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Impact of salicylic acid on wheat growth and nutrient uptake in salinized environments

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Abstract

Field study was performed to explore the salicylic acid (SA) impact applied as priming agent and as foliar spray on wheat growth, yield and nutrient uptake in saline sodic conditions. Soil sampling of the selected field was carried out and composite soil samples were analyzed for salinity and fertility status of soil. The priming of wheat seeds (cv. Inqlab-91) was carried out by soaking 500g of seeds in 1000 mL solution of SA having 0.5, 1.0 and 2.0 mM concentrations for 12 hours. The primed wheat seeds were dried under shade. After the booting stage, 03 foliar sprays of given concentrations were carried out at a 10 days interval. The control was without priming SA and applied only recommended fertilizer @ 120-90-70 kg N-P-K ha^{-1}, respectively. The set of treatments replicated thrice following RCBD. Results revealed that the combination of priming and foliar spray of SA affected the wheat yield components, N-P-K uptake significantly. The highest wheat biomass, grain and straw yield, N-P-K content and uptake were observed at 2.0 mM SA with priming and foliar spray and statistically insignificant to SA at 1.0 mM. The minimum values of yield components and nutrient content and uptake were found in control. At harvest, soil fertility status was quite improved and slight reduction in the salinity/sodicity parameters was observed with SA application.

Keywords: Foliar application, Nutrient content/uptake, Salicylic acid, Saline sodic soil, Seed priming, Wheat

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Introduction

Plant hormones may contribute significantly to regulate development processes in plants under adverse conditions such as salinity/sodicity, nutrient insufficiency, heat, drought, and insufficient light required for photosynthesis. Salicylic acid (SA) is a phenolic signaling molecule that regulates the production of reactive oxygen species (ROS) and peroxides to optimal level and reduce the oxidant damage caused by soil salinization (Koo et al., 2020; Siddique et al., 2020). The SA and its byproducts (salicylates) are phenolic in nature and simulate plant defense mechanisms against stresses (biotic or abiotic). Before the identification of its role as a signaling molecule, it is considered as a phenolic secondary metabolite. The SA mediates the synthesis of osmolytes and thus plays an important role in osmotic adjustments (homeostasis), management of mineral nutrition, reducing ROS generation, produce secondary metabolites comprised of phenols, terpenes, nitrogen/sulfur containing compounds and initiation of biosynthesis pathways of hormones (Rasheed et al., 2020; Idrees et al., 2022; Khan et al., 2022). The literature confirmed the evidence of SA ameliorative effect during plant ontogeny under the different stresses (Hassoon & Abduljabbar, 2019; Zhang & Li, 2019; Khan et al., 2022).

Specific growth stimuli responded specifically upon the synergism or antagonism of hormones i.e., indole-3-acetic acid (IAA), jasmonates (JA), salicylic acid (SA), abscisic acid (ABA) and ethylene. The IAA and SA followed the pathway of shikimic acid (shikimate) (Dempsey & Klessig, 2017; Pérez-Llorca et al., 2019). The substrate i.e., shikimate by the action of chorismate synthase translated into chorismate i.e., the substrate for SA and followed isochorismate synthase and phenylalanine ammonia-lyase pathways (Herrmann & Weaver, 1999; Dempsey & Klessig, 2017; Hayat et al., 2022; Sadak & Dawood, 2022). The SA is known as quite un-important phenolic secondary metabolite in beginning and suppressed disease in tobacco. After the recognition the roles of SA such as imposing disease suppression/ disease resistance, tolerance to stresses, germination, budding, flowering, fruit setting, ripening and yield of crops (Khan et al., 2012; Dempsey & Klessig, 2017; Koo et al., 2020; Khan et al., 2022).

The phenolic phytohormone i.e., SA induced systemic resistance (ISR) in plants by synchronized the defense mechanisms and its SA-derivative's played pivotal part in the regulation of numerous functions (physiological and developmental) especially in stressed environments (Saleem et al., 2021; Hayat et al., 2022). The SA has a well-defined role in transpiration/photosynthesis, nutrient metabolism and also helps to combat hostile environmental conditions (Koo et al., 2020; Rasheed et al., 2020; Abdi et al., 2022).

Various SA application methods were reported in literature such as priming seeds, with irrigation water, foliar spray and addition to hydroponic medium and induced stress tolerance to plants (Horvath & Janda, 2007; Zhang & Li, 2019; Idrees et al., 2022). Application of SA exogenously affected numerous functions (developmental/physiological/ biochemical) viz. enhancing resistance to drought and salinity, influencing better germination and fruiting, rate of transpiration and photosynthesis, stomatal conductance, membrane permeability and ultimately the plant growth (Horvath & Janda, 2007; Hassoon & Abduljabbar, 2019; Koo et al., 2020; Rather et al., 2022). Literature confirmed that lethal effects of abiotic stresses might be reduced by plant-hormones. Plants and microbes are barely a simple source of phyto-hormones in soil (Khan et al., 2022; Idrees et al., 2022; Sadak & Dawood, 2022).

The priming/treating SA @ 0.05 mM enhances wheat growth, accretion of ABA and proline under salinized environment. The exogenously applied SA is beneficial to enhance the cell replication/division and ultimately wheat growth parameters (Sakhabutdinova et al., 2003; Noreen et al., 2009; Saidi et al., 2017; Salem et al., 2021; Rather et al., 2022). The SA has been considered an endogenous regulator and managed biotic/abiotic stress during cell metabolism (Shakirova et al., 2003; Aydin & Nalbantoglu, 2011; Noreen et al., 2017; Saleem et al., 2021; Abdi et al., 2022).

The SA ameliorated the salt stress impairments by promoting nitrogen (N), phosphorus (P), potassium (K) & calcium (Ca) uptake, antioxidant enzymes motions, photosynthetic rate and conclusively crop yields (Khan et al., 2010; Ratnakumar et al., 2016). Application of SA improved in plant processes (biochemical/physiological/developmental) and eliminated the harsh stress environments (Ashraf et al., 2010; Ratnakumar et al., 2016; Salem et al., 2021; Idrees et al., 2022). Seed germination might be improved by priming seeds with growth hormones or different salts. The seed priming with growth stimulants has been considered as meaningful practice and to secure seeds from damaging environmental conditions and increased the growth of crops (Damalas & Koutroubas, 2022; Rather et al., 2022). The priming or soaking seeds of several crops by SA may alleviate deleterious effects of soil salinization and promote growth, improve sugar and chlorophyll content and regulated the osmotic adjustments (Hamid et al., 2008; Noreen et al., 2009; Mandavia et al., 2014; Rizwan et al., 2016; Idrees et al., 2022; Sadak & Dawood, 2022).

Ameliorative impact of by SA application under salinity/sodicity in maize has been reported through plant growth regulation, enhancing protein/relative water and chlorophyll contents, anti-oxidative enzymes, and minimizing electrolyte leakage (Agami, 2013; Hayat et al., 2022; Rather et al., 2022). Exogenous application of SA lessened the detrimental effects of various stresses in millets by enhancing fresh-dry mass, carbohydrates and glycine as reported by Hussain et al. (2010) while Dong et al. (2011) reported the impact of SA on cucumber and high values of sugars used in osmotic agents and metabolic signals viz. glucose, fructose, raffinose and stachyose and improved yield was observed. The SA application to mustard at 0.1/0.5/1.0 mM concentrations resulted in high nutrient contents, better photosynthetic rates, release of antioxidative-enzymes i.e., superoxide- dismutase (SOD), ascorbate peroxidase (APX) and glutathione reductase (GR) (Syeed et al., 2011) while SA applied to tomato diminished the lethal effect of salinity by managing protein, proline and sugar content (Zahra et al., 2010; Idrees et al., 2022). Therefore, this field trial was planned to evaluate the different rates of SAs applied via seed priming or foliar spray for improving growth/yield and up-taking of nutrients in saline-sodic environments.

Materials and Methods

Field experimentation was carried out at the Research Farm of Soil Salinity Research Institute, Pindi Bhattian, District Hafizabad, Pakistan. The experiment was conducted on saline-sodic soil having pH_s 8.68; EC_e 5.71 dS m^{-1}, SAR 26.50 (mmol $L^{-1})^{1/2}$, organic matter 0.42%, available P 8.66 mg kg^{-1}, extractable K 105.6 mg kg^{-1}, and sandy loam soil texture). Experiment was performed to assess the SA applied as seed priming and foliar spray on N-P-K uptake and wheat growth and yield in saline-sodic soils. The study has seven treatments including T_1: Control (Recommended NPK i.e., without seed priming & foliar application), T_2: Priming seeds @ 0.5 mM SA, T_3: Priming seeds @ 1.0 mM SA, T_4: Priming seeds @ 2.0 mM SA, T_5: Priming seeds & foliar spray @ 0.5 mM SA, T_6: Priming seeds & foliar spray @ 1.0 mM SA, T_7: Priming seeds & foliar spray @ 2.0 mM SA.

The priming of wheat seeds (Inqlab-91) was carried out by soaking 500 g seeds in 1.0 L solution of different concentrations of SA for 12 hours as per treatment and dried the seeds under shade. Three foliar spray of SA was performed after each 10 days after wheat boot formation. The recommended dose (120-110-70 kg N-P_2O_5-K_2O ha^{-1}), and P, K applied before sowing and N in three splits i.e., one at sowing and remaining in two splits with 2nd and 3rd irrigation. The treatments were repeated thrice following RCBD having plot-size (5x4 m^2) for each treatment. At harvesting, data regarding yield components were recorded. The biomass samples were collected, oven dried at 65 ^oC. The samples (grain/straw) were ground and processed for NPK determinations. Analyses of soil and plant were performed in accordance with U.S. Salinity Lab. Staff (1954), soil texture by Moodie (1959), soil available P (Olsen & Sommers, 1982) and total N in plant samples by Jackson (1962). Nutrient uptake in grains and straw of wheat crops as well as total nutrient uptake was determined according to Tisdale (1993). The statistical data analyses were performed by ANOVA and significance was checked for mean comparison (Steel et al., 1997).

Results and Discussion

Effect on growth and yield parameters

Results in Table 1 regarding growth and yield components of wheat such as biomass, grain, straw, 1000-grain weight, tillers m^{-2} and plant height demonstrated the effect of SA either applied as priming or priming and foliar spray. Results revealed that SA levels have a significant effect on wheat yield parameters. The biomass, grain and straw yield of wheat ranged from (4.68-5.83 t ha^{-1}), (2.28-2.84 t ha^{-1}) & (2.39-2.98 t ha^{-1}), respectively. Highest biomass 5.83 t ha^{-1}, grain (2.84 t ha^{-1}) and straw yield (2.98 t ha^{-1}) were produced in T_7 (priming seeds and foliar spray @ 2.0 mM) and it was statistically at par with T_6 where priming and foliar spray @ 1.0 mM SA. The lowest biomass, grains/straw was obtained i.e., 4.68, 2.28 and 2.39 t ha^{-1} with control, respectively.

Results regarding 1000-grain weight, tillers m^{-2}, and plant height were ranged (38.26-44.70), (255-298) and (85.0-89.5cm), respectively. The maximum 1000-grain weight (44.70 g), tillers m^{-2} (298) and plant height (89.5 cm) were recorded in T_7 (priming seeds and foliar spray @ 2.0 mM) and differed non-significantly with T_6 (priming and foliar spray @ 1.0 mM SA). The minimum 1000-grain weight (38.26 g), tillers m^{-2} (255) and plant height (85 cm) were observed in the control. Results of the present study were corroborated with findings of Tamoor (2017) who found priming & foliar spray @ 2.0 mM SA at recommended N-P-K, increased biomass, grain/straw yield of wheat, 1000-grain weight, plant height and tillers m^{-2} under saline soil conditions. Results also confirmed the evidence obtained from Khaliliaqdam et al. (2013) who found high grain yield of barley with increasing concentrations of SA application. The ameliorative impact on salts stress in pearl millet seedlings by regulating different growth and yield parameters due to SA application resulting in increased grain yield (Hussain et al., 2010; Rizwan et al., 2016; Naeem et al., 2020; Idrees et al., 2022). Application of SA enhanced plant height by alleviating the adverse effect of salinity as reported by researchers (Desoky & Merwid, 2015; Rather et al., 2022).

Table 1 Effect of salicylic acid on wheat yield components

Treatments	Biomass yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	1000 grain wt. (g)	Tillers m^{-2}	Plant height (cm)
T_1: Control (Recommended NPK)	4.68^{e}	2.28^{c}	2.39^{d}	38.26^{c}	255^{d}	85.0^{b}
T_2: Priming seeds @ 0.5 mM SA	4.76^{de}	2.31^{c}	2.45^{de}	38.60^{c}	258^{cd}	85.0^{b}
T_3: Priming seeds @ 1.0 mM SA	5.12^{cd}	2.46^{bc}	2.65^{cd}	39.80^{c}	264^{cd}	87.0^{ab}
T_4: Priming seeds @ 2.0 mM SA	5.24^{c}	2.54^{b}	2.69^{c}	41.60^{b}	272^{bc}	89.0^{a}
T_5: Priming seeds & foliar spray @ 0.5 mM SA	5.34^{bc}	2.59^{b}	2.75^{bc}	42.95^{ab}	286^{ab}	89.0^{a}
T_6: Priming seeds & foliar spray @ 1.0 mM SA	5.76^{ab}	2.82^{a}	2.94^{ab}	43.80^{a}	296^{a}	89.5^{a}
T_7: Priming seeds & foliar spray @ 2.0 mM SA	5.83^{a}	2.84^{a}	2.98^{a}	44.70^{a}	298^{a}	89.5^{a}
LSD	0.4242	0.2213	0.2083	1.7693	15.48	3.4912

Effect on N-P-K content

Results in Table 2 regarding grain and straw N-P-K of wheat demonstrated the effect of SA either applied as priming or priming + foliar spray. Data demonstrated the different levels of SA have significant impact on wheat grain and straw N-P-K content. The N, P and K values of wheat grains ranged from (1.90-2.08%), (0.34-0.37%) and (0.36-0.48%), respectively. The maximum N in grains (2.08%), P (0.45%) and K (0.48%) content were observed in T_7 (seed priming and foliar spray @ 2.0 mM) and it was at par with T_6 (priming and foliar spray of SA @ 1.0 mM). Minimum N-P-K i.e., 1.90%, 0.34% and 0.36% content were observed in control, respectively. Results of wheat straw suggested that different levels of SA have a trivial effect on NPK content. N, P and K concentration of wheat straw ranged from (0.19-0.29%), (0.10-0.15) and (1.19-1.42%), respectively. The maximum N in straw (0.29%), P (0.15%) and K (1.42%) were observed in T_7 (priming and foliar spray @ 2.0mM SA) and differed non-significantly with T_6 (priming + foliar spray @1.0 mM SA). The least N-P-K (0.19%), (0.10%) and (1.90%) concentration in wheat straw were observed in control, respectively. The results obtained for wheat grains and straw N-P-K content suggested that priming and foliar spray @ 2.0 mM SA in the presence of recommended dose of NPK increased N-P-K concentration of wheat grain and straw and results are in accordance with Tamoor (2017). Application of SA @ 0.5 mM diminished Na^+ and Cl^- content and increased N, P, K and Ca concentrations in *Vigna radiata* (Khan et al., 2010). Amelioration of salt stress by applying SA and improving molecular and biochemical parameters linked with plant ontogeny (Ashraf et al., 2010; Jayakannan et al., 2013; El-Esawi et al., 2017; Abdi et al., 2022; Rather et al., 2022).

Table 2 Effect of salicylic acid on N, P & K content of wheat grain & straw

Treatments	Wheat grains			Wheat straw		
	Total N (%)	Total P (%)	Total K (%)	Total N (%)	Total P (%)	Total K (%)
T_1: Control (Recommended NPK)	1.90^{c}	0.34^{e}	0.36^{e}	0.19^{d}	0.10^{b}	1.19^{d}
T_2: Priming seeds @ 0.5 mM SA	1.90^{c}	0.34^{e}	0.38^{de}	0.19^{d}	0.10^{b}	1.21^{d}
T_3: Priming seeds @ 1.0 mM SA	1.93^{bc}	0.37^{d}	0.40^{d}	0.21^{cd}	0.13^{a}	1.24^{d}
T_4: Priming seeds @ 2.0 mM SA	1.97^{abc}	0.39^{c}	0.43^{c}	0.24^{bc}	0.13^{a}	1.31^{c}
T_5: Priming seeds & foliar spray @ 0.5 mM SA	2.04^{ab}	0.43^{b}	0.44^{bc}	0.27^{ab}	0.14^{a}	1.35^{bc}
T_6: Priming seeds & foliar spray @ 1.0 mM SA	2.06^{ab}	0.45^{a}	0.46^{ab}	0.29^{a}	0.15^{a}	1.38^{ab}
T_7: Priming seeds & foliar spray @ 2.0 mM SA	2.08^{a}	0.45^{a}	0.48^{a}	0.29^{a}	0.15^{a}	1.42^{a}
LSD	0.1314	0.0182	0.0253	0.0374	0.0296	0.0534

Effect on N-P-K uptake

Results regarding N-P-K uptake by wheat grains and straw (Table 3) validated the effect of SA either applied as priming or combination of priming and foliar spray. Results revealed that total N uptake by wheat grain and straw ranged (38.23-54.04 kg ha^{-1}), (4.00-7.62 kg ha^{-1}), respectively. Data showed that SA had a significant effect on N uptake of wheat grain and straw. The maximum N-uptake by wheat grains and straw i.e., 54.04 kg ha^{-1} and 7.62 kg ha^{-1} were observed in T_7 (seed priming and foliar spray @ 2.0 mM) and it was at par statistically with 1.0 mM SA. The minimum N-uptake by wheat grains and straw i.e., 38.23 and 4.0 kg ha^{-1} were observed in control, respectively.

Results depicted that total P-uptake by wheat biomass (grain/straw) ranged between (6.84-11.27 kg ha^{-1}) and (2.10-3.93 kg ha^{-1}), respectively. Highest P-uptake by wheat grains and straw i.e., 11.27 and 3.93 kg ha^{-1} were observed at SA @ 2.0 mM (priming + foliar spray) while the minimum P-uptake by wheat grains and straw i.e., 6.84 and 2.10 kg ha^{-1} were observed in control, respectively. Results depicted that total K-uptake by wheat grains ranged between (7.24-12.01 kg ha^{-1}) and straw (25.09-37.29 kg ha^{-1}). Highest K-uptake by wheat grains and straw i.e., 12.01 kg ha^{-1}and 37.29 kg ha^{-1} were observed in T_7 (priming seeds + foliar spray @ 2.0 mM), and it was statistically at par with 1.0 mM SA. Minimum P-uptake by wheat grains and straw i.e., 7.24 and 25.09 kg ha^{-1} were observed in control, respectively. Results obtained in our study suggested that priming seeds and foliar application @ 2.0 mM SA increased uptake (N-P-K) of wheat grains and straw in salinized conditions which is in accordance with the findings of Tamoor (2017), and Jahangir (2017) who concluded that seed priming and foliar spray @ 2.0 mM enhanced N-uptake in maize on salt affected soil. It had also been observed by Khan et al. (2010) that applying SA increased NPK and Ca content in biomass and improved total N-P-K-uptake and diminished the toxicity of salts.

Table 3 Effect of salicylic acid on N, P & K uptake of wheat grain & straw

Treatments	Total N uptake (kg ha^{-1})		Total P uptake (kg ha^{-1})		Total K uptake (kg ha^{-1})	
	Grains	Straw	Grains	Straw	Grains	Straw
T_1: Control (Recommended NPK)	38.23^{d}	4.00^{d}	6.84^{d}	2.10^{c}	7.24^{d}	25.09^{e}
T_2: Priming seeds @ 0.5 mM SA	38.69^{d}	4.09^{d}	6.92^{d}	2.16^{c}	7.74^{d}	26.08^{de}
T_3: Priming seeds @ 1.0 mM SA	41.83^{cd}	4.92^{cd}	8.02^{c}	3.03^{b}	8.65^{c}	28.98^{cd}
T_4: Priming seeds @ 2.0 mM SA	43.86^{bc}	5.70^{bc}	8.69^{c}	3.09^{b}	9.58^{b}	31.11^{bc}
T_5: Priming seeds & foliar spray @ 0.5 mM SA	46.62^{b}	6.54^{ab}	9.82^{b}	3.40^{ab}	10.05^{b}	32.67^{b}
T_6: Priming seeds & foliar spray @ 1.0 mM SA	51.12^{a}	7.50^{a}	11.17^{a}	3.87^{a}	11.43^{a}	35.71^{a}
T_7: Priming seeds & foliar spray @ 2.0 mM SA	54.04^{a}	7.62^{a}	11.27^{a}	3.93^{a}	12.01^{a}	37.29^{a}
LSD	4.226	1.1605	0.8118	0.7361	0.9016	3.0258

Total N-P-K uptake

Results regarding total uptake (N-P-K) by wheat crop (Fig. 1) validated the effect of SA either applied as priming or priming and foliar spray. Results revealed that total N uptake by wheat crop ranged between (42.23-59.66 kg ha^{-1}), total P-uptake (8.94-15.21 kg ha^{-1}) and total K-uptake (32.34-49.31 kg ha^{-1}). Highest uptake of N-P-K by wheat crop (59.66 kg ha^{-1}), (15.21 kg ha^{-1}) and (49.31 kg ha^{-1}) were obtained while the minimum N-P-K uptake 42.23, 8.94 and 32.34 kg ha^{-1} in control. The results are in accordance with the Tamoor (2017) and Jahangir (2017) who concluded that 2.0 mM SA via seed priming and foliar spray enhanced NPK-uptake in salt affected soil. The SA minimized the lethal impact of salinity and sodicity, and enhanced nutrient uptake was observed (Khan et al., 2010; Jayakannan et al., 2013; Naeem et al., 2020; Sadak & Dawood, 2022).

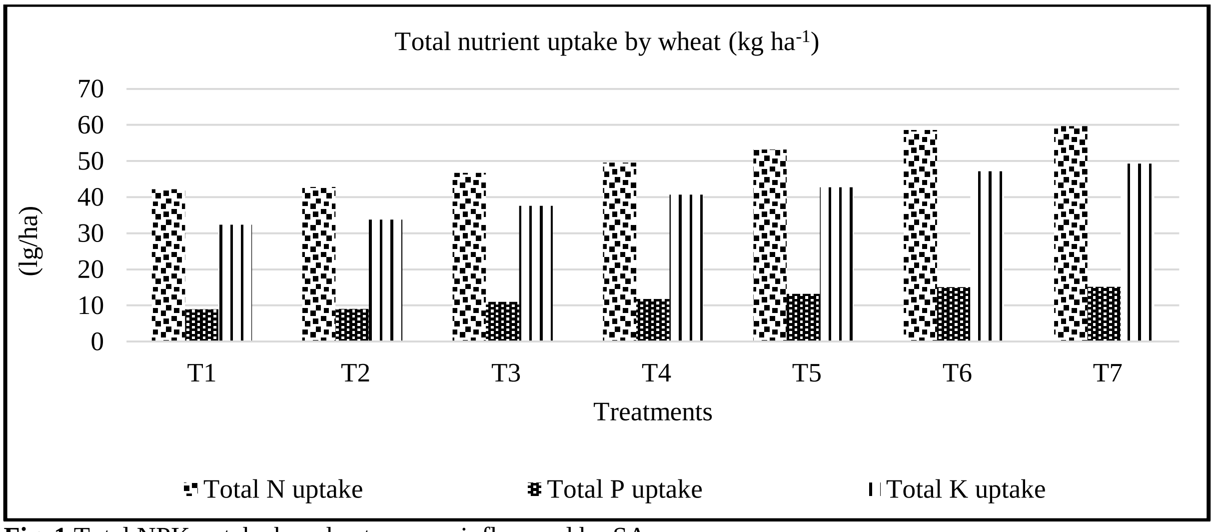

Fig. 1 Total NPK uptake by wheat crop as influenced by SA

Post-harvest soil analysis

Soil analysis at harvest of wheat crop (Table 4) suggested a slight decrease in salinity and sodicity parameters while soil fertility parameters were slightly improved. At harvest of wheat crop, there was decrease in organic content, extractable P and K content of soil with increasing concentration of SA application either applied as priming or in combination via priming and foliar spray suggested that high nutrient uptake by wheat crop in saline-sodic soil.

Table 4 Post-harvest soil analysis after wheat harvest

Treatments	pH_S	EC_e (dS m^{-1})	SAR (mmol L^1)$^{1/2}$	O.M. (%)	Available P (mg kg^{-1})	Extractable K (mg kg^{-1})
T_1: Control (Recommended NPK)	8.68	5.67	25.87	0.52	10.00	109.26
T_2: Priming seeds @ 0.5 mM SA	8.68	5.65	25.31	0.52	10.20	109.26
T_3: Priming seeds @ 1.0 mM SA	8.67	5.65	25.14	0.55	10.13	111.10
T_4: Priming seeds @ 2.0 mM SA	8.67	5.64	24.70	0.55	10.20	111.10
T_5: Priming seeds & foliar spray @ 0.5 mM SA	8.66	5.62	24.56	0.51	10.33	108.20
T_6: Priming seeds & foliar spray @ 1.0 mM SA	865	5.61	24.42	0.48	10.00	104.60
T_7: Priming seeds & foliar spray @ 2.0 mM SA	8.60	5.60	24.28	0.43	9.80	102.00

Conclusion

The SA application either by seed priming and foliar spray or in combined form with 1.0 m M-2.0 mM SA was effective for improving growth and yield components, NPK content in grains and straw, and nutrient uptake in wheat crop by reducing salt stress, and improving nutrient uptake under salt stress condition.

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