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Review Article

Shortcomings in Rice Production: with Special Emphasis on Salinity Stress

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Abstract

Around the world, 811 million people slept hungry every single night during the year 2020. Rice is a salt-sensitive crop. The food production rate is not keeping up pace with the rate at which the global population is rising. The projections of the growth rate estimated that by 2057 the world population would reach 10 million. Providing food to the growing human population is a big challenge. Rice production needs to be increased by at least 40% by the year 2030. Rice production, however, faces challenge from depleting soil, reduced fund in the developing world, land limitation and biotic and abiotic stresses. Biotic stresses due to bacteria, fungi, viruses and insects pests may led to the losses accounting for more than 50% of the yield. Similarly, abiotic stresses due to drought, temperatures, UV radiation and salinity also pose several limitations to the rice production. The losses due to salinity includes the loss of nutrients, amino acids and proteins, and minerals and vitamins. The plants over the course of evolution have developed specific mechanisms to counter these stresses. Present work is a review of previous works to develop an understanding so as to design a suitable strategy to increase rice production for a sustainable future.

Keywords: Rice; Biotic Stress; Abiotic Stress; Salinity

Introduction

Around the world, 811 million people slept hungry every single night during the year 2020 Global Hunger Index (GHI) is a measure of hunger at global, regional, and national levels with an aim to raise awareness and understanding of the struggle against hunger, a tool to compare the differences in the hunger of countries and call for the attention of the local government to take appropriate measures to eliminate the hunger. The global hunger index score considers undernourishment, underweight children, stunted growth in children, and child mortality.

As per the Global Hunger Index, 2021, of the 135 nations, the GHI scores for 19 countries could not be estimated due to the unavailability of data. Of the remaining 116 countries the pie chart is shown in figure 1. 42% of the 116 countries had less than 10 GHI in 2021, while 26% had a GHI score ranging between 10 to 20. In 2021 still, 32% of the world was living with a global hunger index score greater than 20. Somalia had the highest GHI rank and is greater than 50 for the last 20 years.

The GHI score of the year 2021 was compared with the base year 2000, and it showed a decrease in the GHI score of 73% of the countries (Figure 2). However, the GHI score of Jamaica remained unchanged, while, the GHI score of the countries, Yemen and the Bolivarian Republic of Venezuela showed an increase. The increase in the hunger index of the Bolivarian Republic of Venezuela in 2021 was 52.1% as compared with that of the year 2000. The global hunger index of India was 38.8 in the year 2000 and is reduced to 27.5 in the year 2021. Despite a 29% decrease in the GHI, India still ranks 101st among the 116 countries with sufficient data to analyze.

Addressing hunger issues

More than 50,000 edible plants are known. Among these, rice, maize, and wheat are the most important food crops on earth; when combined, contribute nearly 60% of the nutrients to the world population. These three crops are consumed by more than 4000 million people as a staple food. The total land area under cultivation is highest for wheat 214 million hectares followed by rice (154 million hectares), and maize (140 million hectares). 85% of

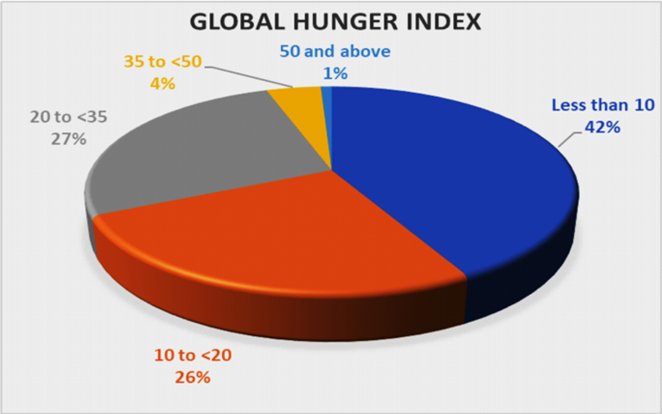

Figure 1: Global Hunger Index, 2001.
Data source: https://www.globalhungerindex.org/ranking.html

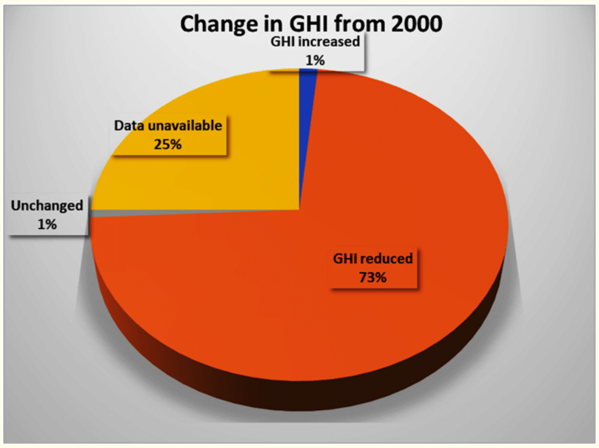

Figure 2: Reduction in Global Hunger Index from the year 2000 to the year 2021.
Data source: https://www.globalhungerindex.org/ranking.html

rice produced is used for human consumption, while 72% of wheat and 19% of maize produced is used for human consumption.

Rice, an important staple food

Rice is eaten as a staple food for over 50% of the global population. Over 1,10,000 rice varieties are known, which differ in their seed size, color, aroma, and taste. Among various rice varieties, *Oryza sativa* is the dominant crop type. The rice is consumed either as white or brown rice. Removal of brown husk from the rice, makes it white, which compromises its nutrient content including vitamin-B, protein, fat, phosphorous, and calcium along with some phytochemicals [73].

Global production of rice

A total of 509.87 million metric tons of milled rice is produced on 164.19 million hectares of land around the globe. China is the largest producer of paddy ride producing 211.86 million metric tons of rice in 2020, followed by India and Bangladesh [65]. India was the largest exporter of Rice in 2021-22 and exported 18,750,000 metric tons of rice.

The food production rate is not keeping up pace with the rate at which the global population is rising. As of date, Mother Earth houses 7.96 billion people and the population is growing at an alarming rate. It was approximately 5 million at the dawn of agriculture in around 8000 BC. The exponential growth of the population led to a 2-fold increase in the world population in the 40 years i.e., from 1859 (3 billion) to 1999 (6 billion), and in the subsequent 40 years, there would be another 50% growth in the population to 9 billion by the year 2039. The projections of the growth rate estimated that by 2057 the world population would reach 10 million. Providing food to the growing human population is a big challenge. Rice production needs to be increased by at least 40% by the year 2030 [36].

Problems faced in rice production

Soil that is used for agriculture for thousands of years without replenishing is exhausted and depleted in nutrients leading to low productivity per hectare. The Indian average yield of nearly all the crops per hectare is the lowest in the world. In addition, the crop plants are exposed to several environmental challenges that pose several stresses including biotic and abiotic stresses. Biotic stress includes stress due to pests and microbes while abiotic stresses are posed by the environment such as drought, flood, salinity, etc.

Quality of rice

The demand for quality rice is on the rise throughout Europe, the United States, and Africa. Especially the demand for longer rice with aroma has been on the rise. Several rice varieties, including the longer rice with aroma, are being developed that are adapted to colder nights. The development of such varieties has altered historically rice-producing areas [85]. Basmati rice varieties with longer grain size, better quality, and pleasant aroma present a better choice [12].

Different rice varieties with specific properties, for example, waxy rice, organic rice, and common (wild) rice are attracting the attention of the consumers. Efforts to synchronize the logical approaches for the development of novel attractive quality rice and their economic production is the need of the hour and concerted efforts of various national and international research agencies are required [58].

Reduced funding in developing rice yield

Funding is the backbone of any project. Farming is not considered a profitable profession and needs Government support, esp., in lower- and middle-income group countries. Crops like paddy are mainly dependent on the availability of water. In earlier times, agriculture was mainly dependent upon rain which is beyond human control. Irrigation channels helped the farmers working on agricultural lands far from rivers. The investments in irrigation along with the water management systems by Expanding Rice Production Project of Global Agriculture and Food Security Program, showed a rise in rice production thereby, improved rural incomes and food security in Tanzania [24]. Further, the project also worked for water use efficiency that had led to a reduction in the water requirement by half.

Rice production in itself has an environmental cost. Approximately, 2.5K liters of water is needed per Kg of rice produced. One-third of the irrigation water is used in rice farming alone. In addition, paddy farming in the flooded area is a big source of global methane. The environmental costs associated with paddy farming may impact its yield and nutritional value in the future. Global warming is making things worse for rice farmers esp., in the Southeast Asian Region. To promote sustainable production, "UN Environment Program in partnership with the International Rice Research Institute and German development agency—Gesellschaft für Internationale Zusammenarbeit initiated the Sustainable Rice Platform in the year 2011 intending to connect governments, development partners, businesses, farmers, and non-governmental organizations around the world to develop and implement proven solutions that benefit rice producers, consumers, and the environment". In the year 2015, the Sustainable Rice Platform finalized a set of indicators to monitor the progress and impact of the adoption of climate-smart, sustainable practices.

Land limitations

Rapid population growth, industrialization, and segment stress have forced farmers to use outlying land for expanding rice production to meet the demands of their families. Corrosive sands, wetlands, forestry areas, etc. have therefore been reclaimed and placed under development, limiting the potential for harvest output. The main soil issues are alterations in soil qualities, impacts of soil mining, and groundwater contamination in intensive flooded rice farming frameworks.

Long-term soil watering and drying cause hard dishes to form 5–15 cm below the surface. The solid dish reduces soil porosity and the root's ability to get nutrients from soil because it has a bulk soil layer with fewer large and medium spaces. Additionally, prolonged waterlogging circumstances, raise soil toxic levels, preventing the growth of dryland plants after rice. The limitless supply of modern rice also stimulates the increased use of machinery in rice farming, particularly in developed nations, which stimulates soil structure.

Biotic stress

Rice faces a challenge from several biotic stresses such as bacterial leaf blight, sheath blight, blast, brown spot, false smut, brown plant hopper, yellow stem borer, and gall midge, which costs heavily in terms of the overall productivity and quality of the yield [69]. Sheath blight, false smut, and brown spot altogether account for nearly 10-15% of the yield loss. The losses can be devastating and may reach 20-40% in case of bacteria leaf blight epidemics [2] or may cross 50% in the case of blast epidemic [37].

Bacterial pathogens of Rice

The causative agent of the bacterial leaf blight is the bacteria *Xanthomonas oryzae* pv. *oryzae* [66]. The bacterium gains entry into the leaves via wounds or hydathodes. Upon gaining access to the internal tissues of leaves, it multiplies and migrates to xylem vessels. In the xylem vessels, the bacteria multiply actively to manifest the disease symptoms in rice leaves. The disease is manifested as a change of leaf color from pale-green to grey-green. In addition, water-soaked streaks are also visible at or near the leaf tips. The lesions grow with wavy edges and eventually, the whole leaf dies. Infection also results in wilting and desiccation of leaves. Young transplanted plants may die of the disease while the leaves of the older ones do not survive. The disease also influences the maturation of the grains.

Xanthomonas oryzae pv. *oryzicola* is another pathogenic bacterium that causes diseases in rice. The disease caused by the bacteria is called rice bacterial leaf streak. *Oryza indica* is more susceptible to the disease than *O. japonica*. The economic loss occurred by the bacteria is comparatively lesser. However, epidemics of the disease may cost up to 10-30% loss [48]. The bacteria infect the rice leaves via stomata and colonize the apoplasts in the mesophyll cells. The symptoms of the disease include interveinal necrotic lesions [21].

Fungal pathogens of Rice

Magnaporthe oryzae

Magnaporthe oryzae, a filamentous fungus is the causative agent of blast in rice. The fungus is a hemibiotroph i.e., it infects a living tissue and continues to live on the dead tissues as well [57]. The annual losses due to infection of the fungus in rice, if averted can feed nearly 60 million people [54]. The parasite has to undergo several transformations to infect the plant cell. Upon infection, it builds an elaborate infection structure and multiplies inside the host cell. Since it is a hemibiotroph, it does not cause many visible symptoms. However, forms a necrotrophic association with the cell resulting in its death.

Rhizoctonia solani Kuhn

Rhizoctonia solani Kuhn causes sheath blight in rice. *R. solani* is a necrotrophic pathogen, i.e., it derives its nutrition from dead tissues. Traditionally, they are considered brutal and were believed to follow the "Kill and feed" strategy. However, recently the line between the hemibiotrophs and necrotrophs is fainting [57]. The disease Rice sheath blight is one of the most devastating rice diseases [60]. The early symptoms of the disease include the appearance of greenish-gray colored circular, oval or ellipsoid, water-soaked spots on the leaf sheaths of the rice plant. As the symptoms develop, the color of lesions changes to grayish white, with browning of the edges. The lesions coalesce to cover the whole sheath eventually killing the tissue [74]. Because of the symptoms, the disease got various names such as "snakeskin disease", "mosaic foot stalk", and "rotten foot stalk".

The Rice sheath blight disease was first identified in rice fields of Japan in the year 1910, and with time spread to other parts of the world [41]. Asia, Africa, and America continents are mainly affected by the disease. The incidence of the disease in the paddy fields increased a lot in the mid-2010s Applications of high dose of nitrogen fertilizers and large-scale planting of semi-dwarf high yield cultivars seems to be the reason for the increased incidence. The losses of the rice yield due to the disease may increase by more than 50% [20].

Viral pathogens of Rice

Rice yellow mottle virus - RYMV

RYMV was first reported in East Africa in 1966. Subsequently, the virus spread to almost all the paddy cultivating countries in the African region via West Africa [55]. *Oryza sativa* is the preferred host of the RYMV virus, however, it can infect several Oryza species. The plants infected by RYMV show many symptoms including leaf mottling, yellow-green streaking, decreased tillering, and stunting of plants during the vegetative stage. While poor emergence of panicles and panicle sterility occur at the reproductive stage. Plants that get infected at early stages usually cannot complete their life cycle [38]. The losses caused by the viral infection are extreme and may range from 10-100%.

Rice dwarf virus- RDV

RDV belongs to the genus Phytoreovirus (family Reoviridae) and it is prevalent in southern China and other Asian countries. It can survive and reproduce in graminaceous plants as well as in insects. The insect, leafhopper (*Nephotettix cincticeps* or *Resilia dorsalis*) acts as its vector for transmission from one plant host to another [71]. The disease caused by RDV manifests in the form of stunted growth, characteristic chlorotic flecks, and seed-lessness.

The structure of RDV is composed of an icosahedral double-shelled spherical coat with a double-stranded RNA genome. The diameter of the spherical virion particle is nearly 70 nm. The dsRNA genome of the RDV has twelve segments encoding 7 structural and 5 non-structural proteins. A non-structural protein of RDV, Pns4 is crucial for the infection, replication, and assembly of the virus particles in the insect vector leafhopper [14]. Upon infection, the RDV virus alters the physiology of its insect vector to ensure increased transmission [77].

Rice Tungro virus disease - RTV

Tungro is a disease in South and South-East Asia causing serious damage to rice yields in Bangladesh, India, Indonesia, Malaysia, Philippines, and Thailand. The annual losses due to the Tungro disease, account for nearly $1.5 billion. Two different viruses viz., Rice tungro bacilliform virus (RTBV) and Rice tungro spherical virus (RTSV) are involved in causing the disease in rice, of these RTBV contributes to the severity of the disease whereas, RTSV plays a helper role in the vector transmission [11]. RTSV may occur as an independent disease as reported in Philippines [3]. The virus is spread by green leaf hopper, *Nephotettix virescens* [28]. The complete genome of the RTBV is recently published by Kannan., *et al*. [30].

Rice yellow mottle virus - RYMV

RYMV are viruses of the Sobemovirus group. RYMV is responsible for the yellow mottle of rice (*Oryza sativa* L.). It is prevalent in the Afrotropical Regions. The virus was first recorded in Kenya in 1966. *Chaetoecnema pulla* is a beetle that acts as a vector of the

RYMV. Besides *C. pulla* another vector of the virus is another species of the same genus – *Chaetocnema sp.* nov. *prope varicornis* Jacoby [7]. The symptoms of the disease include yellowing of the leaves and stunting of plants besides reducing tillering and reproductive potential of the paddy [45].

Insect pests of Rice

Rice Gall-Midge

The scientific name of the rice gall midge insect is *Orseolia oryzae* (Insecta: Diptera). The insect is prevalent in tropical Asia and causes huge damage to rice productivity in Bangladesh, Burma, Cambodia, southern China, India, Indonesia, Laos, Sri Lanka, Thailand, and Vietnam [34]. The insect damages the crop by forming galls which are known as silver shoots or onion tubes. The insect pest is responsible for more than 60% of losses. The pest infestation prevents the formation of panicles in the severely infested plants.

Brown PlantHopper -BPH, *Nilaparvata lugens*

Nilaparvata lugens (Stål) (Hemiptera: Delphacidae) are one of the most destructive pests of rice [16]. The insect is a vascular feeder thereby, it damages the vascular bundles of leaf sheath while transmitting plant viruses from one plant to another. Further, it is a migratory insect that adds to its transmission potential. The insect uses its style to suck the phloem sap of the plant [16].

Control of the agents causing Biotic stress

Various measures for the control of pests and pathogens are being used including the use of chemicals i.e., pesticides and biocides, or various breeding programs. Since the use of chemicals is not environmentally friendly, their use must be discouraged for sustainable development. Extensive use of pesticides, for example, is a common practice for the control of various pests. However, indiscriminate use of chemicals not only adds to the environmental pollution but also kills non-target organisms that are beneficial for the environment thereby causing double harm to the ecology [75]. In addition, the use of chemicals is a costly affair and also poses a health hazard to the farmers.

Plant host resistance is a highly efficient measure to deal with the biotic stress posed by different microbes and pests. Identifying the resistance gene/s in the wild population and efforts to introgress or deploy or pyramid in various lines through resistance breeding programs and molecular approaches are underway [69]. For example, the Broad-Spectrum Resistance2 (BSR2) gene of the CYP78A family, conferred resistance to *R. solani* in rice [42]. Likewise, three RYMV virulence-resistant genes are recognized in rice. Gene introgression and/or pyramiding and rapid deployment of these resistance genes into elite cultivars seem to be an alternative to contain the virus [49].

Breeding does not always yield expected results. In the case of *Nilaparvata lugens,* for example, plant breeding to develop only a few resistant varieties that could reach fields [23]. Thus, some alternative strategy is required that can be employed to contain the pests. One such strategy is silicon amendment in soil. Silicon, which is not an essential nutrient is highly promising in the case of infestation of both sucking and chewing insect pests [61]. The application of silicon in the soil is found to impair the sucking behavior of *Nilaparvata lugens* and also limits its population by controlling its reproduction capacity [81].

Abiotic stress

Abiotic stress is the stress occurred in a plant system, due to the challenges posed by the immediate environment pushing the boundaries of the tolerance limit of the plant. Several abiotic factors affect the growth, biology, and productivity of Rice. These abiotic factors include drought, salinity, high and low temperatures, UV radiations, etc.

Low temperature

Rice-growing farmers living in temperate regions have to deal with the low temperature [78]. The chilling cold may injure the rice plants and the damage may vary with the stage of development, degree of coldness, and duration of exposure. Chilling temperatures may cost the normal growth, development, and productivity of the plant. Plants during the initial stages of life are comparatively tolerant to low temperatures and withstand up to 0 to 15°C while the plants at the reproductive stages cannot withstand temperatures below 18°C. However, chilled water is detrimental to all the stages of the life of the rice plant and negatively influences productivity [79].

The low-temperature stress is manifested as delayed and lower percentage of germination in the early stage [18]. While a vegetative state, it is manifested as yellowing of the leaves, dwarfness, and decreased tillering of the rice plants. Sterility of the spikelets or incomplete panicle exertion and spikelet abortion are major cold-induced damage to rice production [82].

Natural mechanisms of rice to adapt to cold stress may be exploited for protecting the plants from extreme cold. Rice plants under cold stress are known to accumulate proline to stabilize protein synthesis to stabilize the protein content of the cells [32]. Other known mechanisms to cope with cold stress include enhancing scavenging of the reactive oxygen species to prevent or minimize the damage due to oxidative stress [64].

A quantitative trait locus (QTL) is defined as a portion of DNA that is associated with a character. Several QTLs associated with the tolerance to cold stress have been identified. QTLs related to the cold-tolerance, such as Ctb1, qCTB2a, qPSST-3, qLTB3, qCTP11, qCtss11, and qCTS4a are found to be associated with different stages of rice life. Breeding programs based upon the cold tolerance-related QTLs are needed to isolate more cold-tolerant varieties [84].

Najeeb., *et al*. [46] identified 578 QTLs and 38 functionally characterized genes imparting tolerance to low-temperature stress. The combination of stage-specific QTLs and genes from biparental mapping populations and the genome-wide association seems promising for the development of cold-tolerant rice varieties [46].

Water challenges

Waterlogging, drought, salinity, toxic wastes, and contamination due to water are some important issues that need to be addressed. Since all these pose some stress on the rice and affect its growth and productivity. Efficient irrigation systems and sensitivity among farmers for water conservation and judicious use are two factors that would mitigate most of the problems related to water logging or shortage careless response to the functioning structure of the schemes and their economic circumstances are the main causes of this bad drainage status.

Drought

Rice cultivation is directly proportional to the water supply. However, water supply is dependent on several factors and mostly dependent on the quantity and duration of the rainy season. In the case of less water availability, paddy crops have to cope with the drought-like situation and experience stress. Drought stress is one of the important abiotic stresses that has shaped the evolution of plants. It accounts for a lot of loss in terms of productivity in the rainfed ecosystem [51].

Drought affects nearly 35% of the total cultivated land globally. Of the total area, one-third belongs to the developing world and one-fourth to the developing nations [62]. Breeding rice varieties with tolerance to drought stress offers an economically viable and sustainable option to improve rice productivity [51].

Efforts to develop drought-resistance varieties by breeding programs could not produce many drought-resistance varieties due to less availability of drought-tolerant varieties of rice in nature and a lack of suitable screening methods [51]. A thorough screening of nearly 1000s of germplasms from all across the globe could yield only a few drought-tolerant varieties [68]. International Rice Research Institute was house to the screening of thousands of genes deposited in the gene bank for drought tolerance and identified 65 drought-tolerant genes [10]. The importance of molecular genetics and breeding approaches for the development of drought tolerance in rice has been reviewed by Panda., *et al*. [50].

Salinity

Salinity affects 5-7% of the total global area [56]. Further, the total arable area is constantly increasing due to various factors to which human activities are chief contributors. According to an estimate, we shall lose half of the total cultivable land to salinity by 2050 [27].

Increases in soil salinity stimulate osmotic stress resulting in altered growth and physiology. Several physiological, and biochemical processes counting photosynthesis, respiration, nitrogen metabolism, and ion homeostasis are affected negatively by salinity and significantly reduce the yield of crops [56]. High exogenous salt concentrations affect seed germination, and water deficit, causing ion imbalance of the cellular ions resulting in ion toxicity and osmotic stress [35].

Specific effects of salt stress on plant metabolism have been related to the accumulation of toxic Na+ and Cl- ions, or to K+ and Ca2+ ions depletion [35]. The toxic level of Na+ and Cl- ions produced an outside osmotic potential that avoids water uptake or due to increased dormancy of seeds under salinity stress [43]. Amino acids have been reported to accumulate in higher plants under salinity stress. Proline is probably the most widely distributed osmolyte, and it occurs not only in plants but also in many other organisms [30]. Salinity is one of the most serious factors limiting the productivity of crops, with adverse effects on germination, plant vigor, and crop yield.

Salinity stress in rice

Rice is a salt-sensitive crop. Salinity has a tremendous effect on its productivity. Salinity is found to have adverse effects on the overall growth of the plants including CO2 turnover, leaf growth, and net organic content [5].

The salinity in the soil disrupts the ionic and osmotic balance in the plant cells thereby causing stress conditions. Presence of cationic sodium in the soil counters Ca^{2+} ions that may lead to calcium deficiency in the plants [29]. The high salt reaches the leaves causing senescence in the tissues thereby negatively affecting the photosynthetic rate of rice [67]. The initial phase of salt stress is manifested as osmotic stress and stunted leaf development while ionic stress marks the later phase of salt stress [6]. Overall, salinity takes a toll on the growth, metabolism, water and nutrient uptake, spikelet development, and yield [83].

Salinity stress also causes a nutrient imbalance in rice plants. Nitrogen uptake has also been reduced in the presence of high salinity. Other nutrients, the uptake of which have been reported to be reduced in rice include phosphorus, zinc, iron, and manganese [29].

The effect of salinity on rice plants can be observed in the vegetative phase as well as later reproduction phases. According to additive genetic variations, rice genotypes exhibit significant differences in salinity tolerance. Research has shown that rice is much more tolerant during the reproductive and grain-filling stages than during the seedling or vegetative stages, and that low salinity levels can boost rice tolerance to greater and deadly salt concentrations [46].

Nutrient losses of rice due to salt stress

Rice is grown in 114 different nations worldwide and is seen as an important crop to address global hunger. Salinity stress is detrimental not only to the rice yield but also to the nutrient content of rice.

Carbohydrates

Starch granules are a major constituent of carbohydrates in rice grains constituting. 87 percent of the total nutrients. Starch is the main ingredient (50 to 90 %) of the fresh mass of rice grains. Starch granules shape the texture, flavor, and appearance of the grain. Salt stress is known to affect the carbohydrates, insoluble as well as soluble sugars of rice cultivars that vary from genotype to genotype.

Salt stress in the tolerant varieties due to the presence of salt in soil greater than or equal to 8 dS/m is known to reduce the amylose content [59]. While in the sensitive cultivars, salt concentration 2-4 dS/m is sufficient to induce the stress. The effect of the soil salinity on the carbohydrate level was up to 7-11% at 40 mM NaCl concentrations [53]. Starch content of the rice cultivar Nipponbare was reported to increase when no stress was applied i.e., at low salinity of 2- 4 dS/m [72].

Contrarily, salt stress is reported to be countered by an increase in the starch content of the plant [6,52]. The formation of starch from the sugars is considered a mechanism to counter salinity-induced stress [52].

Salinity is reported to adversely affect the grain yield, which was attributed to the less availability of carbohydrates during the vegetative growth and spikelets development [29]. The rate of the translocation of the soluble sugars to the superior and inferior spikelets and reduction in the starch synthetase activity during grain development is proposed to be responsible for the lower productivity of rice under salinity stress [1].

Amino acids and proteins

Proteins constitute 5-12% of the organic matter of the rice grain. The protein content is a determinant of the rice quality, taste, and aroma. Salinity stress is known to influence the protein content of rice. The brown rice crop i.e., cultivar Pokkali when grown under the influence of salinity in the range 6-8dS/m increased the total protein content. The high protein content is important for providing strength to the rice and reducing its breakage during the milling process [40]. The increase in protein content is a desirable trait as far as marketing is concerned.

The effect of salinity on rice varies from genotype to genotype. A study regarding the effect of salinity on the rice protein content of six different rice cultivars. Salinity decreases overall protein content in three out of six varieties; however, it induces glutelin, albumin, and other proteins in rice [9]. Even the flour obtained from the rice produced under high saline conditions had a high pasting temperature.

Minerals and vitamins

Salinity stress also adversely affected the macro and micronutrients of rice. Accumulation of sodium and chloride ions in the plants influences the uptake of other charged ions. Mn, Cu and Zn were found to be accumulated in the salt-tolerant cultivar Pokkali, while nitrogen, phosphorous, potassium, and magnesium levels decreased in both the salt-tolerant 'Pokkali' and salt-sensitive KDML 105 cultivars [63].

In the rice-wheat intercropping system, an increase in salinity nitrogen, sodium, magnesium, and chlorine content witnessed increased accumulation accompanied by a decrease in the phosphorous, potassium, calcium, and sulfate ions [80]. At a salinity concentration of 8 dS/m, a boost in the nitrogen, sodium, and iron content was observed ranging from more than 1.65 folds to 3.50 folds while a marked decline in the phosphorous sulfate and calcium content was reported in the rice crop.

Salinity tolerance mechanisms in Rice

In a biological system there are some inbuilt mechanisms developed during the course of evolution to counter stress posed by various environment factors. Understanding the molecular mechanisms that underlie such resilience could lay the framework for rice varieties with improved salt tolerance [29]. Scientists have created several methods recently for creating salt-tolerant rice cultivars. It has been discovered that using phytoprotectants works well to give rice plants a salt tolerance.

The genetic factors conferring the resistance to salinity stress are important not only for the survival of the rice plants but also for the production of rice [70]. Salt tolerance is controlled by polygenes [17]. Several processes are involved in conferring the tolerance to the rice plant [44].

Osmotic adjustment

Osmotic adjustment is the most important strategy of plants to counter the salinity stress. The accumulation of sodium and chloride ions due to high salinity in soil disturb the ionic balance of the cells. In response to the ionic imbalance the cells make their osmotic adjustments which were determinant of the plant survival. Osmotic adjustments are achieved by accumulation of macromolecules such as, organic solutes, free sugar, glycine betaine, and proline in the cell cytoplasm [30]. Further, in the leaves the osmotic adjustments are made by dilution effects and the transpiration force [4].

Stomata closure

Leaves respond to salinity in the soil by rapidly closing the stomata. The salt concentration in the immediate environment of roots led to the biosynthesis of abscisic acid, which in turn mediate the stomata closure [31]. The closure of stomata leads to decline in the photosynthetic rate in monocot plants like rice and thus carbon dioxide assimilation.

Particle exclusion

Particle exclusion is a phenomenon in which sodium and chloride ions are excluded from the vascular bundles back to the soil and thus, stopped from surplus accumulation in the leaves. Root cap plays an important role in the exclusion of sodium salts. Salt-tolerant lines avoid sodium accumulation and absorb potassium ions [44]. The size of the root cap is bigger in the salt-tolerant varieties [22]. The roots of rice initially selectively uptake the sodium ions by symplastic and apoplastic routes [18]. The uptake of the salt in rice plants mainly takes the apoplastic pathway [39] to which casparian strips pose a barrier. The width of the casparian strips is important to access the effect and response of the stress [13].

Tissue tolerance

Tissue tolerance is a phenomenon in which, sodium ions are sequestered in a cavum and the reactive oxygen species are detoxified [15]. Plants channelize the excess sodium ions to older leaves, thereby minimize the accumulation of sodium ions in the stem. The older leaves decay and are replaced by young greener leaves. The older leaves thus have higher accumulation of sodium, chloride and nitrate ions than the tender ones [76]. The compartmentalization of the sodium ions in the old leaves is accompanied by the induction in the expression of OsHKT1, OsHAK10, OsHAK16, and OsNHX1; and the induction of OsNHX1 in accumulation of older leaves.

Ion homeostasis

Ion pumps such as, H+-pump ATPases, Na+/H+ antiporter, etc are employed by the cell machinery to actively exclude the cationic sodium ions from the system to maintain the ionic homeostasis of the cell. The activation of Na+/H+ antiporter channel involves salt overly sensitive (SOS) pathway to exclude Na+ ions out of the cell [26]. Vacuolar Na+/H+ antiporters function to sequester the sodium ions into the vacuole. The Na+/H+ antiporter activity increases in the case of salinity.

Na+/H+ antiporters are reported in the vacuoles and in endosomes. One endosomal Na+/H+ antiporter (OsNHX5), and four vacuolar Na+/H+ antiporters viz., OsNHX1, OsNHX2, OsNHX3 and OsNHX4 has been reported in rice [8]. The higher expression of the vacuolar Na+/H+ antiporter (NHX1) is found to impart the salinity tolerance in the rice (Fukuda. *et al*. 2004). Uptake of sodium ions in vacuoles confers resistance to the salinity in the soil.

Future Perspectives

Rice production is beset with several limitations. Devising suitable strategies via breeding, genetic engineering, Gene introgression and/or pyramiding and rapid deployment of these resistance genes into elite cultivars to develop stress resistant varieties need to be done. Genetic engineering is not widely accepted and field application of the resistant varieties may face resistance of the law population, thus efforts on breeding should be focused

Declaration

The authors declare no conflict of interest.

Bibliography

1. Abdullah ZK., *et al*. “Causes of sterility in seed set of rice under salinity stress”. Journal of Agronomy and Crop Science 187 (2001): 25-32.

2. Agrawal PK., *et al*. "Induction of bacterial blight resistance in elite Indian rice (Oryza sativa L.) cultivars using gamma irradiation and ethyl methane sulphonate". *Mutation Breeding Newsletter and Reviews* 1 (2005): 17-18.

3. Aguiero VM., *et al*. "Spread of rice tungro spherical virus in Bicol, Philippines". *International Rice Research Newsletter (Philippines)* 11 (1987): 17-18.

4. Akita S and Cabuslay G S. "Physiological basis of differential response to salinity in rice cultivars". In *Genetic Aspects of Plant Mineral Nutrition* Springer. (1990): 431-448.

5. Amirjani M R. "Effect of NaCl on some physiological parameters of rice". *European Journal of Biological Sciences* 3 (2010): 6-16.

6. Amirjani M R. "Effect of salinity stress on growth, sugar content, pigments and enzyme activity of rice". I*nternational Journal of Botany* 7 (2011): 73-81.

7. Banwo OO., *et al*. "Newly recorded species of Chaetocnema, vector of rice yellow mottle virus in Tanzania". *New Zealand Journal of Crop and Horticultural Science* 29 (2001): 61-65.

8. Bassil E., *et al*. "Cellular ion homeostasis: emerging roles of intracellular NHX Na+/H+ antiporters in plant growth and development". *Journal of Experimental Botany* 63 (2012): 5727-5740.

9. Baxter G., *et al*. "Salinity alters the protein composition of rice endosperm and the physicochemical properties of rice flour". *Journal of the Science of Food and Agriculture* 91 (2011): 2292-2297.

10. Bin Rahman ANMR and Zhang JH. "Flood and drought tolerance in rice. Opposite but may coexist". *Food Energy Security* 5 (2016): 76-88.

11. Blas N and David G. "Dynamical rogueing model for controlling the spread of tungro virus via Nephotettix virescens in a rice field". *Journal of Physics: Conference Series* 893 (2017): 012018.

12. Butardo VM. ., *et al*. "Improving Rice Grain Quality: State-of-the-Art and Future Prospects". *Methods in Molecular Biology* 1892 (2019): 19-55.

13. Chen Q., *et al*. "Nonstructural protein Pns4 of rice dwarf virus is essential for viral infection in its insect vector". *Virology Journal* 12 (2015): 211.

14. Chen T., *et al*. "Casparian strip development and its potential function in salt tolerance". *Plant Signaling and Behavior* 6 (2011): 1499-1502.

15. Chen T., *et al*. "Molecular mechanisms of salinity tolerance in rice". *Crop Journal* 9 (2021): 506-520.

16. Cheng XY., *et al*. "Towards understanding of molecular interactions between rice and the brown planthopper". *Molecular Plant* 6 (2013): 621-634.

17. Chinnusamy V., *et al*. "Understanding and improving salt tolerance in plants". *Crop Science* 45 (2005): 437-448.

18. da Cruz R P and Milach S C K. "Breeding for cold tolerance in irrigated rice". *Ciência Rural* 30 (2000): 909-917.

19. Das P., *et al*. "Oxidative environment and redox homeostasis in plants: dissecting out significant contribution of major cellular organelles". *Frontiers in Environmental Science* 2 (2015): 70.

20. Datta S., *et al*. "A comprehensive insight into the biology of Rhizoctonia solani AG1-IA Kühn, the causal organism of the sheath blight disease of rice". *Journal of Plant Pathology* 104 (2022): 79-98.

21. Fang FC., *et al*. "Bacterial stress responses during host infection". *Cell Host and Microbe* 20 (2016): 133-143.

22. Ferdose J., *et al*. "Differential sensitivity of rice cultivars to salinity and its relation to ion accumulation and root tip structure". *Plant Production Science* 12 (2009): 453-461.

23. Fujita D., *et al*. "Rice resistance to planthoppers and leafhoppers". *Critical Reviews in Plant Sciences* 32 (2013): 162-191.

24. GAFSF. "Expanding Rice Production Project: Challenges". Downloaded from Expanding Rice Production Project (ERPP) | Global Agriculture and Food Security Program (gafspfund.org) on 22-07-2022.

25. Goto M. "Fundamentals of Bacterial Plant Pathology". Academic Press, San Diego, (1992): 210-224.

26. Guo Y., *et al*. "Transgenic evaluation of activated mutant alleles of SOS2 reveals a critical requirement for its kinase activity and C-terminal regulatory domain for salt tolerance in Arabidopsis thaliana". *Plant Cell* 16 (2004): 435-449.

27. Hasanuzzaman M., *et al*. "Plant response to salt stress and role of exogenous protectants to mitigate salt-induced damages". In: Ahmad P., Azooz M.M., Prasad M.N.V. (Eds.), Ecophysiology and responses of plants under salt stress. Springer, New York, (2013) pp. 25-87.

28. Hibino H and Cabunagan R.C. "Rice Tungro-Associated Viruses and their Relations to Host Plants and Vector Leafhoppers". Tropical Agriculture Research Series : proceedings of a symposium on tropical agriculture researches. Japan International Research Center for Agricultural Sciences 19 (1985): 173-182.

29. Hussain S ., *et al*. "Effects of salt stress on rice growth, development characteristics, and the regulating ways: A review". *Journal of Integrative Agriculture* 16 (2017): 2357-2374.

30. Jampeetong A. and Brix H. "Effects of NaCl salinity on growth, morphology, photosynthesis and proline accumulation of Salvinia natans". *Aqua Botany* 91 (2009): 181-186.

31. Jouyban Z. "The effects of salt stress on plant growth". *Technical Journal of Engineering and Applied Sciences* 2 (2009): 7-10.

32. Kandpal RP and Rao NA. "Alterations in the biosynthesis of proteins and nucleic acids in finger millet (Eleucine coracana) seedlings during water stress and the effect of proline on protein biosynthesis". *Plant Science* 40 (1985): 73-79.

33. Kannan M., *et al*. "Complete Genome Sequence of Rice Tungro Bacilliform Virus Infecting Asian Rice (Oryza sativa) in Malaysia". *Microbiology Resource Announcements* 8 (2019): e00262-19.

34. Katiyar S K., *et al*. "Biodiversity of Asian rice gall midge (Orseolia oryzae Wood Mason) from five countries examined by AFLP analysis". *Genome* 43, (2000): 322-332.

35. Khan MH and Panda SK. "Alterations in Root Lipid Peroxidation and Antioxidative Responses in Two Rice Cultivars under NaCl-Salinity Stress". *Acta Physiologiae Plantarum* 30 (2008): 89-91.

36. Khush G.S. and Jena K.K. "Current status and future prospects for research on blast resistance in rice (Oryza sativa L.)". In: Wang G.L. and Valent B. (Eds) Advances in Genetics, genomics and control of rice blast disease, Springer, Dordrecht, (2009): 1-10.

37. Khush G.S. "What it will take to feed 5.0 billion rice consumers in 2030". *Plant Molecular Biology* 59 (2005): 1-6.

38. Kouassi N K., *et al*. "Distribution and characterization of Rice yellow mottle virus: a threat to African farmers". *Plant Diseases* 89 (2005): 124-133.

39. Krishnamurthy P., *et al*. "The role of root apoplastic transport barriers in salt tolerance of rice (Oryza sativa L.)". *Planta* 230 (2009).: 119-134.

40. Lee IS., *et al*. "Comparison of terrestrial laser scanner with digital aerial photogrammetry for extracting ridges in the rice paddies". *Survey Review* 41 (2009): 253-267.

41. Li D., *et al*. "Strategies to Manage Rice Sheath Blight: Lessons from Interactions between Rice and Rhizoctonia solani". *Rice (N Y)* 14 (2021): 21.

42. Maeda S., *et al*. "The rice CYP78A gene BSR2 confers resistance to Rhizoctonia solani and affects seed size and growth in Arabidopsis and rice". *Science Reports* 9 (2019): 587.

43. Munns R and James R.A. "Screening Methods for Salinity Tolerance: A Case Study with Tetraploid Wheat". *Plant and Soil* 253 (2003): 201-218.

44. Munns R and Tester M. "Mechanisms of salinity tolerance". *Annual Review of Plant Biology* 59 (2008): 651.

45. Muthaiyan MC. "Principles and Practices of Plant Quarantine". *Allied Publishers* (2009): 1160.

46. Nagarajan S., *et al*. "Understanding the Responses, Mechanism and Development of Salinity Stress Tolerant Cultivars in Rice". In M. Huang (Ed.), Integrative Advances in Rice Research. Rijeka: IntechOpen (2022).

47. Najeeb S., *et al*. "Genetics and Breeding of Low-Temperature Stress Tolerance in Rice". In: Ali, J., Wani, S.H. (eds) Rice Improvement. Springer, Cham. (2021).

48. Niño-Liu RP and Bogdanove A J. "Xanthomonas oryzae pathovars: model pathogens of a model crop". *Molecular Plant Pathology* 7 (2006): 303-324.

49. Odongo PJ., *et al*. "Insights Into Natural Genetic Resistance to Rice Yellow Mottle Virus and Implications on Breeding for Durable Resistance". *Frontiers in Plant Science* 12 (2021).

50. Panda D., *et al*. "Drought Tolerance in Rice: Focus on Recent Mechanisms and Approaches". *Rice Science* 28 (2021): 119-132.

51. Pandey V and Shukla A. "Acclimation and tolerance strategies of rice under drought stress". *Rice Science* 22 (2015): 147-161.

52. Pattanagul W and Thitisaksakul M. "Effect of salinity stress on growth and carbohydrate metabolism in three rice (Oryza sativa L.) cultivars differing in salinity tolerance". *Indian Journal of Experimental Biology* 46 (2008): 736-742.

53. Peiris BD., *et al*. "Chemical characteristics of grains of rice (Oryza sativa L.) cultivated in saline media of varying ionic composition". *Journal of Experimental Biology* 39 (1988): 623-631.

54. Pennisi E. "Armed and dangerous". *Science* 327 (1988): 804-805.

55. Pinel A., *et al*. "Molecular variability of geographically distinct isolates of Rice yellow mottle virus in Africa". *Archives of Virology* 145 (2000): 1621-1638.

56. Porcel R., *et al*. "Salinity stress alleviation using arbuscular mycorrhizal fungi". A review". *Agronomy for Sustainable Development* 32 (2012): 181-200.

57. Rajarammohan S. "Redefining Plant-Necrotroph Interactions: The Thin Line Between Hemibiotrophs and Necrotrophs". *Frontiers in Microbiology* 12 (2021).

58. Rana N., *et al*. "Applications and challenges for efficient exploration of omics interventions for the enhancement of nutritional quality in rice (Oryza sativa L.)". *Critical Reviews in Food Science and Nutrition* 60 (2019): 3304-3320.

59. Rao P., *et al*. "Effects of Soil Salinity and Alkalinity on Grain Quality of Tolerant, Semi-Tolerant and Sensitive Rice Genotypes". *Rice Science* 20 (2013): 284-291.

60. Rao T.B., *et al*. "A comprehensive gene expression profile of pectin degradation enzymes reveals the molecular events during cell wall degradation and pathogenesis of rice sheath blight pathogen Rhizoctonia solan I AG1-IA". *Journal of Fungi* 6 (2020): 71.

61. Reynolds OL., *et al*. "Silicon-augmented resistance of plants to herbivorous insects:" a review". *Annals of Applied Biology* 155 (2017): 171-186.

62. Rijsberman FR. "Water scarcity: Fact or fiction". *Agricultural Water Management* 80 (2009): 5-22.

63. Saleethong P., *et al*. "Effects of exogenous spermidine (spd) on yield, yield-related parameters and mineral composition of rice (Oryza sativa L. ssp.'indica') grains under salt stress". *Australian Journal of Crop Science* 7 (2013): 1293-1301.

64. Sato Y., *et al*. "Enhanced chilling tolerance at the booting stage in rice by transgenic overexpression of the ascorbate peroxidase gene, OsAPXa". *Plant Cell Reports* 30 (2011): 399-406.

65. Shahbandeh M. "Rice - Statistics and Facts". Statista (2022).

66. Shen Y and Ronald P. "Molecular determinants of disease and resistance in interactions of Xanthomonas oryzae pv. oryzae and rice". *Microbes and Infection* 4 (2002): 1361-1367.

67. Shereen A., *et al*. "Salinity effects on seedling growth and yield components of different inbred rice lines". *Pakistan Journal of Botany* 37 (2005): 131-139.

68. Singh R., *et al*. "From QTL to variety-harnessing the benefits of QTLs for drought, flood and salt tolerance in mega rice varieties of India through a multi-institutional network". *Plant Science* 242: (2016): 278-287.

69. Singh P., *et al*. "Biotic Stress Management in Rice (Oryza sativa L.) Through Conventional and Molecular Approaches". In: Rakshit, A., Singh, H., Singh, A., Singh, U., Fraceto, L. (eds) New Frontiers in Stress Management for Durable Agriculture. Springer, Singapore. (2020).

70. Siringam K., *et al*. "Salt stress induced ion accumulation, ion homeostasis, membrane injury and sugar contents in salt-sensitive rice (Oryza sativa L. spp. Indica) roots under sosmotic conditions". *African Journal of Biotechnology* 10 (2011): 1340-1346.

71. Suzuki N., *et al*. "Immunodetection of rice dwarf phytoreoviral protein in both insect and plant hosts". *Virology* 202 (1994): 41-48.

72. Thitisaksakul M., *et al*. "Effects of timing and severity of salinity stress on rice (Oryza sativa L.) yield, grain composition, and starch functionality". *Journal of Agricultural and Food Chemistry* 63 (2015): 2296-2304.

73. Vetha VP., *et al*. "Brown rice-hidden nutrients". *Journal of Bioscience and Technology* 4 (2013): 503-507.

74. Wang AJ and Zheng AP. "Characteristics and control measures of rice sheath blight". *China Rice* 24 (2018): 124-126.

75. Wang H., *et al*. "Assessment of the impact of insecticides on Anagrus nilaparvatae (Pang et Wang) (Hymenoptera:Mymanidae), an egg parasitoid of the rice planthopper, Nilaparvata lugens (Hemiptera:Delphacidae)". *Crop Protection* 27 (2008): 514-522.

76. Wang H., *et al*. "Effects of salt stress on ion balance and nitrogen metabolism of old and young leaves in rice (Oryza sativa L.)". *BMC Plant Biology* 12 (2012): 1-11.

77. Wang Q., *et al*. "Rice dwarf virus infection alters green rice leafhopper host preference and feeding behavior". *PLoS ONE* 13 (2018): e0203364.

78. Xie G., *et al*. "Biochemical identification of the OsMKK6-OsMPK3 signalling pathway for chilling stress tolerance in rice". *Biochemical Journal* 443 (2012): 95-102.

79. Xu L., *et al*. "Identification and mapping of quantitative trait loci for cold tolerance at the booting stage in a japonica rice near isogenic line". *Plant Science* 174 (2008): 340-347.

80. Yadav S., *et al*. "Identification of QTLs and possible candidate genes conferring sheath blight resistance in rice (Oryza sativa L.)". *Springerplus* 4 (2015): 175.

81. Yang L., *et al*. "Silicon amendment to rice plants impairs sucking behaviors and population growth in the phloem feeder Nilaparvata lugens (Hemiptera: Delphacidae)". *Science Reports* 7 (2017): 1101.

82. Zeng Y., *et al*. "Effects of Low Temperature Stress on Spikelet-Related Parameters during Anthesis in Indica-Japonica Hybrid Rice". *Frontiers in Plant Science* 8 (2017): 1350.

83. Zhang J., *et al*. "Effects of 1-methylcyclopropene on function of flag leaf and development of superior and inferior spikelets in rice cultivars differing in panicle types". *Field Crops Research* 177 (2015): 64-74.

84. Zhang Q., *et al*. "Rice and cold stress: methods for its evaluation and summary of cold tolerance-related quantitative trait loci". *Rice* 7 (2014): 24.

85. Zhao M., *et al*. "Improving nutritional quality of rice for human health". *Theoretical and Applied Genetics* 133 (2020): 1397-1413.