Bulletin of Biological and Allied Sciences Research
ISSN: **2521-0092**
www.bbasr.org
DOI: https://doi.org/10.54112/bbasr.v2024i1.58
*Bull. Biol. All. Sci. Res., Volume, **9**: 58*
Original Research Article ***Open Access***

EXPLORING THE RESPONSE MECHANISMS OF RICE TO SALINITY STRESS

ABBAS A[1], ARSHAD A[2], REHMAN AU[1], BUKHARI MS[3*]

[1]Department of Plant Breeding and Genetics, Faculty of Agricultural Sciences, University of the Punjab, P.O BOX. 54590, Lahore, Pakistan
[2]Department of Seed Science and Technology, University of Agriculture Faisalabad P.O BOX, 38000, Faisalabad, Pakistan
[3]Agricultural Research Station Bahawalpur, P.O BOX, 63100, Bahawalpur, Pakistan
**Correspondence author email address: shahjhanbukhari@gmail.com*

(Received, 15th January 2023, Revised 2nd January 2024, Published 5th January 2024)

Abstract *The world's agricultural productivity has been on the decline due to salinity, which is a significant abiotic element. To find a solution to this problem, researchers have been concentrating their efforts on the enzymes and biochemical pathways involved in salt tolerance. The ultimate objective is to develop crops that are resistant to salt. Developments in molecular biology have facilitated the production of salt-tolerant cultivars by conventional breeding techniques. A significant amount of salt can inhibit the growth of rice (Oryza sativa L.), a major food crop in many nations. This is especially true during the early stages of plant development. Rice's physiological, molecular, and biochemical reactions to excessive salinity have been the subject of significant exploration and investigation. The possible applications and implications of salinity tolerance are also discussed in this article, as well as the approaches that can be used to locate plants that are tolerant of salt.*

[Citation: Abbas, A., Arshad, A., Rehman, AU., Bukhari, M.S., Zaman S. (2024). Exploring the response mechanisms of rice to salinity stress. Bull. Biol. All. Sci. Res. ***9****: 58. doi:* https://doi.org/10.54112/bbasr.v2024i1.58]

Keywords: *Salinity; Traditional; Molecular Biology; Physiological; Molecular; Screening of rice*

Introduction

Poaceae is the family to which rice (*Oryza sativa L*) belongs. Rice has n = 12 chromosomes as its fundamental number (Mohapatra et al., 2022; Shchapova, 2012). The species has the option of being tetraploid or diploid. Regarding this, *Oryza glaberrima* L. and *Oryza sativa* L. The two species are diploid (2n=24). Asian rice (Oryza sativa L) is the first agricultural crop with a fully sequenced genome. Rice is an important food crop because it is a staple in many countries. Over three billion people depend on it for 50–80% of their calories (Mohidem et al., 2022). About one-third of the total carbohydrate supply is produced by it. It offers the significant quantity of zinc and niacin that is advised. Because rice has a very high digestion, it has the highest biological protein (88%). Almost 90% of the land in Asia is planted to this crop, the world's second-most important crop after wheat. The crop is used for various purposes in India, including religious ceremonies, flour, rice bran oil, snacks, and brewed drinks. The crop's therapeutic benefits extend the list further (Ahmed, 2021; McHugh, 2021). Throughout history, rice farming has been the main industry in India. Approximately 650 million tons of crops are produced by rice on 156 million hectares of land worldwide (Anand et al., 2022). This food crop is grown throughout 149.15 million hectares worldwide, producing around 550.19 million tons in India over a 44.6-million-hectare area. Rice production in India is second in the world behind China in land area and quantity. Rice is essential to India's economy and industry, accounting for 23% of global rice production and 45% of food grain production (Fahad et al., 2019; Samal et al., 2022). Nonetheless, given the growing population, there is an immediate need to boost agricultural output to maintain the country's food supply and a livelihood security framework. India is a prominent rice supplier specializing in basmati rice (Sharma et al., 2020). But to maintain the country's food and livelihood security system, there is an urgent need to enhance agricultural output due to the growing population. India is a prominent rice supplier specializing in basmati rice (Sofi et al., 2020).

Salinity stress

Salinity reduces crop productivity (Majeed et al., 2019). Mg^{2+}, Ca^{2+}, Na^{+}, SO_4^{2-}, Cl^{-}, and HCO^{3-} are abundant in saline soils. High K^{+}, CO_3^{2-}, and NO^{3-} levels are also common. The soil is saline when its electrical conductivity (EC) is 4 dS/m (Anjum et al., 2023; Chandel et al., 2022; Sakai et al., 2020), corresponding to 40 mM NaCl, and its osmotic pressure is 0.2 MPa. High EC can significantly diminish agricultural yields. Saline soils are pH 7-8.5 (Thorat et al., 2018; Yadav, 2022). Low precipitation and excessive evaporation in dry and semi-arid environments prevent salts from leaching from the soil profile, causing salt buildup. This is a common reason for dry and semi-arid salinity (Meena et al., 2022). Furthermore, the process has been further enhanced by the weathering of the parent rocks (Hussain et al., 2018; Li et al., 2022). Due to seawater overflow, salinity is a well-known natural phenomenon near seashores. However, two of the several well-known human causes of salinity are irrigation and land clearance (Kumar and Sharma, 2020). Salinity has been a possible danger to over 900 million hectares of land, or around 20% of all cultivated land and half of all irrigated land worldwide salt (Zaman et al., 2018). Approximately one billion hectares of land are impacted. The scenario describes India's 8.4 million hectares of salinized soil (Sharma and Singh, 2019). Even though irrigated land makes up just 15% of all agricultural land in India, it produces roughly one-third of global consumption and is twice as efficient as rain-fed land. Given the information above and the current situation, salt-tolerant genotypes must be developed soon.

Salinity Controls Production: An Important Environmental Limitation

Agricultural soil salinity is a major cause of global agricultural production loss. Around 6% of the Earth's surface, 800 million hectares of land have been damaged by salt. Of 1500 million acres of dry land cultivation, secondary salinity has destroyed 32 million hectares (2%). High salt levels damage 45 million hectares (20%) of irrigated land, totalling 230 million (Munawar et al., 2020). Ancient humans faced soil salt as an abiotic stress before cultivation. Modern irrigation and farming have exacerbated the devastation of this abiotic stressor (Tessema et al., 2022). The effects of saltiness on plants greatly affect the output and effectiveness of farming. Two kinds of stress are caused by salinity: osmotic stress (which starts with ionic stress and is harmful because of high ionic concentration) and higher osmotic potential in the rhizosphere because of high salt concentration (Arif et al., 2020; Hussain et al., 2019). High salt levels can slow plant growth due to higher Na^{+} levels (Safdar et al., 2019), cause flowers to bloom later, lower fertility, and cause grains to be lost, which can make it hard for rice panicles to form (Hu et al., 2021; Parida et al., 2022). Low salt levels also cause P^{3-}, K^{+}, and Ca^{2+} levels to drop (Ahmed et al., 2023) and stop photosynthesis from happening. Because salinity is a polygenic trait, plants respond to it differently. This makes responses unpredictable. Most plants have developed ways to handle and control the amount of NaCl present. NaCl is very soluble and is found in many things. To do this, either the roots can effectively keep out Na+ and Cl- or the roots can selectively take them in (Ali et al., 2015; Ali et al., 2016; Ali et al., 2014; Rodríguez Coca et al., 2023).

The exclusion principle helped generate halophytes, which thrive in extremely salty soils. Once salt concentration hits 450 mM, plants like *Hordeum marinum* reject sodium and chloride ions. *Triplex halimus*, another halophyte, contains trichomes on its surface that tolerate salt. These hairs help the plant store salts and protect leaf tissues from salt stress. Barley is the most salt-tolerant, followed by bread and durum wheat, and rice is the most vulnerable. Interestingly, dicots react differently to salt than monocots. Scientists have discovered salt tolerance mechanisms by comparing wild-type and halophytic plant responses. The wild-type plant Arabidopsis ceases growing at 100 mM salt, yet its halophytic cousin, the llungiella, thrives with little effect. This shows these plants' selective salt tolerance.

High salinity affects rice growth

Rice is grown in 114 countries worldwide and is a crop of significant economic importance (Asibi et al., 2019). Abiotic and biotic stressors, however, have the potential to lower production. This issue will worsen in awareness of the growing world population and the shortage of food sources (Teshome et al., 2020). Salt is more harmful to rice throughout its vegetative and reproductive stages (Gerona et al., 2019; Teshome, 2020). Due to gene additive effects, rice genotypes vary in salt tolerance (Chattopadhyay et al., 2020; Gerona, 2019). Rice is more robust during reproductive and grain-filling than germination and vegetative stages (Santanoo et al., 2023). Salinity induction at lower levels can improve rice's salt tolerance (Ganie et al., 2019). After drought, salt has become the second largest stressor and rice production hurdle (Fahad et al., 2019). Salinity affects rice development and yields under field circumstances, and several paddy germplasms have been tested for salt resistance (Ravikiran et al., 2018).

Salinity affects rice growth

Numerous morpho-physiological research has been completed so far to create salt-tolerant rice cultivars. This strategy's primary goal was to increase genetic diversity between the parents' genetics. Plants react to salt randomly and organically**.** According to reports, rice is sensitive throughout the seedling and reproductive phases of the crop (Gerona et al., 2019; Wang et al., 2019; Wu et al., 2019), which has led to a decrease in crop production and output. Regarding rice, salinity has been discovered to cause physiological and metabolic alterations that impede development and reduce production (Arif et al., 2020). True salt-tolerant lines have been evaluated using plant height, dry weight, leaf damage, and Na+-K+ ratio to examine the physiological effects of salt accumulation (Chaurasia et al., 2020; Wangsawang et al., 2021). Salinity has various effects on rice, including inhibiting germination, making it harder to establish crop areas, developing leaf areas, reducing the amount of dry matter produced, delaying seed set, and sterility (Hussain et al., 2018). The effects of salinity on seedling growth and grain production factors, including tiller and spikelet numbers, have been extensively studied. High salinity consistently reduces grain yield. A comprehensive study of varying floodwater salinity across rice types showed the importance of salt tolerance in rice productivity. Further research has indicated that floodwater electrical conductivity (EC) can reduce yield by up to 80% and germination rate by roughly 50% for the most vulnerable rice cultivar, depending on salt exposure. Additionally, independent of the season, salt decreased the number of spikelets per panicle, a rise in sterility, 1000 grain weight, and phase of development (Paik et al., 2020; Radanielson et al., 2018).

Morpho-physiological change

Rice's diverse reaction should be used to study its salt stress tolerance. A complete examination of rice's salinity response must include the physiological processes that activate its defense mechanisms under stress. The osmotic effect, which decreases osmotic potential, causes stress, followed by the ionic effect, which causes ion toxicity. Rice's mitochondria and chloroplasts are particularly vulnerable, according to a study. Thus, chlorophyll content, fluorescence (Fv/Fm), and membrane permeability can help explain how salt inhibits photosynthetic efficiency. Studies have also found that salt stress reduces rice leaf area and structure under greenhouse or in vitro environments. Ultrastructural investigations show salt disrupts photosynthetic activities by expanding thylakoid and damaging leaf chloroplasts. Salinity also affects mesophyll tissue, harming vascular bundles.

Understanding the harmful ionic effect of salt on plants requires evaluating the crop plant's reaction at later stages. The plant reduces the majority of the harmful effects of sodium salt buildup by the following methods: (a) selective ion absorption, (b) salt exclusion, and (c) control of the K+/Na+ ratio (Iqra et al., 2020a; Iqra et al., 2020b; Jam et al., 2023; Mazhar et al., 2020; Wang et al., 2022). A study of the ultra-structure of the roots revealed how saline penetrates rice and how the crop plant responds by increasing the pace. According to [69], vacuolation and vesiculation reduce the mucilage produced in treated plants compared to control. It has been proposed that there is a significant association between the amount of sodium present, the K+/Na+ ratio, seedling development, and grain yield under salt stress (Naseem et al., 2020; Pour-Aboughadareh et al., 2021; Saddiq et al., 2020; Sarwar et al., 2022; Sarwar et al., 2021).

Morpho-physiological evaluations were done to determine the salt tolerance of cultivars. Tiller count, leaf area, panicle length, root length, biomass, dry weight, and RGR were measured. Relative water content (RWC) in leaves can indicate the presence of osmoprotectant, which protects cells from salt stress-induced dehydration. Prakash et al. (2019) found that native landraces may include salt tolerance genes. Hence, the Salt Tolerance Index (STI) should be considered when morpho-biochemically evaluating them. Thus, these landraces may be useful for study and development. Therefore, by evaluating various cultivars at the morpho-physiological level, it was possible to develop a thorough understanding of the various physiological mechanisms the crop plant uses to respond to salt stress. Still, this analysis could not shed light on the precise defense mechanisms, pathways, and components directly or indirectly involved in the process (Ghafoor et al., 2020; Iqbal et al., 2021; Khadka et al., 2020).

Biochemical cellular reaction

Two main ways salinity impacts agricultural plants. When salt concentration rises, plants' osmotic potential rises, and their water potential falls (Okon, 2019). This can reduce water availability and damage plants. To combat this, plants accumulate huge amounts of low-molecular-weight inorganic ions or organic solutes through osmotic adjustment (Polash et al., 2019). Examples are low-molecular-weight sugars, organic acids, polyols, proteins, amides, amino acids, and quaternary ammonium compounds. Osmolytes help plants adjust to salinity changes and stay hydrated. Second, ionic stress occurs when salt accumulation is deadly, harming plants. Understanding these two mechanisms is essential to reducing salinity's negative effects on crops. Salt stress promotes proline assimilation in higher plants (Torre-González et al., 2018). Anee, et al. (2019) found rice with increased proline, active participation in osmotic adjustment, membrane and enzyme protection, and energy and nitrogen delivery after salt exposure. Several plants respond to salt stress by using soluble carbohydrates and starch as osmotic agents, such as Karalija et al. (2018) reporting a rise in sugar levels in shoots, and Prathap et al. (2019) discovered an increase in starch in rice roots. Optimizing primary metabolism store resources aids osmotic compensation. Syeed et al. (2021) found that rice's glycine betaine accumulation reduces salt's negative effects.

It has been reported that these chemicals actively modify osmotic processes, strengthen cellular macromolecules, and store nitrogen. The elimination of reactive oxygen species, the detoxification of cells, and the preservation of the appropriate pH levels within cells depend on their presence. Alterations in protein levels or accumulation are yet another strategy for countering the effects of salt. According to Alkharabsheh et al.'s research from 2021, exposure to salinity can result in the formation of new proteins or an increase in the production of certain proteins already present in the plant, increasing the concentration of such proteins. The proteins found in plants grown in salty settings serve as a sort of nitrogen storage when the conditions are not stressful. In addition, the creation of proteins is essential for regulating osmotic pressure. The levels of soluble protein-intolerant rice seedlings were much higher than those of sensitive rice seedlings, and there was a positive association between the two.

Precise and Directed Molecular Response and Cell Communication

To choose breeding lines that can tolerate salt, efforts have been made to understand salinity tolerance at both the molecular and genetic levels. Research that was done in the past on the mechanisms of salinity tolerance in rice has demonstrated that this abiotic stress is complicated and can result in a variety of responses in plants that span both the same species and distinct varieties (Thorat et al., 2018). To screen for salt tolerance using molecular markers, genetic diversity was evaluated in many genotypes using RFLP, SSLP mapping, and RAPD and SSR analysis techniques. Both of these methods were utilized to screen for salt tolerance. Traditional techniques, including insertional mutagenesis and positional cloning, were utilized to acquire a more comprehensive understanding of the inheritance of salinity in rice (Panini et al., 2021). Several genes in rice, including de novo genes, salt, and catalase, are elevated in response to high salt levels, according to research that was conducted in the past (Singh et al., 2018). Osmotic stress, also known as Osmo-sensing, is something that plants can sense, enabling them to adapt to salinity stress effectively. Although physiological mechanisms can help explain alterations at the cellular or tissue level, the knowledge of the signaling pathway caused by this stress is mostly based on the control and regulation imposed by genetic programming. In addition, research on *Arabidopsis thaliana* mutants uncovered several regulatory genes and pathways involved in salinity tolerance. These include the Plantago thaliana Histidine kinase (Keisham et al., 2018), Ca+ dependent protein kinases (CDPKs) (Wen et al., 2020), Map kinases (MAP kinases) (Bhatt et al., 2020), and the SOS pathway (Ali et al., 2023). Because salinity tolerance is a polygenic trait, researchers have also concentrated on locating quantitative trait loci (QTLs) commonly related to this characteristic. In a population of F8 recombinant inbred lines (RIL) derived from the Pokkali X IR29 cross, a substantial quantitative trait locus (QTL) referred to as "salt" was discovered on chromosome I by the utilization of AFLP markers.

Rice QTL research has found and mapped several salinity-induced QTLs. These include qRL-7 for root length, qDWRO-9a and qDWRO-9b for dry weight root, and qBI-1a and qBI-1b for biomass, with strong QTLs on chromosomes 1 and 2 for shoot growth (Thorat et al., 2018). Chen et al. (2021) found individual QTLs related to sodium and potassium uptake and selectivity. Along with other studies, Yang et al. (2021) revealed eight QTLs for each of the three shoot qualities and five root traits within five chromosomal areas. An F_2 mapping population from a Sadri/FL478 hybrid yielded 35 QTLs, with the largest QTL clusters mapped in chromosomes 2, 4, and 6 for several characteristics under salt stress. The discovery of the QTL for salt tolerance opened up new avenues for research on salinity and how plants respond to subsequent stress. Research is being done to construct and identify several alleles that may or may not be related to the corresponding salinity QTLs (Ali et al., 2017; Asif et al., 2020; Farooq et al., 2021; Sayed et al., 2021; Tahir et al., 2020).

Rice salt-stress defense

Plants use three primary methods to avoid salt stress. First, they modify their osmotic equilibrium to tolerate stress. Second, selective absorption and molecular regulation exclude sodium ions from leaves. Finally, compartmentalization lets plants endure high salt or chloride levels. High salt levels hinder photosynthesis, causing plants oxidative, osmotic, and ionic stress. Plants use xanthophyll pigments and transfer electrons to oxygen acceptors instead of water to fight this, which can produce reactive oxygen species. To mitigate this response, plants additionally upregulate catalase, ascorbate peroxidase, superoxide dismutase, and peroxidases. The plant's antioxidant defense system relies on non-enzymatic antioxidants such as ascorbate and glutathione and enzymes like glutathione reductase. The duration between ROS production and antioxidant scavenging determines this system's efficiency. Studies reveal salt-tolerant rice cultivars have stronger antioxidant enzyme activity, especially catalase, than salt-susceptible variants. Others have seen a decrease in catalase activity with salt exposure, suggesting distinct oxidative responses in rice. These contradicting results suggest more research on antioxidants and salt stress defense in plants.

Salinity stress intolerance screening

The susceptibility of plants to salinity throughout development impacts their salt tolerance. Research shows that rice plants are more sensitive to salt during early growth but less sensitive during reproduction (Singh et al., 2021). Proper screening is needed to assess how rice germplasms react to salt. Both sensitive phases of paddy can be screened. Screening seedlings is easy and fast with clear instructions. This can be done in a lab or field. However, soil variability, climate, and other environmental factors might affect the plant's physiological activities, making field screens difficult. Salt tolerance is complicated by temperature and humidity, which alter evapotranspiration and ion transport (Resende et al., 2019). Thus, lab screenings have many advantages over field screenings. Many physiological, pharmacological, and molecular factors affect plant growth and development. Early attempts to find salinity-tolerant plants used agronomic features. Early experiments produced salt-resistant genotypes using classic selection and breeding methods. Morphological screening assessed physiological and agronomic parameters. Root length, shoot length, plant biomass, and shoot Na+/K+ ratio are good salinity tolerance indicators for morphological screening (Huqe et al., 2021; Pour-Aboughadareh, 2021). Morphological screening should start 10 days after exposure to a saline solution to accurately identify tolerant and susceptible genotypes (Afzal et al., 2023).

Since the environment significantly impacts agronomic parameters, assessing salt tolerance based on them may not be profitable. Many scientists use biochemical screening to understand salt tolerance mechanisms and levels better. This has provided insights and markers on cellular, tissue, and whole-plant salt tolerance (Morton et al., 2019; Rasel et al., 2021; Saradadevi, 2021). With this understanding, salt stress biochemical pathways and plant defense systems can be identified. In particular, rice molecular screening has revealed its salt stress response and identified salt-tolerant genes (Gul et al., 2022; Sampangi-Ramaiah et al., 2020). Saradadevi et al. (2021) identified a salt QTL, enabling genetics studies.

Conclusion

After drought, salinity is the second most destructive abiotic stressor that affects rice productivity and output worldwide. The primary food crop that is grown in many nations worldwide. The demand for rice is rising with the world's growing population. As a glycophyte, rice is sensitive to salinity by nature and responds broadly and vividly to the negative consequences of excessive salt buildup. Rice uses a plant defense mechanism to reduce salt toxicity's physiological, biochemical, and molecular effects. Here is an extensive analysis of the numerous studies conducted to understand the relationship between salt and crop response. It has been extremely difficult to mention the precise method of mitigating stress because of its polygenic character. Recent discoveries of metabolic pathways, enzyme complexes, regulatory genes, and QTLs have illuminated the processes during this abiotic stress. Accruing information about the crop's reaction to salt is crucial given salinity's disastrous impact on this essential food crop. This will support ongoing efforts to increase saltwater tolerance and create salinity-tolerant animals. Many studies are being carried out worldwide to comprehend salinity and the intricate processes of rice to mitigate the same. In this context, it is crucial to summarize all the research to comprehend the relationship between salt and rice. To better understand the reaction and, consequently, the plant defense against salt as a stress, the key contributions and discoveries achieved in this field are briefly summarized in this study.

References

Abobatta, W. F. (2020). Plant responses and tolerance to extreme salinity: Learning from halophyte tolerance to extreme salinity. *Salt and Drought Stress Tolerance in Plants: Signaling Networks and Adaptive Mechanisms*, 177-210. https://doi.org/10.1007/978-3-030-40277-8_7

Afzal, M., Hindawi, S. E. S., Alghamdi, S. S., Migdadi, H. H., Khan, M. A., Hasnain, M. U., . Sohaib, M. (2023). Potential breeding strategies for improving salt tolerance in crop plants. *Journal of Plant Growth Regulation*, 42(6), 3365-3387. DOI: https://doi.org/10.1007/s00344-022-10797-w

Ahmed, A. A. M. (2021). *Examination of Fungal Contaminants of Wheat, Rice, Barely and Maize Grains.* Sudan University of Science & Technology,

Ahmed, H. A. I., & Hou, P. (2023). Portulaca oleracea under Salt Stress. In *Medicinal Plant Responses to Stressful Conditions* (pp. 331-346): CRC Press.

Ali, A., Petrov, V., Yun, D.-J., & Gechev, T. (2023). Revisiting plant salt tolerance: novel components of the SOS pathway. *Trends in Plant Science*. 28(9):1060-1069. https://doi.org/10.1016/j.tplants.2023.04.003

Ali, F., Ahsan, M., Ali, Q., and Kanwal, N. (2017). Phenotypic stability of Zea mays grain yield and its attributing traits under drought stress. *Frontiers in plant science* **8**, 1397. https://doi.org/10.3389/fpls.2017.01397

Ali, F., Kanwal, N., Ahsan, M., Ali, Q., Bibi, I., and Niazi, N. K. (2015). Multivariate analysis of grain yield and its attributing traits in different maize hybrids grown under heat and drought stress. *Scientifica* **2015**. https://doi.org/10.1155/2015/563869

Ali, Q., Ahsan, M., Kanwal, N., Ali, F., Ali, A., Ahmed, W., Ishfaq, M., and Saleem, M. (2016). Screening for drought tolerance: comparison of maize hybrids under water deficit condition. *Advancements in Life Sciences* **3**, 51-58.

Ali, Q., Ali, A., Ahsan, M., Nasir, I. A., Abbas, H. G., and Ashraf, M. A. (2014). Line× Tester analysis for morpho-physiological traits of Zea mays L seedlings. *Advancements in Life sciences* **1**, 242-253.

Alkharabsheh, H. M., Seleiman, M. F., Hewedy, O. A., Battaglia, M. L., Jalal, R. S., Alhammad, B. A., . . . Al-Doss, A. (2021). Field crop responses and management strategies to mitigate soil salinity in modern agriculture: A review. *Agronomy*, 11(11), 2299. https://doi.org/10.3390/agronomy11112299

Anand, A., Kumar, V., & Kaushal, P. (2022). Biochar and its twin benefits: Crop residue management and climate change mitigation in India. *Renewable and Sustainable Energy Reviews*, 156, 111959. https://doi.org/10.1016/j.rser.2021.111959

Anjum, N., Masood, A., Thangavel, P., & Khan, N. A. (2023). *Making Plant Life Easier and Productive Under Salinity: Updates and Prospects*: BoD–Books on Demand.

Arif, Y., Singh, P., Siddiqui, H., Bajguz, A., & Hayat, S. (2020). Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. *Plant Physiology and Biochemistry*, 156, 64-77. https://doi.org/10.1016/j.plaphy.2020.08.042

Asibi, A. E., Chai, Q., & Coulter, J. A. (2019). Rice blast: A disease with implications for global food security. *Agronomy*, 9(8), 451. https://doi.org/10.3390/agronomy9080451

Asif, S., Ali, Q., and Malik, A. (2020). Evaluation of salt and heavy metal stress for seedling traits in wheat. *Biological and Clinical Sciences Research Journal* **2020**. https://doi.org/10.54112/bcsrj.v2020i1.5

Bhatt, T., Sharma, A., Puri, S., & Minhas, A. P. (2020). Salt tolerance mechanisms and approaches: Future scope of halotolerant genes and rice landraces. *Rice Science,* 27(5), 368-383. https://doi.org/10.1016/j.rsci.2020.03.002

Cesarino, I., Dello Ioio, R., Kirschner, G. K., Ogden, M. S., Picard, K. L., Rast-Somssich, M. I., & Somssich, M. (2020). Plant science's next top models. *Annals of Botany,* 126(1), 1-23. https://doi.org/10.1093/aob/mcaa063

Challabathula, D., Analin, B., Mohanan, A., & Bakka, K. (2022). Differential modulation of photosynthesis, ROS and antioxidant enzyme activities in stress-sensitive and-tolerant rice cultivars during salinity and drought upon restriction of COX and AOX pathways of mitochondrial oxidative electron transport. *Journal of Plant Physiology,* **268**, 153583. https://doi.org/10.1016/j.jplph.2021.153583

Chandel, S., Datta, A., & Yadav, R. (2022). Soil salinity indicators and salinity build-up on saline water irrigation in seed spices. *Crop and Pasture Science,* **73**(6), 663-678. https://doi.org/10.1071/CP21585

Chattopadhyay, K., Vijayan, J., Ray, A., Chakraborty, K., & Sarkar, R. (2020). Additive main effect and digenic epistatic quantitative trait loci for chlorophyll fluorescence traits influencing salt tolerance at seedling stage in rice. *Photosynthetica, **58***.

Chaurasia, S., Singh, A. K., Songachan, L., Sharma, A. D., Bhardwaj, R., & Singh, K. (2020). Multi-locus genome-wide association studies reveal novel genomic regions associated with vegetative stage salt tolerance in bread wheat (Triticum aestivum L.). *Genomics,* **112**(6), 4608-4621. https://doi.org/10.1016/j.ygeno.2020.08.006

Chen, C., Travis, A. J., Hossain, M., Islam, M. R., Price, A. H., & Norton, G. J. (2021). Genome-wide association mapping of sodium and potassium concentration in rice grains and shoots under alternate wetting and drying and continuously flooded irrigation. *Theoretical and Applied Genetics,* **134**, 2315-2334. https://doi.org/10.1007/s00122-021-03828-9

De la Torre-González, A., Montesinos-Pereira, D., Blasco, B., & Ruiz, J. (2018). Influence of the proline metabolism and glycine betaine on tolerance to salt stress in tomato (Solanum lycopersicum L.) commercial genotypes. *Journal of Plant Physiology,* **231**, 329-336. https://doi.org/10.1016/j.jplph.2018.10.013

Elsawy, H. I., Mekawy, A. M. M., Elhity, M. A., Abdel-Dayem, S. M., Abdelaziz, M. N., Assaha, D. V., . . . Saneoka, H. (2018). Differential responses of two Egyptian barley (Hordeum vulgare L.) cultivars to salt stress. *Plant Physiology and Biochemistry,* **127**, 425-435. https://doi.org/10.1016/j.plaphy.2018.04.012

Fahad, S., Adnan, M., Noor, M., Arif, M., Alam, M., Khan, I. A., . . . Jamal, Y. (2019). Major constraints for global rice production. In *Advances in rice research for abiotic stress tolerance* (pp. 1-22): Elsevier.

Farooq, M. U., Bashir, M. F., Khan, M. U. S., Iqbal, B., and Ali, Q. (2021). Role of crispr to improve abiotic stress tolerance in crop plants. *Biological and Clinical Sciences Research Journal* **2021**. https://doi.org/10.54112/bcsrj.v2021i1.69

Ganie, S. A., Molla, K. A., Henry, R. J., Bhat, K., & Mondal, T. K. (2019). Advances in understanding salt tolerance in rice. *Theoretical and Applied Genetics,* **132**, 851-870. https://doi.org/10.1016/B978-0-12-814332-2.00001-0

Gerona, M. E. B., Deocampo, M. P., Egdane, J. A., Ismail, A. M., & Dionisio-Sese, M. L. (2019). Physiological responses of contrasting rice genotypes to salt stress at reproductive stage. *Rice Science,* **26**(4), 207-219. https://doi.org/10.1016/j.rsci.2019.05.001

Ghafoor, M. F., Ali, Q., and Malik, A. (2020). Effects of salicylic acid priming for salt stress tolerance in wheat. *Biological and Clinical Sciences Research Journal* **2020**. https://doi.org/10.54112/bcsrj.v2020i1.24

Gul, Z., Tang, Z.-H., Arif, M., & Ye, Z. (2022). An insight into abiotic stress and influx tolerance mechanisms in plants to cope in saline environments. *Biology,* **11**(4), 597. https://doi.org/10.3390/biology11040597

Hasanuzzaman, M., Anee, T. I., Bhuiyan, T. F., Nahar, K., & Fujita, M. (2019). Emerging role of osmolytes in enhancing abiotic stress tolerance in rice. In *Advances in rice research for abiotic stress tolerance* (pp. 677-708): Elsevier. https://doi.org/10.1016/B978-0-12-814332-2.00033-2

Hasanuzzaman, M., Bhuyan, M. B., Anee, T. I., Parvin, K., Nahar, K., Mahmud, J. A., & Fujita, M. (2019). Regulation of ascorbate-glutathione pathway in mitigating oxidative damage in plants under abiotic stress. *Antioxidants,* **8**(9), 384. https://doi.org/10.3390/antiox8090384

He, Y., Li, L., Zhang, Z., & Wu, J.-L. (2018). Identification and comparative analysis of premature senescence leaf mutants in rice (Oryza sativa L.). *International Journal of Molecular Sciences*, **19**(1), 140. https://doi.org/10.3390/ijms19010140

Hu, Q., Wang, W., Lu, Q., Huang, J., Peng, S., & Cui, K. (2021). Abnormal anther development leads to lower spikelet fertility in rice (Oryza sativa L.) under high temperature during the panicle initiation stage. *BMC Plant Biology*, **21**(1), 1-17. https://doi.org/10.1186/s12870-021-03209-w

Huqe, M. A. S., Haque, M. S., Sagar, A., Uddin, M. N., Hossain, M. A., Hossain, A. Z., . . . Ueda, A. (2021). Characterization of maize hybrids (Zea mays L.) for detecting salt tolerance based on morpho-physiological characteristics, ion accumulation and genetic variability at early vegetative stage. *Plants*, **10**(11), 2549. https://doi.org/10.3390/plants10112549

Hussain, M., Ahmad, S., Hussain, S., Lal, R., Ul-Allah, S., & Nawaz, A. (2018). Rice in saline soils: physiology, biochemistry, genetics, and management. *Advances in agronomy*, **148**, 231-287.https://doi.org/10.1016/bs.agron.2017.11.002

Hussain, S., Shaukat, M., Ashraf, M., Zhu, C., Jin, Q., & Zhang, J. (2019). Salinity stress in arid and semi-arid climates: Effects and management in field crops. *Climate change and agriculture*, **13**, 201-226. http://dx.doi.org/10.5772/intechopen.84405

Iqbal, S., Ali, Q., and Malik, A. (2021). Effects of seed priming with salicylic acid on zea mays seedlings grown under salt stress conditions. *Biological and Clinical Sciences Research Journal* **2021**. https://doi.org/10.54112/bcsrj.v2021i1.65

Iqra, L., Rashid, M. S., Ali, Q., Latif, I., and Mailk, A. (2020a). Evaluation for Na+/K+ ratio under salt stress condition in wheat. *Life Sci J* **17**, 43-47.

Iqra, L., Rashid, M. S., Ali, Q., Latif, I., and Malik, A. (2020b). Evaluation of genetic variability for salt tolerance in wheat. *Biological and Clinical Sciences Research Journal* **2020**. https://doi.org/10.54112/bcsrj.v2020i1.16

Jam, B. J., Shekari, F., Andalibi, B., Fotovat, R., Jafarian, V., Najafi, J., . . . Mastinu, A. (2023). Impact of silicon foliar application on the growth and physiological traits of Carthamus tinctorius L. exposed to salt stress. *Silicon*, **15**(3), 1235-1245. https://doi.org/10.1007/s12633-022-02090-y

Karalija, E., & Selović, A. (2018). The effect of hydro and proline seed priming on growth, proline and sugar content, and antioxidant activity of maize under cadmium stress. *Environmental Science and Pollution Research*, **25**(33), 33370-33380. https://doi.org/10.1007/s11356-018-3220-7

Keisham, M., Mukherjee, S., & Bhatla, S. C. (2018). Mechanisms of sodium transport in plants—progresses and challenges. *International Journal of Molecular Sciences*, **19**(3), 647. https://doi.org/10.3390/ijms19030647

Khadka, K., Earl, H. J., Raizada, M. N., & Navabi, A. (2020). A physio-morphological trait-based approach for breeding drought tolerant wheat. *Frontiers in plant science*, **11**, 715. https://doi.org/10.3389/fpls.2020.00715

Kumar, P., & Sharma, P. K. (2020). Soil salinity and food security in India. *Frontiers in Sustainable Food Systems*, **4**, 533781. https://doi.org/10.3389/fsufs.2020.533781

Kumari, A., Goyal, V., & Sheokand, S. (2019). Oxidative stress and antioxidant defence under metal toxicity in halophytes. *Ecophysiology, Abiotic Stress Responses and Utilization of Halophytes*, 115-155. https://doi.org/10.1007/978-981-13-3762-8_6

Li, C., Zhang, C., Yu, T., Liu, X., Xia, X., Hou, Q., Wang, L. (2022). Annual net input fluxes of cadmium in paddy soils in karst and non-karst areas of Guangxi, China. *Journal of Geochemical Exploration*, **241**, 107072. https://doi.org/10.1016/j.gexplo.2022.107072

Majeed, A., & Muhammad, Z. (2019). Salinity: a major agricultural problem—causes, impacts on crop productivity and management strategies. *Plant abiotic stress tolerance: Agronomic, molecular and biotechnological approaches*, 83-99. https://doi.org/10.1007/978-3-030-06118-0_3

Manokari, M., Dey, A., Faisal, M., Alatar, A. A., Joshee, N., & Shekhawat, M. S. (2023). Structural alterations of Cymbopogon citratus (DC.) Stapf leaves and roots caused by silicon nanoparticles during in vitro propagation. *Industrial Crops and Products*, **197**, 116648. https://doi.org/10.1016/j.indcrop.2023.116648

Mazhar, T., Ali, Q., and Malik, M. (2020). Effects of salt and drought stress on growth traits of Zea mays seedlings. *Life Science Journal* **17**, 48-54.

McHugh, J. (2021). *An Unholy Brew: Alcohol in Indian History and Religions*: Oxford University Press. 10.1093/oso/9780199375936.003.0012

Meena, H., Yadav, R., Jain, N., & Meena, M. (2022). Sodium accumulation trend in the different quality seed, cultivars, and yield potential of peanut under salinity stress. *Journal of Plant Nutrition*, **45**(20), 3129-3144. https://doi.org/10.1080/01904167.2022.2046068

Mohapatra, P. K., Sahu, B. B., Mohapatra, P. K., & Sahu, B. B. (2022). Botany of Rice Plant. *Panicle Architecture of Rice and its Relationship* *with Grain Filling*, 27-48. https://doi.org/10.1007/978-3-030-67897-5

Mohidem, N. A., Hashim, N., Shamsudin, R., & Che Man, H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*, **12**(6), 741.https://doi.org/10.3390/agriculture1206074 1

Morton, M. J., Awlia, M., Al-Tamimi, N., Saade, S., Pailles, Y., Negrão, S., & Tester, M. (2019). Salt stress under the scalpel–dissecting the genetics of salt tolerance. *The Plant Journal*, **97**(1), 148-163. https://doi.org/10.1111/tpj.14189

Munawar, S., ul Qamar, M. T., Mustafa, G., Khan, M. S., & Joyia, F. A. (2020). Role of biotechnology in climate resilient agriculture. *Environment, climate, plant and vegetation growth*, 339-365. https://doi.org/10.1007/978-3-030-49732-3_14

Naseem, S., Ali, Q., and Malik, A. (2020). Evaluation of maize seedling traits under salt stress. *Biological and Clinical Sciences Research Journal* **2020**. https://doi.org/10.54112/bcsrj.v2020i1.25

Okon, O. G. (2019). Effect of salinity on physiological processes in plants. *Microorganisms in saline environments: strategies and functions*, 237-262. https://doi.org/10.1007/978-3-030-18975-4_10

Paik, S., Le, D. T. P., Nhu, L. T., & Mills, B. F. (2020). Salt-tolerant rice variety adoption in the Mekong River Delta: Farmer adaptation to sea-level rise. *PloS one*, **15**(3), e0229464. https://doi.org/10.1371/journal.pone.0229464

Pandey, N. (2018). Antioxidant defense system in plants exposed to metal toxicity. *Plants Under Metal and Metalloid Stress: Responses, Tolerance and Remediation*, 107-148. https://doi.org/10.1186/1471-2229-8-87

Panini, M., Chiesa, O., Troczka, B. J., Mallott, M., Manicardi, G. C., Cassanelli, S., Bass, C. (2021). Transposon-mediated insertional mutagenesis unmasks recessive insecticide resistance in the aphid Myzus persicae. *Proceedings of the National Academy of Sciences*, **118**(23), e2100559118.https://doi.org/10.1073/pnas.2100559118

Parida, A. K., Sekhar, S., Panda, B. B., Sahu, G., & Shaw, B. P. (2022). Effect of panicle morphology on grain filling and rice yield: genetic control and molecular regulation. *Frontiers in Genetics*, **13**, 876198. https://doi.org/10.3389/fgene.2022.876198

Parvin, K., Hasanuzzaman, M., Bhuyan, M., Nahar, K., Mohsin, S. M., & Fujita, M. (2019). Comparative physiological and biochemical changes in tomato (Solanum lycopersicum L.) under salt stress and recovery: role of antioxidant defense and glyoxalase systems. *Antioxidants*, **8**(9), 350. https://doi.org/10.3390/antiox8090350

Polash, M. A. S., Sakil, M. A., & Hossain, M. A. (2019). Plants responses and their physiological and biochemical defense mechanisms against salinity: A review. *Trop. Plant Res*, **6**, 250-274.

Pour-Aboughadareh, A., Mehrvar, M. R., Sanjani, S., Amini, A., Nikkhah-Chamanabad, H., & Asadi, A. (2021). Effects of salinity stress on seedling biomass, physiochemical properties, and grain yield in different breeding wheat genotypes. *Acta Physiologiae Plantarum*, **43**, 1-14. https://doi.org/10.1007/s11738-021-03265-7

Prakash, M., & Vignesh, M. (2019). Relationship between biometric and biophysical parameters with yield in traditional rice varieties in coastal saline belts of Tamil Nadu. *Indian Journal of Traditional Knowledge (IJTK)*, **18**(4), 805-817. https://doi.org/10.56042/ijtk.v18i4.29026

Prathap, V., Ali, K., Singh, A., Vishwakarma, C., Krishnan, V., Chinnusamy, V., & Tyagi, A. (2019). Starch accumulation in rice grains subjected to drought during grain filling stage. *Plant Physiology and Biochemistry*, **142**, 440-451.https://doi.org/10.1016/j.plaphy.2019.07.027

Radanielson, A. M., Gaydon, D. S., Khan, M. M. R., Chaki, A. K., Rahman, M. A., Angeles, O., . . . Ismail, A. (2018). Varietal improvement options for higher rice productivity in salt affected areas using crop modelling. *Field Crops Research*, **229**, 27-36. https://doi.org/10.1016/j.fcr.2018.08.020

Rasel, M., Tahjib-Ul-Arif, M., Hossain, M. A., Hassan, L., Farzana, S., & Brestic, M. (2021). Screening of salt-tolerant rice landraces by seedling stage phenotyping and dissecting biochemical determinants of tolerance mechanism. *Journal of Plant Growth Regulation*, **40**, 1853-1868. https://doi.org/10.1007/s00344-020-10235-9

Ravikiran, K., Krishnamurthy, S., Warraich, A., & Sharma, P. (2018). Diversity and haplotypes of rice genotypes for seedling stage salinity tolerance analyzed through morpho-physiological and SSR markers. *Field Crops Research*, **220**, 10-18. https://doi.org/10.1016/j.fcr.2017.04.006

Resende, N. C., Miranda, J. H., Cooke, R., Chu, M. L., & Chou, S. C. (2019). Impacts of regional climate change on the runoff and root water uptake in corn crops in Parana, Brazil. *Agricultural Water Management*, **221**, 556-565. https://doi.org/10.1016/j.agwat.2019.05.018

Riaz, M., Arif, M. S., Ashraf, M. A., Mahmood, R., Yasmeen, T., Shakoor, M. B., . . . Arif, M. (2019). A comprehensive review on rice responses and tolerance to salt stress. *Advances in rice research for abiotic stress tolerance*, 133-

158. https://doi.org/10.1016/B978-0-12-814332-2.00007-1

Rodríguez Coca, L. I., García González, M. T., Gil Unday, Z., Jiménez Hernández, J., Rodríguez Jáuregui, M. M., & Fernández Cancio, Y. (2023). Effects of Sodium Salinity on Rice (Oryza sativa L.) Cultivation: A Review. *Sustainability*, *15*(3), 1804. https://doi.org/10.3390/su15031804

Saddiq, M. S., Afzal, I., Basra, S. M., Iqbal, S., & Ashraf, M. (2020). Sodium exclusion affects seed yield and physiological traits of wheat genotypes grown under salt stress. *Journal of Soil Science and Plant Nutrition*, **20**, 1442-1456. https://doi.org/10.1007/s42729-020-00224-y

Safdar, H., Amin, A., Shafiq, Y., Ali, A., Yasin, R., Shoukat, A., Sarwar, M. I. (2019). A review: Impact of salinity on plant growth. *Nature and Science*, **17**(1), 34-40.

Sakai, Y., Shimizu, C., Murata, H., Seto, H., Fukushima, R., Koga, T., & Wang, C. (2020). Changes in soil physicochemical properties and maize production following improvement of salt-affected soils using coal bio-briquette ash in northeast China. *Agronomy*, **10**(3), 348. https://doi.org/10.3390/agronomy10030348

Samal, P., Babu, S. C., Mondal, B., & Mishra, S. N. (2022). The global rice agriculture towards 2050: An inter-continental perspective. *Outlook on Agriculture*, **51**(2), 164-172. https://doi.org/10.1177/00307270221088338

Sampangi-Ramaiah, M. H., Jagadheesh, Dey, P., Jambagi, S., Vasantha Kumari, M., Oelmueller, R., . . . Uma Shaanker, R. (2020). An endophyte from salt-adapted Pokkali rice confers salt-tolerance to a salt-sensitive rice variety and targets a unique pattern of genes in its new host. *Scientific reports*, **10**(1), 3237. https://doi.org/10.1038/s41598-020-59998-x

Santanoo, S., Lontom, W., Dongsansuk, A., Vongcharoen, K., & Theerakulpisut, P. (2023). Photosynthesis Performance at Different Growth Stages, Growth, and Yield of Rice in Saline Fields. *Plants*, **12**(9), 1903. https://doi.org/10.3390/plants12091903

Saradadevi, G. P., Das, D., Mangrauthia, S. K., Mohapatra, S., Chikkaputtaiah, C., Roorkiwal, M., . . . Sakhare, A. S. (2021). Genetic, epigenetic, genomic and microbial approaches to enhance salt tolerance of plants: A comprehensive review. *Biology*, **10**(12), 1255. https://doi.org/10.3390/biology10121255

Sarwar, M., Anjum, S., Alam, M. W., Ali, Q., Ayyub, C., Haider, M. S., Ashraf, M. I., and Mahboob, W. (2022). Triacontanol regulates morphological traits and enzymatic activities of salinity affected hot pepper plants. *Scientific Reports* **12**, 1-8. https://doi.org/10.1038/s41598-022-06516-w

Sarwar, M., Anjum, S., Ali, Q., Alam, M. W., Haider, M. S., and Mehboob, W. (2021). Triacontanol modulates salt stress tolerance in cucumber by altering the physiological and biochemical status of plant cells. *Scientific reports* **11**, 1-10. https://doi.org/10.1038/s41598-021-04174-y

Sayed, M. A., Nassar, S. M., Moustafa, E. S., Said, M. T., Börner, A., & Hamada, A. (2021). Genetic mapping reveals novel exotic and elite QTL alleles for salinity tolerance in barley. *Agronomy*, **11**(9), 1774. : https://doi.org/10.3390/agronomy11091774

Shahid, M. A., Sarkhosh, A., Khan, N., Balal, R. M., Ali, S., Rossi, L., Garcia-Sanchez, F. (2020). Insights into the physiological and biochemical impacts of salt stress on plant growth and development. *Agronomy*, **10**(7), 938. https://doi.org/10.3390/agronomy10070938

Sharma, P., & Singh, A. (2019). Reviving the productivity of salt-affected lands: technological options, constraints and research needs. *Research Developments in Saline Agriculture*, 591-627.https://doi.org/10.1007/978-981-13-5832-6_20

Sharma, R. K., Abidi, N., & Misra, R. K. (2020). Assessment of agricultural sustainability-a study of farmers growing basmati rice under conventional and fair-trade systems in India. *International Journal of Sustainable Agricultural Management and Informatics*, **6**(1), 1-21. https://doi.org/10.1504/IJSAMI.2020.106549

Shchapova, A. (2012). Evolution of the basic chromosome number in Poaceae Barnh. *Russian Journal of Genetics: Applied Research, 2*, 252-259. https://doi.org/10.1134/S2079059712030100

Shingote, P. R., Kawar, P. G., Pagariya, M. C., Muley, A. B., & Babu, K. (2020). Isolation and functional validation of stress tolerant EaMYB18 gene and its comparative physio-biochemical analysis with transgenic tobacco plants overexpressing SoMYB18 and SsMYB18. *3 Biotech*, **10**, 1-13. https://doi.org/10.1007/s13205-020-02197-2

Singh, R. K., Kota, S., & Flowers, T. J. (2021). Salt tolerance in rice: seedling and reproductive stage QTL mapping come of age. *Theoretical and Applied Genetics*, **134**, 3495-3533. https://doi.org/10.1007/s00122-021-03890-3

Singh, V., Singh, A. P., Bhadoria, J., Giri, J., Singh, J., TV, V., & Sharma, P. (2018). Differential expression of salt-responsive genes to salinity stress in salt-tolerant and salt-sensitive rice (Oryza sativa L.) at seedling stage. *Protoplasma*, **255**, 1667-1681. https://doi.org/10.1007/s00709-018-1257-6

Sofi, N. R., Hussain, A., Shikari, A. B., Sofi, M., Teeli, N., Mohiddin, F., & Bhat, N. (2020). Rice crop in Kashmir Valley: Historical perspective, challenges and opportunities for sustainable production and livelihood improvement. *SKUAST Journal of Research*, **22**(1), 123-129.

Syeed, S., Sehar, Z., Masood, A., Anjum, N. A., & Khan, N. A. (2021). Control of elevated ion accumulation, oxidative stress, and lipid peroxidation with salicylic acid-induced accumulation of glycine betaine in salinity-exposed Vigna radiata L. *Applied Biochemistry and Biotechnology*, **193**(10), 3301-3320. https://doi.org/10.1007/s12010-021-03595-9

Tahir, T., Ali, Q., Rashid, M. S., and Malik, A. (2020). The journey of crispr-cas9 from bacterial defense mechanism to a gene editing tool in both animals and plants. *Biological and Clinical Sciences Research Journal* **2020**. https://doi.org/10.54112/bcsrj.v2020i1.17

Teshome, D. T., Zharare, G. E., & Naidoo, S. (2020). The threat of the combined effect of biotic and abiotic stress factors in forestry under a changing climate. *Frontiers in plant science*, **11**, 1874. https://doi.org/10.3389/fpls.2020.601009

Tessema, N., Yadeta, D., Kebede, A., & Ayele, G. T. (2022). Soil and irrigation water salinity, and its consequences for agriculture in Ethiopia: a systematic review. *Agriculture*, **13**(1), 109. https://doi.org/10.3390/agriculture13010109

Thorat, B., Bagkar, T., & Raut, S. (2018). Responses of rice under salinity stress: A review. *Int J Chem Stud*, **6**, 1441-1447.

Wang, C.-F., Han, G.-L., Qiao, Z.-Q., Li, Y.-X., Yang, Z.-R., & Wang, B.-S. (2022). Root Na+ content negatively correlated to salt tolerance determines the salt tolerance of Brassica napus L. inbred seedlings. *Plants*, **11**(7), 906. https://doi.org/10.3390/plants11070906

Wang, Y., Wang, L., Zhou, J., Hu, S., Chen, H., Xiang, J., Zhu, D. (2019). Research progress on heat stress of rice at flowering stage. *Rice Science*, **26**(1), 1-10. https://doi.org/10.1016/j.rsci.2018.06.009

Wangsawang, T., Chuamnakthong, S., Ueda, A., & Sreewongchai, T. (2021). Na+ exclusion mechanism in the roots through the function of OsHKT1; 5 confers improved tolerance to salt stress in the salt-tolerant developed rice lines. *Science Asia*, **47**(6). https://doi.org/10.2306/scienceasia1513-1874.2021.106

Wen, F., Ye, F., Xiao, Z., Liao, L., Li, T., Jia, M., . . . Wu, X. (2020). Genome-wide survey and expression analysis of calcium-dependent protein kinase (CDPK) in grass Brachypodium distachyon. *BMC genomics*, **21**, 1-17. https://doi.org/10.1186/s12864-020-6475-6

Wu, C., Tang, S., Li, G., Wang, S., Fahad, S., & Ding, Y. (2019). Roles of phytohormone changes in the grain yield of rice plants exposed to heat: a review. *PeerJ*, **7**, e7792. https://doi.org/10.7717/peerj.7792

Xie, X., He, Z., Chen, N., Tang, Z., Wang, Q., & Cai, Y. (2019). The roles of environmental factors in regulation of oxidative stress in plant. *BioMed research international*, **2019**. https://doi.org/10.1155/2019/9732325

Yadav, P., Singh, P., & Verma, O. (2022). Estimating genetic variability, heritability and genetic advance in rice (Oryza sativa L.) for yield and its components under sodic soil. *The Pharma Innovation Journal*, **11**(1), 1386-1389.

Yang, M., Wang, C., Hassan, M. A., Li, F., Xia, X., Shi, S., He, Z. (2021). QTL mapping of root traits in wheat under different phosphorus levels using hydroponic culture. *BMC genomics*, **22**(1), 1-12.https://doi.org/10.1186/s12864-021-07425-4

Zaman, M., Shahid, S. A., Heng, L., Shahid, S. A., Zaman, M., & Heng, L. (2018). Soil salinity: Historical perspectives and a world overview of the problem. *Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques*, 43-53. https://doi.org/10.1007/978-3-319-96190-3_2

Declarations

Acknowledgments

Not applicable

Funding

Not applicable

Author's contributions

AA wrote the initial draft of manuscript. AA, AUR and SSB edit the manuscript in original. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable

Consent for Publication

Not applicable

Competing interests

The authors declare that they have no competing interests.