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Amelioration strategy of saline stress in wheat with salicylic acid: a review

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Abstract. Salinity, an adverse abiotic stress, is lowering the productivity of agricultural crops including wheat worldwide. It creates obstacles in normal crop growth and development. Salinity is affecting the morpho-physiology and productivity of wheat. It is also responsible for inducing oxidative, osmotic and ionic stress (high Na^+/K^+ ratio), while decreasing the K^+ concentrations in plants. Many insights indicate a positive relationship between salicylic acid application and improvement of the morpho-physiological attributes and productivity of wheat both in saline and non-saline conditions. Salinity-induced morphological and physiological alterations have resulted in a drastic decline in wheat yields globally. Morpho-physiological parameters and yield contributing parameters are correlated with each other. Salinity stress reduces the shoot length, shoot fresh mass, root length, root fresh mass, leaf area, leaf fresh weight, number of tillers, shoot dry mass, root dry mass, leaf dry weight, chlorophyll contents (SPAD), leaf relative water content, stomatal conductance, photosynthetic rate, transpiration, CO_2 assimilation rate, internal CO_2 concentration, spikelets per spike, grain weight per spike, number of grains per spike grain yield, straw yield, biological yield, harvest index in wheat. It also induces autophagy and programmed cell death in wheat. Application of salicylic acid on saline stressed wheat significantly improves all the aforementioned parameters along with maintaining lower Na^+ concentrations and a Na^+/K^+ ratio. Furthermore, salicylic acid alleviates the detrimental effects of salt stress ultimately promoting salt tolerance in wheat. Hence, this paper aims to provide a comprehensive review of major research advances on amelioration of salinity on morpho-physiology and productivity of wheat by the application of salicylic acid.

Keywords: salt stress, wheat, salicylic acid, morpho-physiology, productivity, autophagy.

INTRODUCTION

Rapid global climate change has increased the frequency and severity of abiotic stresses on plants (Ghosh et al., 2022; Fairoj et al., 2023; Austin and

Ballaré, 2023; Mao et al., 2023). Throughout their life cycle, plants are frequently subjected to a variety of abiotic stresses that disrupt cellular membrane and developmental processes (Fadiji et al., 2023; Jing et al., 2023). Salinity is a major abiotic stress that reduces the productivity of agricultural crops including wheat worldwide (Corti et al., 2023a; Jing et al., 2023). Wheat (*Triticum aestivum* L.) is a major cereal crop which is used as staple food by approximately one third people of the world (Fairoj et al., 2023).

Salinity causes osmotic stress and ionic stress which affects plant growth and development (Mariyam et al., 2023; Rostampour et al., 2023; Sóti et al., 2023). Osmotic stress is caused mainly by Na^+ and Cl^- in the soil solution which reduces the availability of water to roots (Naz et al., 2023a; Soni et al., 2023; Wang et al., 2023). When plant roots uptake Na^+ and/or Cl^- and these ions accumulated to pernicious levels in leaves, ion toxicity occurs (Hayat et al., 2022; Saeed et al., 2023). Ion imbalances and nutrient deficiency occur due to salinity (Naz et al., 2023b). Salinity reduces the growth of plant through osmotic effects; declines the ability of plants to take up water and this causes reduction in growth (Abrar et al., 2022; Zarbakhsh and Shahsavar, 2023). Thus, reduced water uptake is the common feedback of plants subjected to salinity stress (Masarmi et al., 2023; Tammam et al., 2023). Lower water status in plant body slows the rate of cell division and expansion mainly through a loss of turgor (Ahmad et al., 2023; Ullah et al., 2023). It affects almost every aspect of the morphology both external and internal physiology of plants and significantly reduces the yield. High salinity in soil badly affects the quality and quantity of crop production (Khan et al., 2023; Thampi et al., 2023) by inhibiting seeds germination, seedlings growth and developmental phases due to cumulative influences of higher osmotic potential and toxicity of specific ions (Hadjadj et al., 2023; Sarkar et al., 2023). Salinity restricts the growth and production by affecting physiological processes, including modification of ion balance, mineral nutrition, water status, stomatal behavior and photosynthetic efficiency (Iftikhar et al., 2023; Kumar et al., 2023) and oxidative damage due to manufacture of higher levels of reactive oxygen species (ROS), variations in the antioxidant enzymes (Loudari et al., 2023; Mangal et al., 2023; Singh et al., 2023). Salinity stress has been shown to increase chromosomal abnormalities, MDA, and proline buildup, impair the ascorbate-glutathione (AsA-GSH) cycle function, and cause programmed cell death (PCD) (Fedoreyeva et al., 2022; Prajapati et al., 2023). Various strategies have been evolved by plants to adapt to hostile surroundings (Blonder et al., 2023; Liu et al., 2023). To address salinity hassle, application of salicylic acid to wheat might be an effective strategy. Salicylic acid is phenolic in nature that is held by plants (Esmaeili et al., 2023; Rubio-Rodríguez et al., 2023). It has been allowed as an endogenous regulator in plants after discovering that it is involved in many plant physiological processes like photosynthesis, transpiration, nutrient uptake, chlorophyll synthesis, protein synthesis and transport (Arif et al., 2023; Azeem et al., 2023a; Pirasteh-Anosheh et al., 2023). SA induces changes in leaf anatomy and chloroplast structure and mitigates the antagonistic impact of salinity (Aazami et al., 2023; Sharma et al., 2023). A large number of studies advocate that salicylic acid treatment significantly increased quantities of endogenous salicylic acid, enhanced the antioxidant enzymes and contents of non-enzymatic compounds, improved the ratio of potassium to sodium and increased the plant growth resulting in the improved abiotic tolerance (Feng et al., 2023; Jalili et al., 2023; Pai and Sharma, 2023; Youssef et al., 2023). However, the influence of salicylic acid is mainly dependent on the concentration, plant species and application type (Ben Youssef et al., 2023; Elhindi et al., 2023). It is a cell reinforcement compound which controls plant development (Kaya et al., 2023; Virág et al., 2023). Exogenous application of salicylic acid has impact on stomatal conclusion and increases plant dry biomass (shoot and root) in wheat (Abdi et al., 2022; Iqbal et al., 2022; Fairoj et al., 2023).

Salicylic acid helps to induce abiotic stress tolerance by by scavenging ROS, enhancing RWC, gas exchange activities and photosynthetic pigments, maintaining lower Na^+ concentrations and a Na^+/K^+ ratio, maintaining cell turgor, protecting cell structures and maintaining ion homeostasis (Ali et al., 2023; Arikan et al., 2023; Hussain et al., 2023; Omidi et al., 2022; Shaukat et al., 2022). The production of wheat, which is Bangladesh's second most important cereal crop, is inadequate in the country's coastal regions. The nation still produces a lot less wheat each year than is needed. Incorporating wheat into the current farming pattern on the saline soil could prove to be a worthwhile endeavor in utilizing these lands to address the food and nutritional deficit of Bangladesh's rapidly growing population. The understanding of changes in physiological processes controlled by salicylic acid and NaCl may offer a foundation for improving wheat plant yield in regions severely impacted by salt stress. Thus, the primary goal of this review is to assess the advantageous effects of salicylic acid on the morpho-physiology and productivity of wheat grown in saline environments.

EFFECTS OF SALICYLIC ACID ON MORPHOLOGICAL TRAITS

Reduction in plant height by salt stress is a common phenomenon for different crops (Ali et al., 2022; Kumar et al., 2022). Salinity had negative effect on the rate of photosynthesis, enzymatic activity level of carbohydrates and growth hormones that resulted in reduced plant height (Hu et al., 2022; Yan et al., 2022). Biswas et al. (2019) reported that the reduction in plant height was probably resulted from a slow growth caused by osmotic stress imposed by high concentration of salts in the rooting zone.

Khanam et al. (2018) analysed the growth and yield returns of two rice cultivars, BR55 and BR43 under salt stress and reported that plant height, total tiller, leaf number, leaf area decreased significantly with the increasing levels of NaCl. High salt stress may create obstacles in root and shoot elongation and reduce fresh and dry weight in plant by decreasing of osmotic potential (Azeem et al., 2023b; Trușcă et al., 2023). The cell wall thickening and inhabitation of cell elongation are the most common effects which results in reduction in growth and development of shoot and root under saline condition (Dabravolski and Isayenkov, 2023; Liu et al., 2022). Dry matter production and number of green leaves per plant were reduced with the increasing salinity due to inhibition of the formation of leaf primordia under salt stress (Fairoj et al., 2023; Mariyam et al., 2023). It has been reported that leaf number per plant was reduced by salinity and the effect was alleviated by SA treatment. SA treatment increased leaf number per plant in wheat (Abdi et al., 2022; Fan et al., 2022).

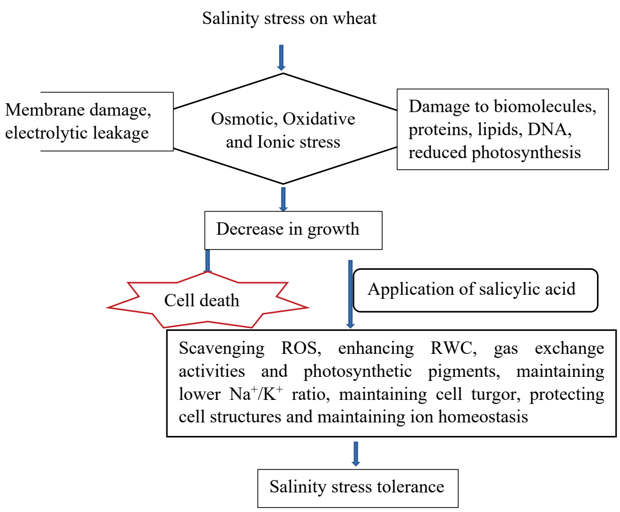

Figure 1. Schematic representation of salinity stress effects on wheat and tolerance to it.

Suhaib et al. (2018) performed an experiment with two wheat cultivars (Faisalabad- 2008 and Punjab-2011) with two levels of salicylic acid (0.25 mM and 0.50 mM) under two salt levels (75 mM and 150 mM). Salt stress had negative impact on shoot length of wheat plant. The results are agreed with the findings of Corti et al. (2023b) and observed that leaf area and shoot surface area were reduced in saline situation in *Eruca sativa*. Suhaib et al. (2018) observed significant enhancement in shoot length, root length, number of tillers when salicylic acid was applied (Figure 2a, 2b, 2c).

Ghafiyehsanj et al. (2013) evaluated the influence of salicylic acid on some biochemical characteristics of wheat under saline stress and reported that salinity significantly reduced the plant growth but application of salicylic acid improved the growth by increasing root length. Abdel-Lattif et al. (2019) conducted two field experiments to evaluate the response of using different concentrations of salicylic acid viz. zero (control), 100 and 200 mg L^{-1} in three wheat varieties, Gemmeiza7, Sakha 93 and Giza168 under salt stress.. They reported that spraying wheat with 100mg L^{-1} of salicylic acid significantly increased the plant height, plant dry weight, plant fresh weight of all varieties (Gemmeiza7, Sakha 93 and Giza168) compared with control. They concluded that, exogenously applied SA increased the salinity tolerance of wheat, particularly by reducing the negative effects of salts.

Cornelia et al. (2010) evaluated the effect of Salicylic acid on salinity treated wheat. They used following treatment combinations, control (C) 12 hour soaked in water and germinated in water; sample 1 (S_1) 12 hour soaked in water and germinated in 200 mM NaCl solution; sample 2 (S_2) 12 hour soaked in 0.1 mM SA solution and germinated in 200 mM NaCl solution; sample 3 (S_3) 12 hour soaked in 0.05mM SA solution and germinated in 200 mM NaCl solution (Table 1). The salt treatment significantly reduced plant height, leaf area, leaf fresh weight, leaf dry weight. The negative effect of salt stress was reduced for both concentration of SA solution but maximum enhancements in plant height, leaf area, leaf fresh weight, leaf dry weight were recorded in case of treatments with 0.1 mM SA solution.

Turkyilmaz (2012) had also studied the consequence of SA application under salinity stress. He reported that, plant height, dry weight per plant of wheat was reduced by salinity, and the effect was alleviated by SA treatment. SA treatment significantly increased plant height, dry weight per plant of wheat. The results are in agreement with Fairoj et al. (2023).

Loutfy et al. (2020) concluded that during combined interaction of 0.5 mM SA and 150 mM NaCl treatment

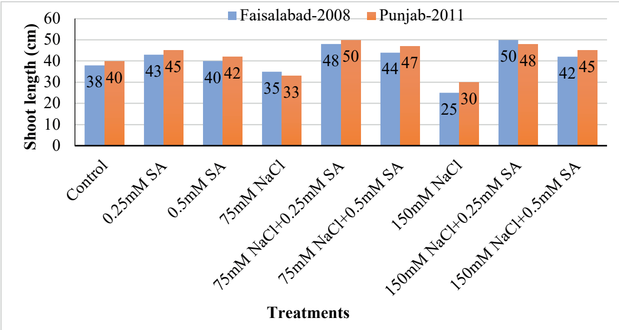

Figure 2a. Mitigation of salt stress on shoot length of wheat through the application of salicylic acid. (Source: Modified from Suhaib et al., 2018).

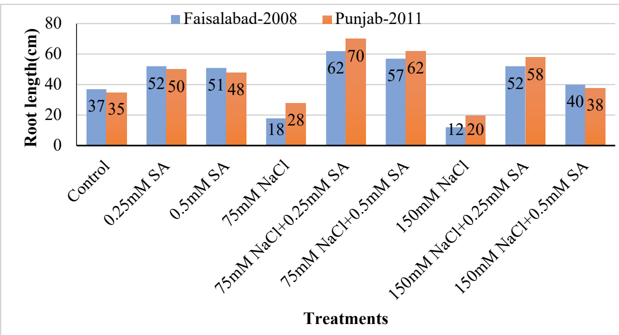

Figure 2b. Mitigation of salt stress on root length of wheat through the application of salicylic acid. Source: (Modified from Suhaib et al., 2018).

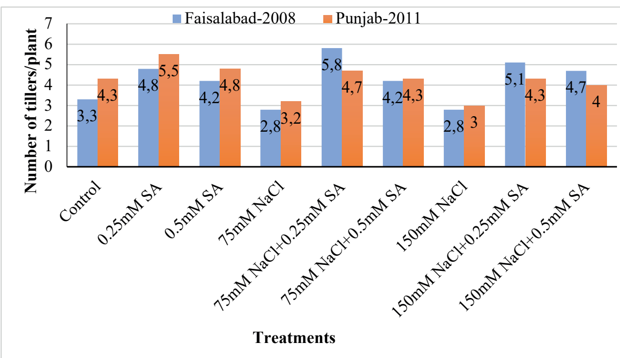

Figure 2c. Mitigation of salt stress on number of tillers of wheat through the application of salicylic acid. Source: (Modified from Suhaib et al., 2018).

root fresh mass, root dry mass shoot dry mass, root dry mass were increased in both Gemaza-1 and Sakha-69 wheat variety than 150 mM NaCl treatment (Figure 3a, 3b, 3c, 3d). Desoky and Merwad (2015) evaluated the

Table 1. Salicylic acid mitigates the effects of salinity on leaf area, leaf fresh weight and leaf dry weight of wheat.

Treatment	Leaf area (cm^2)	Leaf fresh weight (g)	Leaf dry weight (g)
Control	7.14	0.082	0.0092
150mM NaCl	5.23	0.058	0.0053
150mM NaCl+ 0.05mM SA	6.25	0.065	0.0054
150mM Nacl+0.1mM SA	6.98	0.084	0.0114

Source: (Modified from Cornelia et al., 2010).

response of exogenous application of salicylic acid (SA) under NaCl stress on wheat plants (*Triticum aestivum* L.) to different levels of foliar spray of salicylic acids at a rate of 0.1% and 0.2 %. SA_1 was 0.1% and salinity levels were, 3 dSm^{-1}, 6 dSm^{-1}, 9 dSm^{-1}. They concluded that NaCl treatment significantly reduced the plant height, dry weight per plant and the effect was alleviated by SA treatment.

Afzal et al. (2006) assessed the mitigation of salinity stress by hormonal priming with abscisic acid (ABA), salicylic acid and ascorbic acid in spring wheat. Seeds primed with 50 ppm ascorbic acid and 50 ppm SA significantly increased root length, shoot length, root dry weight, root fresh weight, shoot fresh weight and shoot dry weight. Fardus et al. (2018) examined to evaluate salicylic acid-induced improvement in germination and growth parameters of wheat under salinity stress. . Five salinity levels recorded as control, 50 mM, 100 Mm, 150 mM and 200 mM of NaCl were imposed on salinity tolerant and salinity sensitive (variety of wheat namely, BARI Gom 25 and BARI Gom 21. They reported that, plant height, length of shoot, length of root, tiller number per hill, fresh weight per plant, dry weight per plant, fresh weight of root per seedling, dry weight of root per seedling, fresh weight of shoot per seedling, dry weight of shoot per seedling was reduced by salinity and the negative effect of salt stress was alleviated by SA treatment.

EFFECTS OF SALICYLIC ACID ON PHYSIOLOGICAL TRAITS

Salicylic acid is a plant hormone which plays diverse physiological roles in plants, including growth, flower induction, nutrient absorption, stomatal closure, ethylene biosynthesis and photosynthesis (Desire and Arslan, 2021; Jangra et al., 2023). The response of plants to salinity is the reduction of total chlorophyll and carotenoids contents in leaves of reported by most of the studies. Plants that are grown under saline stress, photosynthetic

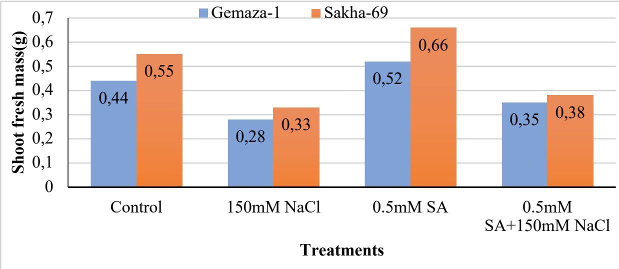

Figure 3a. Mitigation of salt stress effects on shoot fresh mass of two wheat cultivars through the application of salicylic acid. Source: (Modified from Loutfy et al., 2020).

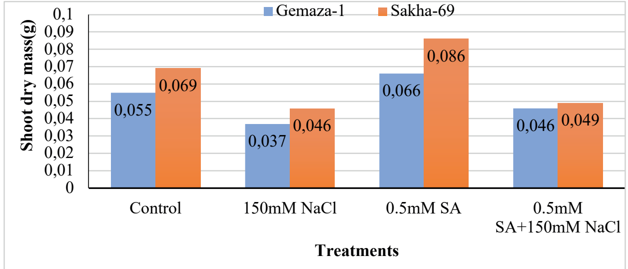

Figure 3b. Mitigation of salt stress effects on shoot dry mass of two wheat cultivars through the application of salicylic acid. Source: (Modified from Loutfy et al., 2020).

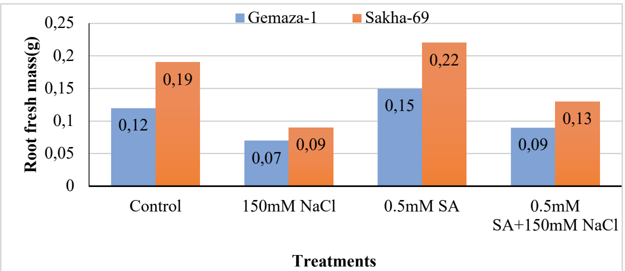

Figure 3c. Mitigation of salt stress effects on root fresh mass of two wheat cultivars through the application of salicylic acid. Source: (Modified from Loutfy et al., 2020)

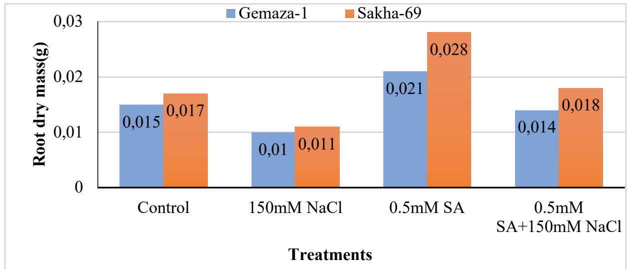

Figure 3d. Mitigation of salt stress effects on root dry mass of two wheat cultivars through the application of salicylic acid. Source: (Modified from Loutfy et al., 2020).

activity reduces resulting in reduced plant growth, leaf area, chlorophyll content and chlorophyll fluorescence (Mousavi et al., 2022; Song et al., 2019). It has been observed that under the influence of salinity the photosynthetic pigments greatly decreased due to chlorophyll a, b and carotenoids reduced significantly in saline stressed plants (Askari et al., 2023; Singh et al., 2022).

Turan et al. (2007) investigated variations in chlorophyll concentrations and growth of wheat plants (*Triticum aestivum* L. cv: Cakmak-79) which were grown under salinity stress in greenhouse conditions. They found that the normal growth and development of plants were disturbed by salt stress. The increased amount of NaCl applied to soil resulted in lower chlorophyll content. Hossain et al. (2006) performed an experiment with two wheat varieties namely Aghrani and Kanchan that were exposed to to 50, 100 and 150 mM NaCl till their maturity. They found decreasing trends of chlorophyll content with increasing salinity levels in both variety. Biswas et al. (2019) reported that longer the exposure to salinity stress higher the decreases the SPAD value. It has been reported by the pre-treatment of salicylic acid as a foliar spray mitigated the salt stress impact on the total chlorophyll (SPAD) pigment content of wheat seedling leaves (Hafez, 2016; Noreen et al., 2019).

Suhaib et al. (2018) evaluated the response of two wheat cultivars (Faisalabad-2008 and Punjab-2011), with two levels of salicylic acid (0.25 mM and 0.50 mM) under two salt levels (75 mM and 150 mM). Salt stress had negative impact on chlorophyll content and Na^{+}/K^{+} ratio of wheat plant under both levels of salt stress whereas, 0.25 mM salicylic acid was more effective than 50 mM salicylic acid. Chlorophyll content significantly increased with the application of salicylic acid. They reported that the maximum chlorophyll content per plant was observed in 0.25 mM SA under 75 mM NaCl (Figure 4). The salinity treatments significantly increased the Na^{+}/K^{+} ratio in wheat plants. The maximum Na^{+}/K^{+} ratio was observed under 150 mM NaCl treatment and in Punjab-2011. But salicylic acid remarkably reduced the sodium uptake by the plantsand increased uptake of K^{+}. As a result, Na^{+}/K^{+} ratio was decreased for using salicylic acid (Figure 5).

Biswas et al. (2019) concluded that, chlorophyll content of wheat was reduced by salinity and the effect was alleviated by SA treatment. Loutfy et al. (2020) reported the response of 2 wheat cultivars (Gemaza-1 and Sakha-69) under four different treatments i.e. (i) Control (ii) 150 mM NaCl (iii) 0.5 mM SA, and (iv) 0.5 mM SA and 150 mM NaCl. They reported that, with the pres-

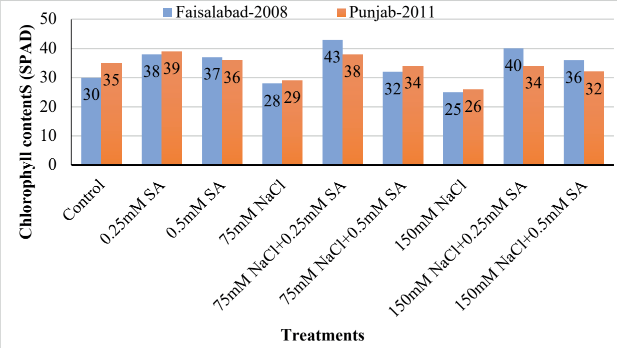

Figure 4. Salicylic acid mitigates the salinity effects on chlorophyll contents (SPAD value) of wheat. Source: (Modified from Suhaib et al., 2018)

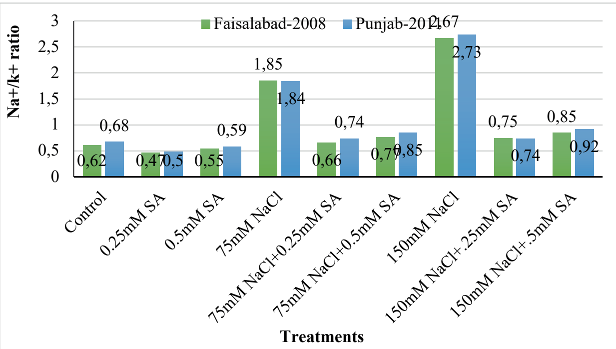

Figure 5. Salicylic acid mitigates the salinity effects on Na^+/K^+ ratio of wheat. Source: (Modified from Suhaib et al., 2018)

ence of 150 mM NaCl, SA significantly recovered chlorophyll content of wheat. Salt stress caused a reduction of 16–24% in PPC in Gemaza-1 and 12–18% reduction in Sakha-69.SA increased PPCs in both cultivars, by 10–20% for carotenoid or Chlorophyll a, but only 2–4% for Chlorophyll b. SA also recovered the reduced PPCs, near to control levels for carotenoid (99–98%), or to 90–96% and 85–91% of control for Chlorophyll a and Chlorophyll b, respectively. They also reported that leaf relative water content was lowest under 150mM NaCl treatment but addition of 0.5mM SA increased leaf relative water content of wheat under both saline and non-saline condition in both Gemaza-1and Sakha-69.

Cornelia et al. (2010) evaluated the effect of SA on salinity treated wheat following treatment combinations, control (C) – 12 h soaked in water and germinated in water; sample 1 (S_1) – 12 h soaked in water and germinated in 200 mM NaCl solution; sample 2 (S_2) – 12 h soaked in 0.1 mM SA solution and germinated in 200 mM NaCl solution; sample 3 (S_3) – 12 h soaked in

Table 2. Effect of salicylic acid (SA) on leaf relative water content, stomatal conductance and photosynthetic rate of wheat plant under salt stress.

Treatment	Leaf relative water content (%)	Stomatal conductance (mol $m^{-2}s^{-1}$)	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})
Control	81.9	0.08	2.33
150 mM NaCl	67.9	0.04	1.29
150 mM NaCl+.05 mM SA	74.9	0.06	1.35
150 mM Nacl+.1 mM SA	82.9	0.07	2.17

Source: (Modified from Cornelia et al., 2010).

0.05mM SA solution and germinated in 200 mM NaCl solution. They found that salicylic acid application increased the content of assimilatory pigments as compared with salt stressed samples. The effect of the salicylic acid solutions treatment was contingent on the concentration which was used. The content of chlorophyll an increased non-significantly after seeds presoaking in 0.05 mM SA solution. Chlorophyll a and chlorophyll b contents increased very significantly than salt stressed when treated with 0.1 mM SA solution. Cornelia et al. (2010) also reported that maximum leaf relative water content, stomatal conductance, photosynthetic rate was observed in addition of 0.1 mM SA with the presence of 150 mM NaCl treatment (Table 2).

Silva et al. (2020) conducted an experiment where the treatments consisted of five levels of electrical conductivity of supplied water - ECw (0.8, 1.6, 2.4,3.2 and 4.0 dS m-1) and four concentrations of salicylic acid (0, 1.2, 2.4 and 3.6 mM). They reported that SA treatment mitigated salts tress and increased stomatal conductance, transpiration, CO_2 assimilation rate, internal CO_2 concentration of salinity treated soursop (*Annona muricata* L.). Methenni et al. (2018), analysing the influence of salicylic acid (0, 0.5 and 1.0 mM) and salt stress (0 and 200 mM of NaCl) on olive plants *(Olea europaea* L.) confirmed that 1.0 mM salicylic acid upgraded increments in CO_2 assimilation rate and stomatal conductance.

Khan et al. (2019) investigated the feasible influence of foliar and soil-applied SA and bagasse compost (BC) introduction on wheat (*Triticum aestivum* L.) grown under saline condition (EC 14 dSm^{-1}). They reported that the artificially developed salinity significantly reduced chlorophyll content of wheat plants but application of SA significantly increased chlorophyll content of salinity treated wheat.

The advantageous effect of salicylic acid on CO_2 assimilation rate, confirmed in plants subjected to concentrations of up to 1.4 mM, may be related to the ability of salicylic acid to promote enzymatic and photosynthetic activities, while also maintaining the balance between the manufacture and elimination of reactive oxygen species (Batista et al., 2019). Morad et al. (2013) evaluated the effect of salt stress and salicylic acid application on growth and yield component traits of wheat where they concluded that foliar application of salicylic acid stimulated the growth of wheat plants via the enhancement of the biosynthesis of photosynthetic pigments; increased relative water content and thus salicylic acid promoted wheat growth.

Salinity stress has been shown to increase chromosomal abnormalities, MDA, and trigger autophagy, as well as programmed cell death (PCD) (Fedoreyeva et al., 2022; Liu et al., 2009; Ma et al., 2024; Prajapati et al., 2023; Tabur et al., 2021; Tabur et al., 2022).

PCD is a series of processes that occur in different tissue cells that are intended to die but have a specific positive effect related to the function of the cell, the tissue itself, or the whole organism (Kabbage et al., 2017). It has been observed that this process can occur in a variety of highly specialized tissues depending on their developmental stage, such as tapetum cells during lysis, prior to pollen release, abnormal megaspore death during megasporogenesis in angiosperms by forming antipodal cells or nucellus dissolution during gametophyte formation (Hanaoka et al., 2002; Reggiori et al., 2005; Thumm et al., 1994; Tsukada and Ohsumi, 1993; Xie and Klionsky, 2007).

Autophagy is a protein degradation process in which cells recycle cytoplasmic contents when subjected to environmental stress conditions or during certain stages of development. Upon the induction of autophagy, a double membrane autophagosome forms around cytoplasmic components and delivers them to the vacuole or lysosome for degradation. In plants, autophagy has been shown previously to be induced during abiotic stresses including nutrient starvation and oxidative stress (Liu et al., 2009). Although autophagy appears to be implicated in plant responses to abiotic stresses, its exact involvement has yet to be revealed. Salt and osmotic stress can enhance ROS generation and cause protein damage, and a possible hypothesis is that autophagy aids in the degradation of oxidized proteins during salt and osmotic stress (Pilot et al., 2004).

Fedoreyeva et al. (2022) conducted an experiment and found that in control wheat roots, the Carboxy-H2DFFDA marker detects ROS only in the apical part of the root cap, whereas under salt stress, Carboxy-H2DFFDA accumulates in cells of different root zones, indicating an increase in ROS content and the activation of oxidative stress and cellular damage. Thus, the buildup of the ROS fluorescent marker Carboxy-H2DFFDA in root cells in response to salt indicates that ROS homeostasis was disrupted in these cells and root tissues, potentially leading to PCD.

Liu et al. (2009) stated that autophagy is induced in high salt and osmotic stress conditions, which coincides with an increase in the expression of the *Arabidopsis thaliana* autophagy-related gene *AtATG18a*. Autophagy-defective *RNAi-AtATG18a* plants are more sensitive to salt and drought than wild-type plants, indicating that autophagy plays a role in stress responses. NADPH oxidase inhibitors prevent autophagy induction under nutritional restriction and salt stress, but not during osmotic stress, demonstrating that autophagy can be initiated via NADPH oxidase-dependent or -independent mechanisms.

An experiment was conducted by Tabur et al. (2021) to investigate the efficiency of salicylic acid (SA) on cytotoxicity and genotoxicity induced by salinity stress in the barley apical meristems and they found that salt stress caused a significant decrease in mitotic index of barley seeds depending on concentration increase, while the frequency of chromosomal abnormality increased. Similarly, it was discovered that the mitotic index value dropped with SA therapy alone, although chromosomal aberrations increased. However, when SA and varied salt concentrations were used concurrently, the greatest salt concentration performed better than low salt concentrations in reducing the mitodepressive effect of salt stress by boosting the mitotic index by about twofold (Table 3). In contrast, low salt levels in this application were more effective than high salt levels in mitigating the clastogenic effect of salt stress on chromosomal structure and behaviors. Thus, they suggested that SA's protective role against the cytotoxic effects of salinity stress is more effective at low salt concentrations.

The pretreatment process of seeds was performed by soaking 24 h in constant volumes of distilled water (control) or SA. Various concentrations of salt were added to germination medium. All data were evaluated as three replicates

EFFECTS OF SALICYLIC ACID ON YIELD CONTRIBUTING PARAMETERS AND YIELD

Salt stress decreased the grain yield through a reduction in various components like in grains spike^{-1}, thousand grain weight, grain yield plant^{-1} spike number and grain number in most of the genotypes under saline condition (Al-Khafaji and Al-Burki, 2021; EL Sabagh et al., 2021; Sen et al., 2022). Decrease of grain yield by salt stress has been reported by Shah et al. (2023) and Gandahi et al. (2020). Khan et al. (2019) examined to evalu-

Table 3. Mitotic index values and frequency of chromosome abnormalities in meristem cells of barley exposed to different NaCl concentrations after salicylic acid pretreatment.

Mitotic Index (%)			Chromosome Abnormalities (%)		
NaCl Concentration (M, mol/L)	Control	SA (1µM, micromolar)	NaCl Concentration (M, mol/L)	Control	SA (1µM, micromolar)
0.00 (Distilled water)	*6.92 ± 0.6^{d}	5.50 ± 0.3^{c}	0.00 (Distilled water)	*0.00 ± 0.0^{a}	1.06 ± 0.0^{a}
0.32	6.10 ± 0.2^{c}	3.55 ± 0.2^{a}	0.32	2.07 ± 0.1^{b}	1.77 ± 0.4^{b}
0.35	3.57 ± 0.2^{b}	3.47 ± 0.3^{a}	0.35	2.80 ± 0.0^{c}	2.71 ± 0.3^{c}
0.40	2.41 ± 0.3^{a}	4.68 ± 0.8^{b}	0.40	3.48 ± 0.5^{d}	3.73 ± 0.3^{d}

* ($P \leq 0.05$), ± Standard deviation Source: (Modified from Tabur et al., 2021).

ate the feasible effects of foliar and soil-applied SA (0.5 mM) and bagasse compost (BC) addition on wheat (*Triticum aestivum* L.) growth in saline soil (EC 14 dSm^{-1}). They concluded that artificially developed salinity significantly reduced length of spike, thousand grain weight of wheat plants while application of SA significantly increased spike length, thousand grain weight of salinity treated wheat.

Akher et al. (2013) conducted an experiment to observe the role of salicylic acid on alleviation of salt stress in wheat. Four different salinity levels and three different levels of salicylic acid (SA) was used to their experiment. They reported that salicylic acid (0.2 mmol SA and 0.4 mmol SA) had increased spikelets per spike, grains per spike, grain weight per spike, thousand grain weight, grain yield, straw yield, biological yield and harvest index under saline and non-saline condition (Figure 6 to 11). Under salt stress, the highest no of spikelets per spike, grains per spike, grain weight per spike, thousand grain weight, grain yield, straw yield, biological yield, harvest index was observed in case of application of 0.4 mmol SA with the presence of 2.8g NaCl /kg of soil.

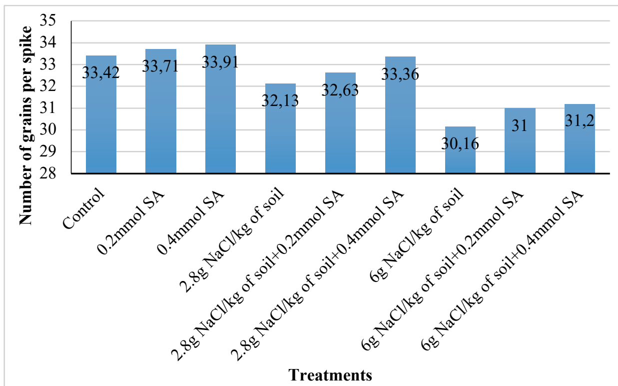

Figure 7. Amelioration of salinity stress on number of grains per spike of wheat through exogenous application of salicylic acid. Source: (Modified from Akher et al., 2018).

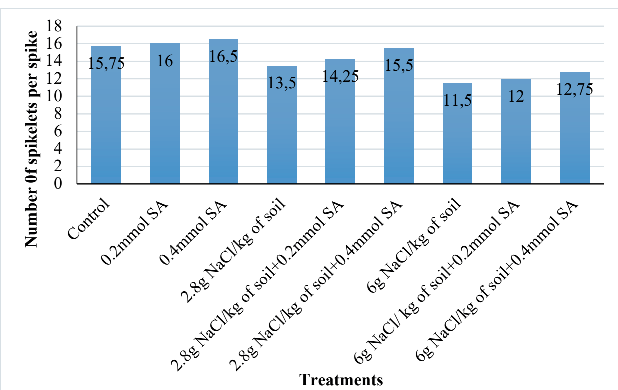

Figure 6. Amelioration of salinity stress on spikelets per spike of wheat through exogenous application of salicylic acid. Source: (Modified from Akher et al., 2018).

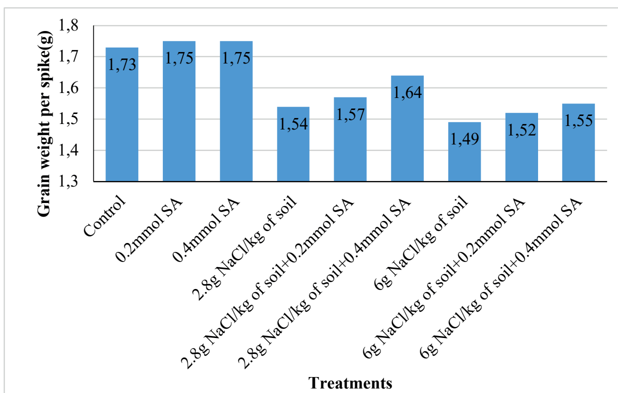

Figure 8. Amelioration of salinity stress on grain weight per spike of wheat through exogenous application of salicylic acid. (Modified from Akher et al., 2018).

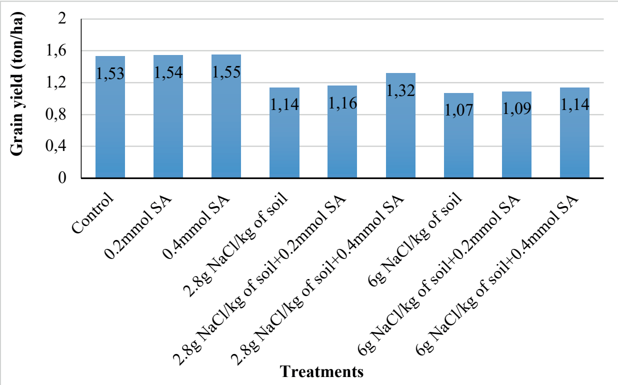

Figure 9. Combined effect of different levels of salinity and salicylic acid (SA) on grain yield of wheat. Source: (Akher et al., 2018).

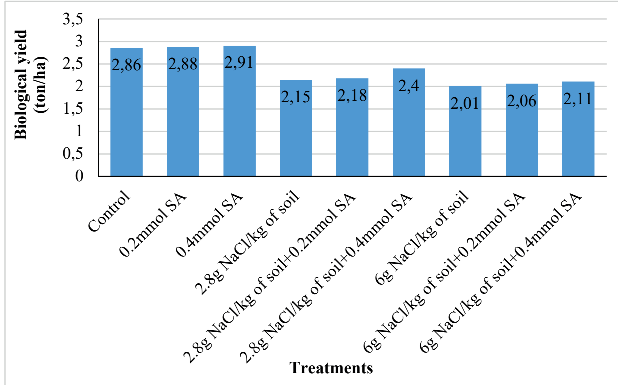

Figure 11. Combined effect of different levels of salinity and salicylic acid (SA) on biological yield of wheat. Source: (Akher et al., 2018).

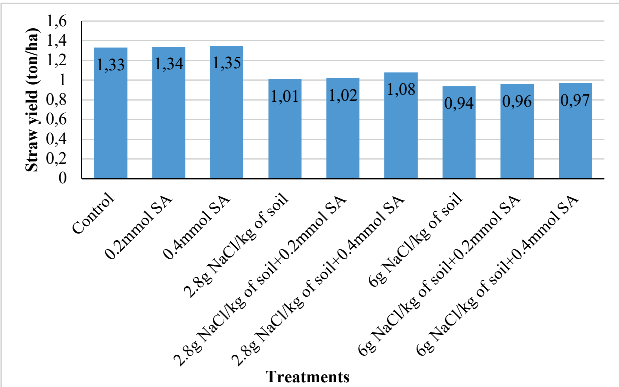

Figure 10. Combined effect of different levels of salinity and salicylic acid (SA) straw yield per plant of wheat. Source: (Akher et al., 2018).

Abdel-Lattif et al. (2019) conducted two field experiments to evaluate the response of using different concentrations of salicylic acid viz. control (zero), 100 mg L^{-1} and 200 mg L^{-1} in three wheat varieties, Gemmeiza7, Sakha 93 and Giza168 under salt stress. They reported that spraying the wheat (*Triticum aestivum* L.) plants with salicylic acid in both concentrations (100 and 200 mg L^{-1}) improved number of spikes per plant, filled grains per spike, spike weight/plant, grain yield per plant, grain yield(ton/ha), 100 grain weight.

Desoky and Merwad (2015) examined the response of exogenous application of salicylic acid (SA) under NaCl stress on wheat plants (*Triticum aestivum* L.) to different levels of foliar spray of salicylic acid. They concluded that NaCl treatment significantly reduced the grain yield per plant, straw yield per plant, biological yield, 1000 grain weight, efficiency yield and the effect was alleviated by SA treatment. SA treatment increased grain yield per plant, straw yield per plant, biological yield, 1000 grain weight, efficiency yield.

Morad et al. (2013) evaluated the response of salinity stress and salicylic acid on growth and yield traits of two variety of wheat. Three levels of NaCl treatment (control, 4 dS/m and 8 dS/m) and salicylic acid. They reported that, minimum no of grains per spike, weight of grains per spike, spike length was observed under 8 dS/m salinity but SA application alleviated the salt stress effect and under saline stress the highest no of grains per spike, weight of grains per spike, spike length was observed in addition of SA with the presence of 4 dS/m NaCl.

CONCLUSION

This review highlighted the deleterious effects of salinity stress on the morpho-physiological parameters of wheat, including transpiration, photosynthetic rate, internal CO_2 concentration, shoot and root length, number of total tillers, leaf area, leaf fresh and dry weight, shoot fresh and dry mass, root fresh and dry mass, chromosomal structure and behaviors. However, it is also conspicuous that application of salicylic acid has a positive influences on improving those morpho-physiological parameters of wheat under saline condition by scavenging ROS, enhancing RWC, gas exchange activities and photosynthetic pigments, maintaining lower Na^+ concentrations and a Na^+/K^+ ratio, maintaining cell turgor, protecting cell structures and maintaining ion homeostasis, all of which ultimately lead to induce abiotic stress tolerance. Therefore, more comprehensive research is required to investigate endogenous salicylic acid production, as well as improve wheat morpho-physiology and ionic homeostasis, both of which are critical for future sustainable crop productivity. Furthermore, increased field research on wheat genotypes is necessary to effectively mitigate salt stress by the use of exogenous salicylic acid, but it also needs to be cost-effective.

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