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Pallavi Parmar
Department of Biochemistry, Anand Agricultural University Anand, Gujarat, India

JD Dobaria
Department of Biochemistry, Anand Agricultural University Anand, Gujarat, India

JJ Dhruv
Department of Biochemistry, Anand Agricultural University, Anand, Gujarat, India

Corresponding Author:
Pallavi Parmar
Department of Biochemistry, Anand Agricultural University Anand, Gujarat, India

Understanding the role of Humic acids on cereals under saline condition: Review

Pallavi Parmar, JD Dobaria and JJ Dhruv

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Abstract
Salinity is one of the most significant abiotic stresses affecting crop production globally. It induces several inhibitory effects on growth and development of several plants. Saline soil reduces the development and productivity of many cereal crops such as rice, wheat, maize and sorghum. There are various chemicals in different parts of the world to improving plant growth against salinity stress. Improving the physiological status expressed in adjusting the osmolytes and nutrients balance of plant cell is a crucial matter for ameliorating the hazards of salinity. Humic acid helps cereals grow under saline conditions by improving soil properties, enhancing nutrient uptake, modulating plant physiological processes, and promoting overall stress tolerance. In this review, we describe the mechanism and influence of humic acid on cereal crops.

Keywords: Salinity stress, cereal crops, humic acid, nutrient uptake, soil properties, stress tolerance

Introduction

Cereals can be defined as a grain or edible seed of the grass family, Gramineae (Bender & Bender 1999) [9] Cereals are regarded as the world's most significant food group. Cereals are the grain-producing crops that provide more than 50 percent of human energy and protein needs. Cereals are considered to be the earliest cultivated crops and have been the staple food for most human societies for over 10,000 years due to specific features such as ease of growth, storage and transport (Calderini and Slafer, 1998) [11]. They are grown in many regions of the world and comprise of numerous species and varieties adapted to different climatic conditions. Conway and Toenniessen (1999) [16] stated that Cereal crops have a number of adaptations which enable them to survive and grow well in the particular environmental conditions. There are over 8000 kinds of herbaceous plants known as grasses, which contain tiny blooms and dry fruits called grains or "caryopses." In wheat, corn, and rye, these caryopses are naked, displaying only the germ, endosperm, and seed membrane; in rice, oats, barley, and sorghum, they are coated, displaying the same structure covered with a husk. Cereals are grown for their highly nutritious edible seeds, which are often referred to as grains. Cereals are the most important sources of food (FAO 2002), and cereal-based foods are a major source of energy, protein, B vitamins and minerals for the world population.

Wheat, rice, corn, barley, oats, rye, and sorghum are the primary cereals used in human and animal nutrition. While, millet, triticale, spelt, and pseudocereals such quinoa, amaranth, wheat buckwheat, are comes under the roof of less common cereals. Cereals possess a huge number of various biomolecules such as carbohydrates (70-80%), moisture (12-13%), protein (9-13%), lipids (2-5%), fiber (0.5-2%), and minerals (1-3%). Cereals are mostly used to make flour for baked goods and to make animal feed by turning them into fiber and bran (Papageorgiou and Skendi, 2018) [49]. Cereals consist of an embryo (or germ) which contains the genetic material for a new plant. The main part of the grain is the endosperm, packed with starch grains. If the cereal grain germinates, the seedling uses the nutrients provided by the endosperm until the development of green leaves (McKevith, 2004) [44].

In 2024, total cereal production estimated was 2859.9 million tones globally (FAO, 2025). India's cereal production for 2024-25 is estimated to reach an all-time high of about 328.72-3539.59 lakh metric tones (Press Release: Press Information Bureau). The total area under cereals in India for 2024-25 is estimated at approximately 734.89 lakh hectares.

The total cereal productivity of India in 2024-25 is estimated at approximately 4,818 kg per hectare. Gujarat's cereals area for 2024-25: roughly 1,354.28 thousand hectares; production is led by rice (2.23 million tonnes); overall productivity is consistently above 2,000 kg/ha for major cereals (Press Release: Press Information Bureau).

Cereals differ in their biochemical makeup depending on the species and cultivars. Cereals are mostly composed of carbohydrates, which account for 65-75% of their weight. Protein accounts for 7-12% of the weight of cereals, making it the second greatest component. Cereal protein varies in molecular weight and amino acid content. Although they vary greatly by grain variety, lipids make up 2-6% of cereals. Cereals contain 12-14% water. Mineral salts such as calcium, magnesium, potassium, iron, zinc, and copper can be found in whole grains. Vitamins such as thiamine, riboflavin, niacin, pyridoxine, biotin, folic acid, vitamin E, and vitamin A are also found in whole grains (Garutti *et al*., 2022) [27]. Cereals contain lignins, flavonoids, tannins, alkylresorcinols, and phenolic acids, all of which have antioxidant qualities (Tufail *et al*., 2023) [66]. Cereals' chemical constituents are not dispersed uniformly throughout the grain e.g., twenty-five times higher mineral accumulation was observed in wheat's aleurone layer as compared to the endosperm.

Insights towards reducing the negative effects of salt stress on wheat can be gained from a thorough study of the physiological, biochemical and molecular changes that occur in wheat under salt stress. Salt stress negatively impacts wheat production and is linked to decreased germination, growth, enzymatic activity and reproductive behavior, interrupted photosynthesis, hormonal imbalance, oxidative damage, and yield losses. Therefore, a deeper comprehension of how wheat responds to salinity stress is crucial for developing compensatory and mitigating strategies. To address salt stress tolerance, a variety of strategies can be employed, such as conventional breeding, molecular methods, and cultivar selection. But these methods are time-consuming, expensive, and labour-intensive. Under salinity stress, management techniques continue to be beneficial for enhancing wheat performance. Important strategies to enhance wheat performance under salinity stress include seed priming, nutrition control, and the exogenous use of phytohormones and biostimulants (Majeed *et al*., 2019 [41], Saddiq *et al*., 2021 [56], El Sabagh *et al*., 2021 [20], Zhang *et al*., 2022, Zheng *et al*., 2023) [71].

The regulation of plant growth and the development and alleviation of the negative effects of environmental stresses during ontogenesis, are important factors determining the productivity of cultivated plants. Biostimulants can be treated as an additive to fertilizers and support the uptake of nutrients promote plant growth, and increase tolerance to abiotic stress. Biostimulants can be obtained from plants rich in secondary metabolites, which are also one of the main kinds of bioactive compounds proposed as responsible for activating the physiological responses of plants (Magdalena Drobek *et al*., 2019) [40]. Glutamic acid, humic acid, proline, glycine betaine and other natural compounds are examples of biostimulants that may be utilized to lessen the consequences of water stress. However, little research has been done on how they affect food quality and plant productivity when there is a water scarcity. According to certain research, the use of biostimulants improves nutrient absorption efficiency and stress tolerance through improved osmotic adjustment, hence mitigating the adverse effects of drought stress. However, compared to synthetic compounds, other research has shown that BS has greater beneficial effects in reducing drought stress. In contrast to chemical fertilizer application, recent studies have demonstrated that BS administered as organic and bio-fertilizers may improve the nutrient utilization efficiency in plants under drought stress. Additionally, biostimulants encourage nitrogen-fixing bacteria, improve potassium and phosphorus solubilisation, control the secretion of phytohormones like auxin, cytokinin, gibberellin and regulate the acquisition of nutrients. These factors may improve soil structure and aggregation and boost plant productivity (Rezaei-Chiyaneh *et al*., 2023) [53].

Based on their impact and/or function in affecting plant growth, biostimulants are classified into a number of different categories. According to various scientists (Calvo *et al*., 2014 [12]; Rouphael and Colla, 2018) [54] there are several types of biostimulants, including inorganic substances such as aluminum, copper, sodium, selenium, and silicon; organic natural substances such as fulvic and humic acid; animal and vegetal protein hydrolysates; seaweed extracts; and compounds derived from smoke; and beneficial microorganisms like arbuscular mycorrhizal fungi, N_2-fixing bacteria and plant growth-promoting rhizobacteria.

The residues of degraded plant and animal components, including lignin, tannins, cellulose, and cutins, are known as humic substances (HS) (Tan *et al*., 2000 [66]; Billingham, 2012 [10]; Hayes and Swift, 2020) [31]. According to their solubility in aqueous, acidic, or alkaline solutions, HS are categorized as humins, fulvic acids and humic acids (HA, FA, HA) (De Melo *et al*., 2016) [19]. An essential part of soil, humic acid is a naturally occurring organic polymer with numerous vital functions. There is a wide molecular weight distribution; considerable chemical heterogeneity and an acidic nature owing to carboxylic and phenolic groups are characteristics of humic acids, which are naturally occurring polymers with aromatic blocks. About 50-80% of the organic matter in water from terrestrial sources, such as lakes and rivers, is made up of humic acid, which are produced by the decomposition of plants and animals (Capasso *et al*., 2007) [14]. The physical, chemical, and biological characteristics of soil, such as its pH, texture, structure, and ability to retain water, are all enhanced by humic acid. By improving metabolism, boosting food availability, and assisting plants in coping with stress, humic acid enhances plant development. Ampong *et al*., (2022) [6] suggested that humic acid can adsorb pollutants in water and soil, thus it can help to determine their fate in the environment. By precipitating harmful heavy metals, HA lowers their transit and, thus, the amount of toxic heavy metals that plants consume (Wu *et al*., 2017) [69].

Various scientists (De Melo *et al*., 2016 [19]; Nardi *et al*., 2021) [48] revealed that humic acid structure contains many functional groups, the most predominant are phenolic and carboxylic groups. The COOH and OH functional groups are mainly responsible for humic acid functions such as improving soil physical and chemical properties as well as plant growth). The mechanisms and functions of humic acids (Fig. 1) in soils and plants can be summarized in different six parts i.e. (1) Dissociation of functional groups of humic acid (2) Hydrophilic ends of dissociated groups form a bridge between metal ions and soil surface (3) Humic acids chelate cationic nutrients and transport them through root's plasma membrane; (4) hydrophilic ends of dissociated group attract cations (increase soil cation exchange capacity); (5) humic acids replenish nutrients in the soil solution (increase soil buffering capacity); (6) other functions of HA (Ampong *et al*., 2022) [6].

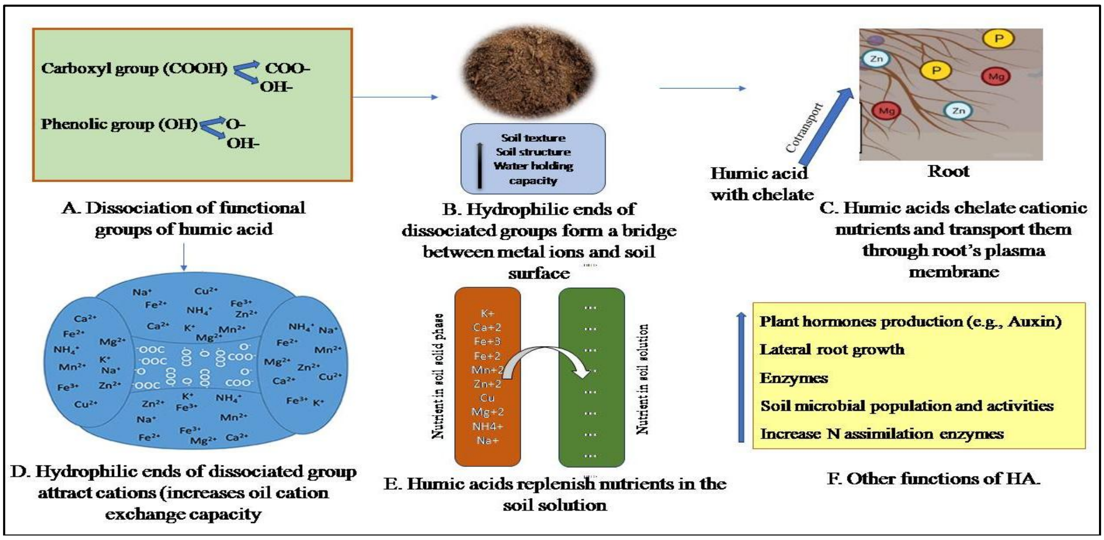


Fig 1: The mechanisms and functions of humic acids in soils and plants.

Mode of action

According to Saidimoradi *et al*., (2019) [57], Amerian *et al*., (2024) [5] and Aydin *et al*., (2012) [7] humic acid can help to maintain water absorption and decrease membrane damage as well as help to plants absorb more potassium and other mineral elements. Humic acid can also help to activate antioxidant enzymes that protect plants from stress (Meng *et al*., 2023) [45]. HA can act like plant hormones, integrating hormonal signaling and stress response pathways (Canellas *et al*., 2024).

Effects of Salt Stress on Plants

Salinity is considered a global threat to agriculture and causes a significant reduction in crop yield. Salinity stress is the accumulation of excessive salt contents in the soil which eventually results in the inhibition of crop growth and leads to crop death. Salt stress is considered an alarming condition as it decreases the agricultural productivity of soil and results in reduced crop yields. In particular, salinity stress promotes reactive oxygen species accumulation and ionic imbalance in cells, leading to oxidative stress and even cell death. Plants respond to salinity stress through a series of physiological, biochemical and molecular mechanisms.

Salinity affects 6.73 million hectares of land in India, or roughly 5% of the nation's net cultivated area. West Bengal, Maharashtra, Uttar Pradesh, and Gujarat have the biggest tracts of land damaged by salt. In addition to inland Gujarat and Rajasthan, saline soils can be found in mangrove, coastal, and deltaic plains. Globally, salinity affects over 1.2 billion hectares of land. About 15% of the world's saline land is severely to extremely limit for crop cultivation, while the remaining 85% is only mildly to moderately affected (Kumar and Sharma, 2020 [36], Singh, 2017) [61]. Gujarat has the largest saline agricultural land in India, with 2.23 million hectares. The coastal regions of Kutch and Saurashtra are particularly affected by salinity (Gururaja Rao *et al*., 2019) [26].

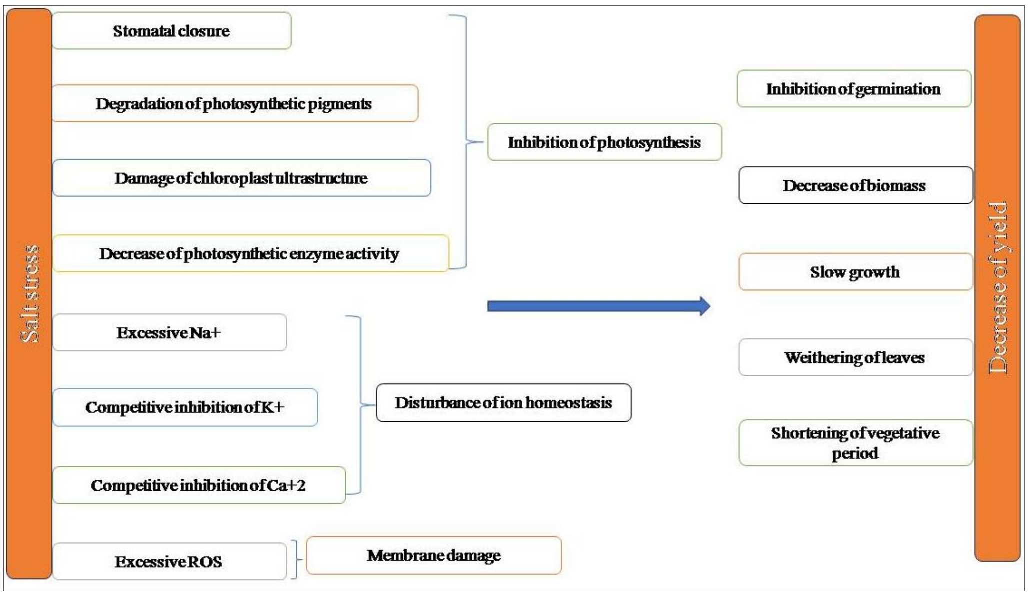


Fig 2: Plant salt injury mechanism and its impact on plant

According to earlier research (Hao *et al*., 2021) [30], plants under salt stress exhibit signs such as withering leaves, decreased germination rate, decreased plant height, delayed growth, and decreased growth of new branches (Fig. 2) These outcomes are caused by salt stress through two sequential processes, i.e. (1) Salt stress inhibits plant growth by decreasing the plants' ability to absorb water and (2) Ion toxicity, which further affects plant growth, occurs when too many salty ions enter the transpiration stream of plants and harm plant cells by preventing photosynthesis, disrupting ion homeostasis, and peroxiding membrane lipids. To sum up, understanding how plants' bodies react to salt stress is essential to enhancing their ability to withstand it.

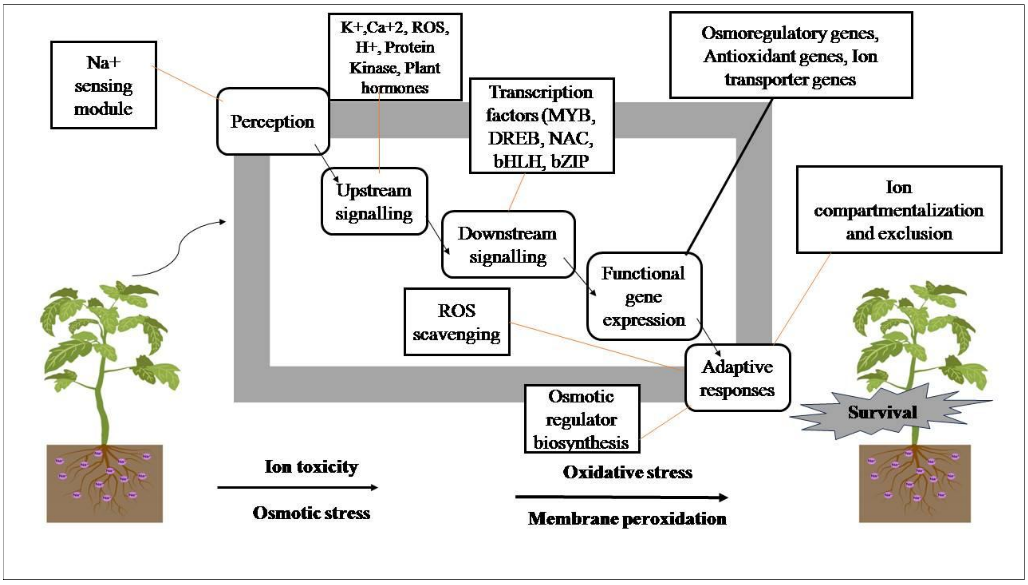
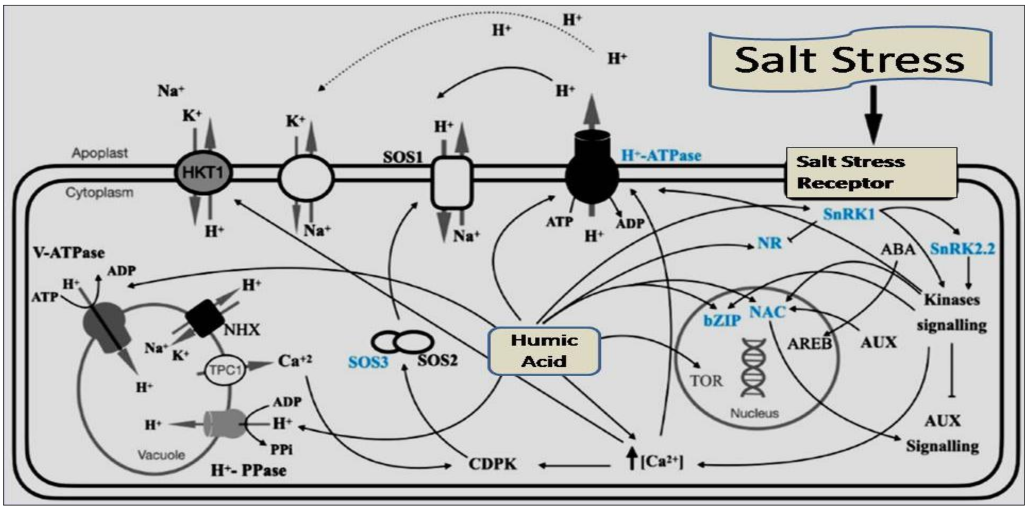


Fig 3: The process of plant salt tolerance development

There is a particular Na^+ sensing module that has not yet been identified that senses Na^+. Signaling responses upstream are triggered following early perception (Hao *et al*., (2021) [30]. Various protein kinases, ROS, phospholipids, K^+, Ca^{+2}, H^+ and plant hormones are all part of the intricate signal pathway. After then, transcription factors that control genes that react to stress are activated. Functional genes, such as those for ion transporters and antioxidants, are thus effectively expressed. Lastly, plants that can endure and develop tolerance to salt stress are able to scavenge ROS.

The following mechanisms of saline stress tolerance are induced by humic substances: (1) ion homeostasis, (2) membrane transport, (3) induction of antioxidative metabolism, (4) buildup of osmoprotective and antioxidant chemicals, (5) activation of signaling pathways, and (6) adjustment of hormonal balance (Canellas *et al*., 2024). Osmotic adjustment and ROS scavenging are two physiological regulating systems that can improve the tolerance of all higher plants to salt stress.

NaCl stress-signaling pathways and interactions with humic acids were explained by Canellas and his coworkers (2024).



White and Broadley (2003) concluded that the quantity of Ca^{+2} in plant cells rises dramatically when exposed to salt stress. Ca^{+2} has long been thought to be a signal molecule engaged in salt stress signal transduction in addition to being an osmotic regulator. The primary determinant of Ca^{+2} 's involvement as a second messenger is the variation in Ca^{+2} concentration within cells. Various Ca^{+2} channels, Ca^{+2} pumps, and H^+/Ca^{+2} antiporters found on the membranes of plant cells regulate Ca^{+2} input and outflow. As a result, cells have the flexibility to control variations in Ca^{+2} concentration and intensity and initiate a series of distinct signaling pathways.

Salt Overly Sensitive (SOS) pathway

The SOS pathway is a plant signaling pathway that maintains salt tolerance andion homeostasis by regulating sodium (Na^+) levels within plant cell. It affects calcium sensing proteins SOS3 and other related proteins, like protein kinase SOS2 and plasma membrane Na^+/H^+ antiporter SOS1. This antiporter leads to exclusion of Na^+ from cell. Thus, this pathway is essential for plant survival in saline stress condition by preventing toxic sodium accumulation and promoting adaptation to high salt conditions.

Quintero and his coworkers (2002) [50] indicated that significant concentration of sodium (Na^+) enters the cytoplasm of plants exposed to high salinity through high-affinity potassium transporters and non-selective cation channels. Cells may become ion poisonous if there is an excessive amount of Na+ in the cytoplasm. Plant cells primarily use the SOS signal transduction pathway to release sodium ion from the cytoplasm or separate it into vacuoles. A Ser/Thr protein kinase with an N-terminal catalytic region and a C-terminal regulatory region is encoded by the SOS2 gene. A protein that binds calcium ion (Ca^{+2}) is encoded by the SOS3 gene.

As a result, the transduction mode of the SOS signal is: high exterior Na^+ causes an increase in internal Ca^{+2}. Prior to binding to SOS2, SOS3 initially binds to Ca^{+2}. SOS3 disinhibits SOS2's self-inhibition, which in turn stimulates SOS2 kinase activity. The SOS1 transporter on the plasma membrane is then phosphorylated by the SOS3 and SOS2 complex, improving its capacity to move Na^+ out of the cell. On the vacuole membrane, NHX1 is another Na^+/H^+ antiporter. It can use a proton gradient to move both K^+ and Na+ into the vacuole. Apart from being involved in the salt response mechanism, NHX1 also controls protein localization, vesicle transport, K^+ concentration, and vacuole pH (Sottosanto *et al*., 2004) [62]. By controlling NHX1, which is likewise controlled by ABA, SOS kinases control the entry of Na+ into vacuoles (Shi and Zhu, 2002) [59]. H^+-ATPase and H^+-PPase are abundant on the vacuole membrane to promote Na^+ compartmentation because NHX requires a proton gradient to supply energy during Na^+ transport (Gaxiola *et al*., 2007) [25].

ABA Pathway

Through a Ca^{+2}-dependent signaling cascade, salt stress initially triggers ABA production by controlling the expression of the ABA synthase genes. According to Chen *et al*. (2020) [15], the ABA produced using this technique can further stimulates ABA synthesis via a positive feedback mechanism. ABA primarily controls stomatal opening and triggers the production of resistance genes in response to salt stress.

Merlot *et al*., (2001) [46] suggested that ABA can regulate the expression of corresponding genes directly without the participation of Ca^{+2}. In the absence of ABA, the phosphatase ABI1-insensitive1 (ABI1) inhibits the action of SNF1-related protein kinases (subfamily 2) (SnRK2s). ABA is perceived by the PYR/PYL/RCAR family proteins. When the PYR/PYL/RCAR family protein binds to ABA induced by abiotic stress, the complex inhibits the action of ABI1. When SnRK2s are released from inhibition, they activate several transcription factors from the ABA-responsive element-binding factor (ABF) family. ABFs then regulate the expression of a large number of stress-related genes. It can also be transformed into a Ca^{+2} signal for indirect regulation. ABA increases the Ca^{+2} concentration of cytoplasm by promoting the activity of selective Ca^{+2} channels on the plasma and vacuole membrane (Hamilton *et al*., 2000) [29]. Then, Ca^{+2} dependent phosphorylations, in turn, activate the activity of OST1 (ABA activated SnRK2 protein kinase open stomata 1), which is inhibited by 2C-type protein phosphatases (PP2C). OST1 further regulates the activity of guard cells SLAC1 anion channel (slowly activating anion conductance 1) and K^+ channel KAT1, resulting in stomatal closure (Lee *et al*., 2009) [38].

CDPK pathway

Ca^{+2} dependent protein kinases (CDPKs) are widely distributed in plants. Sub cellularlocalization shows that CDPKs can exist in either membrane-bound or a membrane-free state in cells. Most of them are located on the plasma membrane and organelle membrane. They are involved in the regulation of the whole process of plant growth and development and the process to resist abiotic stress (Dammann *et al*., 2003) [18]. It is generally believed that CDPKs regulate plant tolerance to salt stress mainly through regulating the stomatal opening and the expression of ion channel-related genes. The CDPK genes have been identified in a variety of plants, which decode transcription factors related to signal transduction, thus increasing the activity of protein kinase and other downstream signaling elements. CDPKs can also regulate the balance of ROS by inducing the expression of antioxidantgenes and inhibiting the expression of NADPH oxidase, thus playing a role in the responseto oxidative stress and improving the salt tolerance of plants.

Influence of humic acid on wheat

Abbas *et al*., (2022) [1] studied the effect of HA for improving salinity tolerance and nutrient uptake in two wheat genotypes with contrasting salt tolerance. They have found that shoot-root length, shoot-root dry weight, chlorophyll content and stomatal conductance decreased in saline stress conditions. In saline stress, exogenous HA (2 g/kg) after six weeks treatment enhanced photosynthetic activity, antioxidant enzyme activities, membrane stability index and nutrient uptake in both SARC 1 and SARC 5 wheat genotypes. Shah *et al*., (2023) [58] studied the effect of humic acid on wheat under saline conditions and found that application of humic acid @ 25 kg ha-1 had positively influenced all the growth and yield characters. Results indicated minimum germination percentage (66.67%), tillers per plant (3.00), grains per spike (39.83), 100 grain weight (3.41 g), grain yield (1648 kg/ha), and harvest index (16.50%) in S4 (15 dSm^{-1}) treatments. Similarly, maximum germination percentage (88.33%), tillers/plant (4.83), grains/spike (55.05), 100 grain weight (5.52 g), grain yield (2519 kg/ha) and harvest index (43.75%) in treatments which were applied humic acid @ 25 kg/ha. Based on the aforementioned results, it is advisable that if wheat crop is grown in saline soil in District Swabi for grain purpose then humic acid application @ 25 kg ha^{-1} is recommended. Rousta and Enayati (2019) [55] observed the effects of humic acid application on yield and yield components of wheat and some chemical properties of a saline sodic soil the data obtained from the experiment showed that the interaction between humasterfood and pars humic and the interaction effects of salinity, humasterfood and pars humic on shoot dry weight were significant at $p<0.05$. The effect of treatments on soil specific properties also showed that the interactions between salinity levels and humaster food and pars humic on sodium adsorption ratio (SAR) were significant at $p<0.01$. Means comparison showed that the application of humasterfood in March and April, decreased the concentration of sodium, calcium, magnesium, and SAR as amount as 37.3%, 30.1%, and 28.4%, respectively. Mazal *et al*., (2021) [43] researched on the effect of potassium fertilization and the addition of humic acid on the growth and yield of wheat crop under different levels of salinity of irrigation water. They applied treatment in which three levels of salinity of irrigation water such as 1.2 dSm^{-1}(S1), 3 dSm^{-1} (S2) and 6 dSm^{-1}(S3). Humic acid was added (0.02%) by different methods of addition, namely: ground addition HT, foliar application HF and combined addition HFT and the total amount was divided into three stages of growth i.e. branching, elongation and flowering. The results showed the superiority of S1 treatment (1.2 dSm^{-1}) significantly in plant height (52.56 cm), weight of 1000 grains (47.21 g), number of spikes in the pot (20.92 spike spikes-1) and weight of grains in pot, while the treatment of saline water S3 recorded the least significant difference for all of the above traits. The results showed a significant superiority of the HFT co-additive in ART the plant high (67.00 cm) and the weight of 1000 grains (49.06 g), which does not differ significantly from the ground addition HT, while the comparison treatment H0 showed the least significant difference for all the above traits. The ground addition of humic also achieved a significant superiority in the number of spikes in the pot (19.83 gm pot^{-1}) and weight. Cereals (6.35 tons H-1) and grain weight (56.89 gm pot^{-1}). Hamed (2021) [28] studied influence of salicylic, humic and fulvic acids on the growth, productivity and elements contents of two wheat varieties grown under saline stress condition. Main treatments were two different wheat cultivars (Sids 12 and Sakha 94) while sub-main plot was control, potassium fulvate as foliar application (1 kg fed-1), salicylic acid as foliar application (1.600 kg fed-1), potassium humate as foliar application (1 kg fed-1), potassium fulvate (1 kg fed-1) + salicylic acid (1.600 kg fed-1) + potassium humate (1 kg fed-1) as foliar application, potassium fulvate as soil application (2 kg fed-1), salicylic acid as soil application (3.200 kg fed-1), potassium humate as soil application (2 kg fed-1) and potassium fulvate (2 kg fed-1) + salicylic acid (3.200 kg fed-1) + potassium humate (2 kg fed-1) as soil application. The obtained results showed that potassium fulvate + salicylic acid + potassium humate as soil application was significantly superior and had the best means of all Studied traits; namely, plant height, grains weight, weight 1000 grains, grain yield, macronutrients in straw, secondary elements in straw, micronutrients in straw, elements in grains, protein in grains, micronutrients in grains, element in soil, nutrient use efficiency and agronomic efficiency compared with the control and with foliar application of organic acid under salinity stress. In addition results showed that Sids 12 was the best and more tolerant in the most studies traits under salinity stress compared with Sakha 94 cultivar.

Influence of Humic acid on Rice

Ibraheem *et al*., (2023) [32] investigated the effects of humic acid as a stress-alleviator on the germination, vegetative growth, and yield of Giza 179 rice cultivar under saline condition. They have found that salinity stress adversely effects on rice cultivar Giza 179 germination through decreasing GA3 content and α-amylase activity. The results indicated that the humic acid (100 mg/l) soaking significantly decreased most of the salinity-induced injury and maintaining vigorous germination, growth, and yield in saline condition. Mindari *et al*., (2018) [47] studied on efficiency of various sources and doses of humic acid on physical and chemical properties of saline soil and growth and yield of rice. They used first factor was three organic matters: compost, manure and coal, and the second factor was six doses of humic acid: 0, 0.5, 1.0, 1.5, 2.0 and 2.5 g/kg. They examined the effectiveness of humic acid to change soil salinity, pH, electric conductivity, cation exchange, permeability, aggregate stability and plant growth. The experimental results showed that humic acid from peat increased plant biomass weight, plant roots, grain number of tillers and chlorophyll content more than others. Humic acid efficiently can improve rice yields 10-20% supported by the suitability of soil pH, nutrient availability and soil salinity. de Silva *et al*., (2022) [17] investigated arbuscular mycorrhizal fungi and humic substances increased the salinity tolerance of rice plants and found that HSs containing mainly nonfunctionalized and functionalized aliphatic carbons in association with the AMF *Glomus formosanum* and *Acaulosporamellea* stimulated plant growth, improved root morphological characteristics, resulted in the lowest Na^+/K^+ ratio detected, and increased both shoot and root biomass production. The protective effect seems to be promoted by a decreased Na^+/K^+ ratio and increased phosphorus content in the leaves of plants inoculated with AMF, especially *A. mellea* and *R. clarum*, and treated with HSs, indicating the synergistic action of HSs and AMF. In addition, the sodium concentration increased in the shoots under SS in the absence of HSs. Shukry *et al*., (2023) [60] researched the efficiency of humic acid effects on salinity tolerance in salt sensitive rice. Seeds of Giza 177 were primed in 40mg/l humic acid, sown, and maintained. Then growth and physiological responses of the humic acid-primed plants to increased levels of salinity (EC: 0.55, 3.40, 6.77, and 8.00mS/cm) were evaluated at the reproductive stage. Increasing salinity induced a progressive retardation in plant height, leaf area, fresh and dry weights. Such retardation was associated with Na^+ buildup in shoot and root, high electrolyte leakage and accumulation of malondialdehyde, total soluble sugars, sucrose, glucose, proline, total soluble proteins, flavonoids, and phenolics. In contrast, salinity reduced K^+, K^+/Na^+ ratio, total carbohydrates, and the activity of catalase, peroxidase, and polyphenol oxidase. Humic acid enhanced growth under non-saline and saline conditions. The humic acid-induced improvement in salt tolerance was associated with the reduction of Na^+ toxicity, increasing K^+/Na^+ ratio, regulating osmolytes concentration, and enhancing the activities of antioxidant enzymes and thus reduce the oxidative stress. Humic acid successfully reduced the salinity-induced plant damage, improved metabolism, and maintained active growth of Giza 177 under saline irrigation.

Influence of Humic acid on Maize

Malik *et al*., (2023) [42] studied the effect of humic acid on growth, antioxidative capacity and ion uptake in maize grown under saline soil condition. Humic acid (0.15%) as a soil amendment substantially decreased salinity-induced hazardous effects by encouraging plant growth attributes, physiological activity, ionic attributes, and improving the antioxidant protection mechanism against ROS. Kaya *et al*., (2018) [34] observed that exogenous application of humic acid mitigates salinity stress in maize plants. They analyzed that salt stress significantly reduced plant fresh and dry biomass, quantum yield, chlorophyll contents and leaf water potential, while it increased leaf osmolality, proline, hydrogen peroxide and enzymatic antioxidants activity. Foliar application of humic acid reduced the activities of antioxidant enzymes, socium and leaf osmolality, but it enhanced quantum yield and chlorophyll contents. Pre sowing treatment with HA was effective in improving plant bio mass and proline contents and lowering hydrogen peroxide contents. The results showed that out of both cultivars, Apex 836 cultivar was higher in Na, P, Ca, K, chlorophyll pigments, hydrogen peroxide and activities of antioxidant enzymes. The response of both cultivars was similar to other studied attributes in the maize cultivars under stress conditions. Khaled and Fawy *et al*., (2011) [35] researched on effect of different level of humic acid on the nutrient content, plant growth and soil properties under the condition of salinity of corn. The application doses of solid humus were 0, 2 and 4 g/kg and those of liquid humic acids were 0, 0.1 and 0.2%. Salinity negatively affected the growth of corn and also decreased the dry weight and the uptake of nutrient. Soil application of humus increased the N uptake of corn while foliar application of humic acids increased the uptake of P, K, Mg, Na, Cu and Zn. Liu *et al*., (2019) [39] observed maize growth and nutrient uptake following integrated improvement of vermicompost and humic acid fertilizer on coastal saline soil. They conducted experiment included three treatments: (1) control without humic acid fertilizer and vermicompost (CK); (2) treatment with humic acid fertilizer (H); (3) treatment with vermicompost (V). The result showed that humic acid fertilizer and vermicompost could enhance nitrogen nutrient absorption of the maize plant in the vegetative growth period (6S) and the phosphorus and potassium nutrient absorption in the reproductive growth period (tasseling stage and harvest stage) of maize, which played an important role in increasing the maize yield in coastal saline soil. Turan *et al*., (2011) [67] analyzed the effects of soil-applied humic substances to the dry weight and mineral nutrient uptake of maize plants under soil-salinity conditions. Sodium chloride was added to the soil to obtain 0, 15, 30, 45 or 60 mM NaCl. Three different doses of solid humus (0, 1 or 2 g kg-1) were applied to the soil one month prior to planting. High levels of salt (45 and 60 mM NaCl) had negative impacts on the dry weight and the N, P, K, Ca, Mg, Fe, Cu, Zn and Mn uptake of the maize plants. The highest mean dry weight, Mg and Mn uptake were observed for the 1 g humus kg-1 treatment and the highest mean Cu content was in the 2 g humus kg^{-1} treatment. On the contrary, the highest mean uptakes of N and P were found in the soils in which humic substances were not added. The interactions of NaCl and the soil humus content were significant for the uptake of Cu ($p \leq 0.01$), and we found that adding humus increased the content of Cu in maize plants under slight salt stress (15 mM NaCl) ($p \leq 0.01$).

Influence of Humic acid on Sorghum

Ali *et al*., (2022) suggested that humic acid treatment (373.21 kg/ha) improved the forage sorghum performance under salinity conditions through anthesis stages, better photosynthetic and growth parameters, which reduced the impacts of salinity, and resulted in better plant growth and help the plant to improved salt tolerance. Ali *et al*., (2020) studied exogenous jasmonic acid and humic acid increased salinity tolerance of sorghum and investigated the effects of humic acid (HA) (0, 3, and 6 g $HAkg^{-1}$ soil) on growth and physiological parameters of forage sorghum (*Sorghum bicolor* L. Moench) under different NaCl salinity levels (0, 100, and 200 mM NaCl, with an equivalent electrical conductivity (EC) of 0.12 dSm^{-1} as control treatment, 3.22, and 5.78 dSm^{-1}, respectively). NaCl salinity reduced emergence percentage, emergence rate, salt tolerance index and seedling vigor index, all seedling growth parameters, ascorbate peroxidase (APX) activity, chlorophyll a, b and total chlorophyll content. Proline content and soluble protein content were increased with salinity. At 200 mM NaCl salinity level, seeds treated with 6 g HA kg^{-1} soil had increased root length, total dry weight, salt tolerance index, seedling vigor index, shoot length, protein content, APX, chlorophyll b, and total chlorophyll in seedlings. Yang *et al*., (2023) [70] investigated biomass composite with exogenous organic acid addition supports the growth of sweet sorghum by reducing salinity and increasing nutrient levels in coastal saline-alkaline soil and found that humic acid and fulvic acid with pine needle composite having higher chlorophyll content, root activity, malondialdehyde content, soluble sugars content. Also found higher SOD, CAT and POX activity in humic acid and fulvic acid with pine needle compost treated sweet sorghum. Kusvuran *et al*., (2021) [37] analyzed the effect of different organic matters on plant growth regulation and nutritional components under salt stress in sweet sorghum. They used total eight organic matter under salt stress. The result showed that higher leaf area, leaf number, chlorophyll content and relative water content observed in humic acid treated sorghum as compared to the salt stress condition. The studied showed that salt stress caused reduced growth parameters and chlorophyll, RWC, K^+ and Ca^{++} ion content, while MDA content, Na^+ and Cl^-accumulation showed an increase. The results showed that the humic acid treatment diminished the damaging effects caused by salt stress via a reduction in the uptake of $Cl^-$and Na^+, which enhanced K^+ and Ca^{++} uptake and reduced the MDA levels, presenting a favorable effect in reducing the oxidative stress that emerged from salt stress.

Influence of Humic acid on Barley

Jarosova *et al*., (2016) investigated humic acid protects barley against salinity and found that salt stress severely damaged cell functions and inhibited photosynthesis. While, the foliar (6.0 mg/L) HA application could reduce the accumulation of harmful substances and improve the function of cells during salt stress. They have also recorded that HA alleviated damage to membranes, increased in proline and soluble sugar content in leaves and reduced water loss. They have indicated the potential of HA to protect barley against NaCl stress by limiting Na uptake and positively impacting amount of some metabolites. Alsudays *et al*., (2024) [4] studied the applications of humic acid under saline soil conditions in barley. They have suggested that application of humic acid (4.75 kg/ha) is a beneficial tool for enhanced nutrient availability, uptake and enhanced plant growth, and this may be the reason for increased salinity tolerance in barley to promotion barley growth and yield, particularly in saline soils. Rekaby *et al*. (2020) [52] researched on effect of some organic amendments on barley under saline condition. The influences of biochar, humic acid and compost on barely growth were investigated under saline conditions. The results showed that humic acid increased the total soil organic matter, plant nutrients and chlorophyll content of barley. The investigated organic amendments increased the nutrients availability and uptake and enhanced the synthesis of chlorophyll in the plant tissues and this may be the reason of increasing the ability of barley to tolerate salinity. Belal *et al*., (2019) [8] analyzed integrative soil application of humic acid and sulfur improves saline calcareous soil properties and barley plant performance and found that under humic acid treated barley plant shows higher soil nutrients and plant nutrients. They investigated that humic acid (100 kg ha^{-1}) showed higher content of P, Fe, Mn, Cu and Zn in both barley plant and barley grains as compare to control. Higher protein content observed in humic acid as compare to the control. EL-Sharkawy *et al*., (2017) [21] observed alleviating salt stress in barley by use of plant growth stimulants and potassium sulfate. They used seaweed extract and humic acid as a plant growth stimulant. The results showed that in the salt-tolerant genotype humic acid resulted in the highest RWC under 10 dS m^{-1} and was only 19% lower than that for the non-salt control. In the salt-tolerant genotype the application of humic acid resulted in the highest accumulation of proline less than 10 dS m^{-1} with 0.76 µmol g^{-1} fresh weight. The application of humic acid resulted in the highest catalase activity in the salt-tolerant genotype at 10 dS m^{-1} and the lowest activity in the salt-sensitive genotype at the same salt level while only humic acid application resulted in a significant increase in SOD at the 15 dS m^{-1}.

Conclusion

According to this review, applying humic acid to cereals under saline stress conditions may have a major impact. The humic acid source is the most significant of the parameters that this review found to influence the performance of humic acid in crops and soils. The effects of humic acid on crop performance are further influenced by its chemical and molecular makeup, solubility, and other elements like crop type, soil, and rate of application also. Through the analysis of numerous studies, this review determined how humic acid affected the growth and quality characteristics of cereal crops in saline stress condition. Long-term studies involving various soil types, crops, and weather patterns are necessary to fully exploit the benefits of humic acid. More research is required to optimise the combined effect of varying humic acid application rates and mineral fertilisers on crop performance and soil quality parameters under specific field conditions.

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