant system. Maize’s level of chlorophyll was significantly reduced in response to the water-stressed environment.Chlorophyll "a" and "b" control the process of photosynthesis (Neelam et al., 2014). Similar studies have also documented decreased levels of chlorophyll in other crops, including wheat(Yang et al., 2020), soybeans (Çimrin et al., 2010), and cowpea(Kalaji et al., 2011). On the other hand, applying salicylic acid on cotton (Noreen et al., 2017) and soybean (Noreen et al., 2013) under conditions of both water stress and no water stress has also been shown to boost the concentration of chlorophyll.

The ionic balance was upset by the widespread drought, which had an effect on the plant's physiological functions (Farooq et al. 2013)The drought stress increased the uptake of Na$^+$ ions and decreased the absorption of K$^+$ ions. However, the implementation of salicylic acid promoted K$^+$ ion absorption in the plant system at the expense of Na$^+$. Additionally, applying a salicylic acid solution to wheat seed increased its resistance to drought stress(Estaji& Niknam, 2020). The plant tissues gathered more K$^+$ ions than Na$^+$ ions, with a notable decrease in Na$^+$ absorption. The growth and development of the wheat crop was therefore improved by the increased translocation of K$^+$ from the roots to the higher portions of the plants(Bates et al., 1973)

The results also showed that, in response to water stress, maize retained a higher quantity of soluble protein. Stressful conditions significantly increased the activity of protein synthesis in plants(Chakma et al., 2021). According to two more studies (Sedaghat et al., 2020; Ahmad et al., 2021), in barley and chlorella, amount of soluble protein rose when salt levels rose. On the other hand, in tomato and sorghum, soluble protein levels decreased as a result of drought stress. The breakdown of protein into amino acids under conditions of water stress is the cause of the protein decrease(Khadka et al., 2020). Our research results are consistent with those of Arif et al. (2020) andAltaf et al. (2022) who found that stressed rice and wheat crop plants had higher levels of soluble protein.

When compared to no water stress, the grain yield obtained from both wheat cultivars declined in response to drought stress. Sustainable photosynthetic capacity and overproduction of scavenging phytohormones are the causes of the steady increase in grain production(Munsif et al., 2022).A negative correlation among photosynthetic capacity and yield output(Aftab et al., 2023). It has been documented that applying salicylic acid on a variety of agricultural plants under drought stress circumstances improves grain yield (Yang & Lu, 2005; Shemi et al., 2021).

Sohag et al. (2020) found the results similar to the current findings, indicating that the application of salicylic acid improves the soil philological process, on the other hand, pH value is positively affected by its implementation under drought conditions but negative consequences has been reported with the urea and DAP fertilizers in crops such as barley and maize. Additionally, according to a number of studies, applying salicylic acid stimulated the increase of soil properties like available nitrogen and phosphorus that results in boost up the level of pHand CEC in the maize crop as a reaction to drought stress (Adelaal et al., 2020). These findings concur with those of Tayyab et al. (2020), who found that most soils responded to drought stress by increasing their amount organic matter.Applying 200 mg of salicylic acid per liter might improve and maintain a number of physiological parameters of soil including the potassium and organic matter under drought stress(Saheri et al., 2020).

The increased buildup of organic osmolytes in water stressed soil has led to a prolonged increase in organic matter content that raised the nitrogen and phosphorus capability, which has improved grain production and its constituent parts. Increased salicylic acid and humic acid content improved the plant and soil ability to withstand drought conditions. These findings are sameasNoreen et al. (2017)and Naz et al. (2021) who observed that cation exchange capacity of soil increased due to accumulation of K^+ which leads to increase the pH of soil.

CONCLUSION

The results revealed that salicylic acid and humic acid application significantly improved chlorophyll content, soluble protein content, and free amino acids in water-stressed maize, demonstrating its potential to enhance plant resilience to drought stress. Furthermore, the application of salicylic acid led to a substantial increase in 1000 grain weight and grain yield, highlighting its effectiveness in mitigating the negative impacts of drought on maize productivity.

In terms of soil parameters, the mitigation strategies, particularly salicylic acid and humic acid, significantly enhanced soil organic matter content, available nitrogen, phosphorus, and potassium, and cation exchange capacity. These improvements in soil fertility and physicochemical properties further contributed to the positive outcomes observed in maize growth and yield.

The study underscores the potential of salicylic acid as an effective mitigation strategy to alleviate the detrimental effects of water stress on maize production. The positive impact on both plant and soil parameters suggests that salicylic acid and humic acid application can be a valuable tool in sustainable agriculture, contributing to enhanced crop resilience and productivity in water-limited environments.

CONFLICT OF INTEREST

Authors have declared that no competing interests exist.

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