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Physiological Response of Rice (*Oryza sativa L.*) Plant to Biotic and Abiotic Stress: Review

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Abstract

The response of rice plant to biotic and abiotic stresses is custom-tailored for the nature of stresses due to additive, negative or interactive effects of responses initiated by any of stresses. Rice plants sense environmental signals before being able to answer appropriately to abiotic and biotic stress. Chlorophyll pigment declines when rice plant faces water deficiency and harms potential of mesophyll cell to capably utilize carbon dioxide. Drought stress cause stomatal closure and limits gas exchange, reduces water content and results in wilting of the plant. Physiological features in net photosynthetic rate, transpiration rate, stomatal conductance, water use efficiency and CO_2 concentration disrupted by deficiency of water. Drought stress tolerance achieved through operating hormone metabolism, photosynthesis, respiration and water relation of physiological processes. Salinity influences osmotic and ionic stress and salt stressed plants exhibit enhanced concentration of reactive oxygen. The effect of salinity on rice plant is initiated by osmotic ingress characterized by lowered osmotic potential followed by later ionic effect causing ionic toxicity. Among physiological response level of rice, mitochondria and chloroplast proves more vulnerable organisms than the rest. Rice genotypes response to heat stress varies with phonology which contains morpho-anatomical and cellular to molecular level. High temperature above the threshold level with in a certain period causes physiological processes of rice plant such as stomata opening, photosynthesis, growth and reproductive stage. Increase in temperature will lead to more rapid development, increased reproductive potential and more generations of pests and pathogens in a season. Reduction in photosynthetic rate at a high level of root knot nematodes infestation observed due to damage of local tissue of the plant. Silicon has an essential role to offset biotic and abiotic stress faced by rice plant. Abscisic acid is major abiotic stress responsive phytohormone involved in response to drought, osmotic and salt stress, cold and high temperature specific response. The shoot and root growth of rice inhibited by existence of higher NaCl but application of silicon alleviated salt induced injury. Physiological traits of rice, parades extremely vulnerable to biotic and abiotic stress however, alarming stress tolerance hormonal and osmotic mechanism settled by the plant as well as application of silicon alleviated drawbacks. Improved plant reaction against pathogen infections and abiotic stresses has innovative product, the painstaking mechanism which modulates plant physiology through potentiation of host defense mechanisms.

Keywords: Physiological trait; Biotic stress; Abiotic stress; Stress perception; Stress tolerance

Introduction

World wide rice (*Oryza sativa* L) is the topmost and broadly consumed food crop. However, rice production and productivity are markedly influenced by several biotic (diseases and insects) and abiotic (drought, salinity, heat and submergence) stresses. Environmental stresses are responsible for large-scale crop loss each year and with the predicted climate change, such losses are expected to increase. The predicted climate change, characterized by an increase in temperature, increased concentration of green house gases, intensified hydrologic cycle and increase in tropospheric ozone levels will have a multifaceted effect on crop growth and productivity. Physiology of rice plant affected by different factors such as a combination of genotype, environment and management factors. Harmonizing and improving soil fertility is one of the main factors in enhancing rice growth and development as well as yield. Rice Plants can be able to sense the environmental signals before being able to answer appropriately to the abiotic and biotic stress. Due to the multifaceted nature of stress, multiple sensors, rather than a single sensor, are more likely to be responsible for perception of the stress. The major stresses responsible for the yield gap in crop production can be abiotic stress, such as extreme or minimum temperature, water deficiency or drought, heat and salt and biotic stresses, such as fugal (blast) or insect attack (root knot nematodes).

Growth and development of rice plant affected as imposed in the environment stress facing conditions in a changing environment. During growth, plants perceive process and translate various stimuli to the adaptive response. The health of rice plant adversely influenced in excessive use of commercial fertilizer and enhances the outbreak of disease and soil toxicity [1].

Drought is the key limiting factor for crop production and productivity and the world is suffering severely. Rice is a water loving crop and seriously influenced by water stress. Improving physiological traits of rice intended to be desirable due to its agronomic importance towards the achievement of high rice yield [2]. However, both biotic and abiotic stress greatly reduce rice yield. The productivity of rice by the cause of drought is estimated to be reduced by 50% due to an even and insufficient rain fall during the growth stage [3]. The negative implications of drought stress on the physiological functioning of rice plants are mainly due to its limited water potential and turgor pressure that suppress plant growth and metabolism. Drought is characterized by decreased soil moisture potential and reduced available water for the plant. Plants respond to this initial reduction in soil water potential by reducing the water loss and maximizing water absorption at the lower soil water potential to ensure normal cell function. The results from free air carbon dioxide shows that increase in CO_2 level in the atmosphere will lead to photosynthetic carbon gain, increased nitrogen use efficiency, and decreased water use in the leaves. The field drought condition can manifest physiological changes similar to other abiotic stresses like high temperature, disturbed ion intake and nutrient deficiencies in plants.

The physiological response mechanism for abiotic stresses occurs from a complex pathway of responses, starting with the perception of stress, which triggers a cascade of molecular events, ending at various levels of physiological, metabolic, and developmental responses [4].

Literature Review

Abiotic stress

Drought stress: Drought is a situation where water potential and the turgor of plant leaf cells reduces to a level where normal functions are impaired. It causes stomatal closure and limits gas exchange, reduces water content and results in wilting of the plant [5]. Drought stress affects rice plant at each developmental stage in all rice growing ecosystems and the crop responds differently to the stress in different life stages [6]. Water deficiency alters the standard path of photosynthesis as well as the gas exchange characteristics in plant. When the plant faces water stresses the stomata closed and flux density of CO_2 in the leaf becomes low. Chlorophyll pigment declines when the rice plant faces water deficiency and these harms the potential of mesophyll cell to capably utilize carbon dioxide.

Improved water use efficiency, accumulation of osmolytes and higher antioxidant enzyme activity and enhanced photosynthesis are observed in transgenic rice by interrogation of genes [7]. This implies drought tolerance rice genotypes will be developed by testing different genes through transgenic approach. The response to drought stress by rice plant is dependent on the environment and swerves across genotype and genetic interaction but physiological traits to select drought-tolerant germplasm of rice plants are more critical [8].

Physiological traits of rice plant experience and cope up various environmental factors particularly in upland rice condition. Stress tolerance genes enable rice plants to cope up when the stress situation occur in the short and long-term responses. When the rice plant face stresses with drought, stress tolerance such as compatible solutes and proteins involved in metabolism of carbohydrates. Furthermore, to regulate water balance of the plant in the guard cell and osmotic stress tolerance through cellular dehydration tolerance, regulatory molecules in stress response and functions will be exhibited. Scarcity of water negatively affects the physiological characteristics of rice in numerous ways, such as decreases in net photosynthetic rate, transpiration rate, stomatal conductance, water use efficiency, internal CO_2 concentration and photosystem II [9].

The source sink association has a key role for drought tolerance rice plants due to carbohydrate reserves utilized by grain filling and grain yield under drought stress. Another drought stress copping mechanism by rice plant is osmotic adjustment which is mainly observed in the root development available in deep soil to efficiently access water. Plants install drought escaping mechanisms such as leaf rolling, reduced tillering, stomata closure and accumulation of osmoprotectants to thwart sever damage. Silicon can alleviate water stress by decreasing transpiration. Transpiration from the leaves occurs mainly through the stomata and partly through the cuticle. As silicon is deposited beneath the cuticle of the leaves forming a silicon-cuticle double layer, transpiration through the cuticle may decrease by silicon deposition.

Salinity stress: Under high Salt accumulation, plants change their morphological and physiological features such as leaf rolling, impaired root system, reduced tiller number, lower biomass, fewer number of grains and osmotic and turgor pressure reduced. Appropriate chemical fertilizer application is one of the key improvement strategies for salt tolerance. However, soil amendments in water logged conditions have a promising result to enhance the performance of the plant in osmotic and ionic stress. Salinity influences osmotic and ionic stress and salt stressed plants exhibit enhanced concentration of reactive oxygen. Plant physiologists set out different strategies to realize the growth, development, and physiological processes of rice plants when stress occurs. Salt stress is a bottle neck constraint for physiological process of rice understanding various salt tolerance mechanism such as genetic modification, agronomic management practice for the growth and yield of rice, role and management of phytohormone and enzymes and altering biochemical pathways are the promising stress tolerance [10]. The arid and semi-arid zones, characterized by low precipitation and high evaporation are highly affected due to minimum lixiviation of salt from the soil profile resulting in increased salt accumulation. Early vegetative and later reproductive rice stages are highly susceptible to salinity. Plants suffer from sever osmotic pressure and a scarcity of water as a result of salinity causes ions to accumulate in their tissue. However, salinity tolerance will vary between genotypes due to the additive effect of genes. Reproductive and grain filling stages of rice are more resistant than germination and vegetative stages. The effects of salinity on plants are initiated by the osmotic effect characterized by the lowered osmotic potential followed by later ionic effect causing ionic toxicity. Among physiological response level of rice mitochondria and chloroplast expressions more vulnerable organisms than the rest. This shows that, chlorophyll content alters in to chlorophyll florescence and membrane permeability efficient and potential indicators for understanding the inhibitory effect on salt on photosynthetic efficiency [11]. The shoot and root growth of rice inhibited in the presence of higher NaCl but application of silicon alleviated salt induced injury. Silicon may be ascribed to the silicon-induced decrease of transpiration and to the partial blockage of the transpiration bypass flow, the pathway by which a large proportion of the uptake of Na in rice occurs [12]. Salt toxicity and water stress are notorious to induce lipid peroxidation by reactive oxygen species in plants and silicon is able to alleviate salt and drought induced oxidative stress by stimulating the antioxidant system.

Heat stress: Heat stress is vital abiotic stresses that reduce plant biomass production and productivity, especially in tropical and subtropical countries. Extreme temperature influence rice growth and development processes with germination, emergence and seedling establishment, and reproductive and grain filling stages. High temperature above the threshold level with in a certain period causes the physiological processes of rice plant such as stomata opening, photosynthesis, growth and reproductive stage. High temperatures above 35°C at the flowering stage inhibit anther dehiscence this results in lower pollen shed on the stigma, resulting incomplete fertilization. Reduced temperature in the vegetative stage becomes a cause for retarded growth, reduced seedling vigor and increased plant mortality [13]. Heat tolerance in rice at the reproductive stage is more critical because of high sensitivity and development of physiological grain maturity [14]. Due to this consequence, heat stress brings poor pollen viability and reduces efficiency of pollen production and anther catastrophe in rice genotypes. Rice grain quality and spikelet fertility more strongly affected by heat stress at flowering and grain filling stage. In the ripening period high temperature stress results in chalky grains having starch granules but the appearance of the grain quality of rice decrease [15]. Tolerance to heat stress is a prominent trait associated with genotype that can be leveraged to identify genetic regulation of heat stress tolerance in rice. Rice genotypes response to heat stress varies with phonology which contains morpho-anatomical and cellular to molecular level [16]. Heat tolerance probably associated with well-organized scavenging of Reactive Oxygen Species (ROS) developed as a consequence of distressed metabolism. At the photosynthetic apparatus, heat stress generates ROS, which could damage both PS-I and PS-II. Under stress, different plant species may accumulate a variety of osmolytes such as sugars and sugar alcohols (polyols), proline, tertiary and quaternary ammonium compounds, and tertiary sulphonium compounds [17]. Silicon increases the tolerance to heat stress in rice plants. Electrolyte leakage caused by high temperature (42.50°C) is less pronounced in the leaves grown with silicon. This finding explains that silicon may be involved in the thermal stability of lipids in cell membranes although the mechanism has not been elucidated.

High light intensity stress: Light dependent reactions use light energy and not affected by changes in temperature. The more photons of light that fall on a leaf, the greater the number of chlorophyll molecules that are ionized and the more ATP and NADPH are generated. The stomatal density ratio of the lower to the upper leaf surface increased with declining light intensity. Reduced stomatal conductance under low irradiance probably has impact on stomatal conductance. This implies that rice plants develop a strategy for balance assimilation and transpiration rate to allow efficient influx of CO_2 for low assimilation rate by decreasing stomatal conductance under low irradiance [18]. The intensity of light is very high due to the cause of high temperature. However, high light intensity as a function of high temperature influences mineral nutrients uptake in plants and negatively distresses plant growth. High temperature enhances chlorophyllase activity and decreases the quantities of photosynthetic pigments. Tang and Zheng reported that chlorophyll content in rice flag leaves were significantly lower by high temperature stress [19]. This emphasizes high temperature accelerates the senescence of rice leaf and decreases the photosynthesis rate during the grain filling period. Exposure of photosynthetic organisms to strong light results in inhibition of the activity of Photosystem II (PSII) when the rate of absorption of light energy by photosynthetic pigments exceeds the rate of its consumption in chloroplasts, the absorbed light energy accelerates the process of photoinhibition [20]. In rice plant chloroplast movement is a typical organellar response that is regulated by light. During photo-relocation, the chloroplasts situated along the periclinal cell walls, optimizing their potential to harvest sufficient sunlight for optimal photosynthesis under low-light conditions. Under high light, the chloroplasts move away from the periclinal walls and toward the anticlinal walls, minimizing potential.

Biotic stress

Root knot nematodes: Root Knot Nematodes has cosmopolitan effect in all rice ecosystem in various countries across the globe. Reduction in photosynthetic rate at a high level of root knot nematodes infestation observed due to the damage of local tissue of the plant. The root-knot nematode, *M. ethiopica* influences the plant water status and reduces the stomatal conductivity, transpiration and photosynthetic rate by up to 60 % in tomato plants [21]. Hormonal signaling induces systemic acquired resistance in the non-infected plant parts. Rice in particular has high endogenous levels of salicylic acid and the mutants deficient in salicylic acid content are highly susceptible to pathogen attack [22]. Research findings reported that increased carbon dioxide levels in the atmosphere will lead to suppression of plant defense responses by manipulation of the hormonal signaling pathways in plants [23]. Nematodes feed plant parts and primarily cause soil born diseases leading to nutrient deficiency, stunted growth and wilting. Drought can increase susceptibility of rice to root knot nematodes infection in all ecosystems, especially in aerobic rice cultivation. A reduction in photosynthetic rate measured as maximum quantum yield (Fv/Fm) and relative chlorophyll content is seen in rice plants infected with the cyst nematode. Due to the effect of root knot nematodes the chlorophyll content or rice is reduced.

Blast disease: Blast disease in rice has high temperature dependent resistance. Increase in temperature lead to more rapid development, increased reproductive potential and more generations of pests and pathogens in a season. Drought can aid pest and pathogen outbreaks in fields, at the same time pathogens can severely influence plant water relations and lead to low water potential in plant cells. Stomatal closure is a drought avoidance strategy, thus drought induced stomatal closure reduces pathogen entry into the plant tissue. In the other condition pathogen induced stomatal closure helps the plant in efficient use of water. Drought leads to reduction in plant water status causing concentration of metabolites in the plant tissue. In areas where the soil is silicon deficient application of silicate fertilizer is as effective as fungicide application in controlling rice blast.

Discussion

Stress perception

Under the stress condition in rice plants a number of genes involved on morphological and physiological responses that expand the chance of survival and occurs the acclimation of stress launched from the process of perception to expression. Signal perception is the primary phase in a signal transduction pathway which is tracked by the production of secondary pathway. During stress states in a plant organelle such as mitochondria and chloroplast stimulate enormous amount of reactive oxygen species which develop highly corrosive and reactionary to nucleic acids, proteins and lipids unavoidably leading to apoptosis or cellular damage. Ethylene hypothetical to be the signaling path between plant growth and weather fluctuations. Calcium is a harmful ion whose concentration in eukaryotic cell is controlled. The ion travel through specific calcium ion channels, the cell membrane or organelles into cytosol after activation.

Conclusion

The quantum efficiency and chlorophyll content both decrease in rice and other crop species under drought stress. Heat stresses at the vegetative stage have higher negative effect compared with the booting stage. Rice plants with a high root or shoot silicon concentration are less prone to pest attack and exhibit enhanced tolerance to abiotic stresses such as drought, low temperature, salinity and heat stresses. Photosynthesis and the antioxidant system improved for silicon supplied plants. Improved plant reaction against pathogen infections and abiotic stresses has innovative, painstaking mechanism which modulates plant physiology through the potentiation of host defense mechanisms. Drought stress causes oxidative stress by producing a buildup of reactive oxygen species in the chloroplast and mitochondria. It harms physiological acclimation of plants by altering antioxidant responses. Salinity delay flowering, repining, reduces the number of tillers, biomass and leaf area in rice crop. Pollination is the most sensitive phenological phase to extreme temperature leads to poor seed set and low grain quality. Low temperature stress impede photosynthesis in the dark and light reaction this become a cause to disrupt electron routes and deterioration of membrane. Responses to abiotic stress triggered by a variety of stimuli but phytohormones are responsible to become a remedy. The initial response of pathogen attack on plants comprises the generation of reactive oxygen species and activation of mitogen-activated protein kinase.

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