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Physiological Adaptation and Tolerance Mechanism of Rice (*Oryza sativa* L.) in Multiple Abiotic Stresses

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ABSTRACT

Rice is the most important cereal crop; provide 40% daily calories for half of the world population. To ensure food security in near future, productivity must be increased double to maintain balance between population growth and food security. Unfortunately, rice production is not further increasing due to facing problem of various abiotic stresses in field. Multiple stress drastically affect on the plant photosynthesis, mineral nutrition, water relation, growth and development and major cause for reduction in production and productivity in major crop including rice. However, Plant adopts various mechanism or strategy to cope these unfavorable situations but there were yield penalty always associated with these stresses. To maintain yield stability under unfavorable situations plant physiologist and breeder start selection and improvement of physiological, morphological genetical trait. Effects of various abiotic stresses are complex in nature to sustain yield stability selection and improvement in complex trait can achieve the food security in near future. Therefore, consideration of all these in this review we summarized the effect of abiotic stresses and their tolerance mechanism in rice.

Key words: *Multiple abiotic stresses, yield penalty, Physiological trait, Food security.*

INTRODUCTION

Rice: Production, productivity and future challenge

Rice is the most important staple food crop of the world, is grown over 160 million hectares and providing 40% daily calories for half of the world's population. More than 3.5 billion people are depending upon rice as a staple food and one fifth of the world population depend on rice cultivation for their livelihoods. Asia produces and consumes about 90 % of the world's rice. During the past 35 years, world rice production doubled as results of the management practices and adaptation of modern varieties. The international grain council estimated the 2015 global rice production at about 474 million tons. Rice consumption will increase day by day with the increase in population.

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Rice account for 26.6 % of worldwide cereal production and consumption. The international rice research institute[13] studies the food problem in relation to world population, and predict that 800 million tons of rice will be required in 2025.A study by the University of Minnesota, U.S, has found that the current growth in rice production is not sufficient to global rice demand by 2050.

The study says that to ensure food security in future, production of rice and other crop have to double by 2050. However, rice yield is growing around 1% growth now[32], which means global rice production will around 750 million ton instead 1000 tons in 2050. However rice productivity is showing sign of decline, growing area is limiting, productive land are using for another purposes and cost of cultivation is increasing.

Plants have evolved responses to complex environmental fluctuations that take place at time scales that vary from seconds to years and shape plant growth and physiological responses. Variations in environmental signals, including temperature, water levels, solar radiation, biotic interactions and resource availability are often unpredictable and need to be integrated and transduced to changes in gene expression, which may then be associated with physiological and/or morphological adaptations[1,36]. The study of plant response to multiple concurrent stimuli, however, can provide insights into both ecological adaptation and, in the context of crop species and crop performance.

Thus, enhancing food production under the looming and crisis resource condition like water scarcity, multiple abiotic stress and limited land resources are becomes one of the major challenges to modern agriculture research. The only option available is to raise yield potential in favorable environments and to enhance adaptability of rice cultivars in stress situations through physiological, morphological and genetic improvement.

Improve yield stability and productivity under stress conditions: Rainfed rice growing areas constitutes about half of the total rice growing areas of the world. Based on hydrology, rainfed ecosystem are classified into rainfed lowland, upland, deepwater and tidal wetland ecosystem[12]. Growing conditions of these rice ecosystems are lower compared to irrigated ecosystem due to the complexity of abiotic and biotic constraints and the uncertainty associated with rainfall pattern. Superior traits that allow traditional cultivars to survive and produce well under such extreme conditions need to be incorporated into modern cultivars. This will require a systematically understanding of the physiological, morphological and genetical complex traits together with complete evaluation for a target environment. Some attempts made on major abiotic stress are highlighted followed.

Drought: Rice is highly susceptible to drought stress throughout its life cycle, mainly during reproductive stage. The capacity of the rice plant to sustain itself, yield stability and to reproduce in limited water conditions is main limiting factor for rice production in drought situation[27]. Adaptation of rice crop to drought is complex and this complexity arises from the requirement to adapt to two extreme conditions ranging from draught to deep water[24]. Drought stress affects rice plant in direct and indirect ways. The direct effects include reduction in turgidity, growth rate, tiller number, delayed flowering and even complete death of plant in severe drought stress condition. The major indirect effects include reduction in nutrient uptake, change in pattern of nutrient uptake, homeostasis and weed competition. As soil water potential reduces, pore space are filled with air and it became more aerobic, which might be affect crop performance by disrupting ionic movement. Changes in soil redox potential are associated with availability of phosphorus and affect availability of other nutrient[21,28]. Drought stress less damaging during seedling stage than the reproductive stage[25] Although reduction in yield might be associated with leaf area and tiller number. During reproductive phase, it cause desiccation of spikelets and anther, reduction in pollen viability, inhibition of panical initiation and increase in spikelet sterility[8].

Thus, it is imperative for rice breeders or physiologist to develop drought tolerant high yielding rice cultivars. Even though several efforts were made to breed for drought tolerance by including tolerant donor's parent line in breeding programs; there are few successful examples of improved rice cultivars that combine acceptable yield potential and drought tolerance. This is mainly because of the genetic complexity of drought tolerance due to its polygenic inheritance, low to medium heritability, significant genotype and environmental interactions, and the confounding effects of other abiotic stresses on drought.

Broadly mechanism of drought adaptation can be classified as Drought escape, Dehydration avoidance and dehydration tolerance. Traits associated with drought escape, avoidance and tolerance are presented in **Table 1 and Fig 1.**

Sr.No.	**Mechanism**	**Trait**	**Referances**
1.	Drought Escape	Short growth duration, Photoperiod sensitivity	Hall[11], Mackill *et al*[20].,
2.	Dehydration Tolerance	Root length, branching, diameter, dry weight, Root length density, root number, root to shoot ratio, deep root, Root pulling force, Leaf water potential, higher cuticular resuatance, Leaf rooling,	Kato *et al*[15]., Mohan kumar *et al*[22]., O'Toole and Bland[26], Armenta-Soto *et al*[3]., O'Toole and Chang, O'Toole et al[25]., Mackill *et al*[20].,
3.	Dehydration tolerance	Osmotic adjustment, Cell membrane stability, Antioxidant defence, Plant growth regulator	Fukai and Cooper[10], Premachandra *et al*[30]., Chen *et al*[6].,

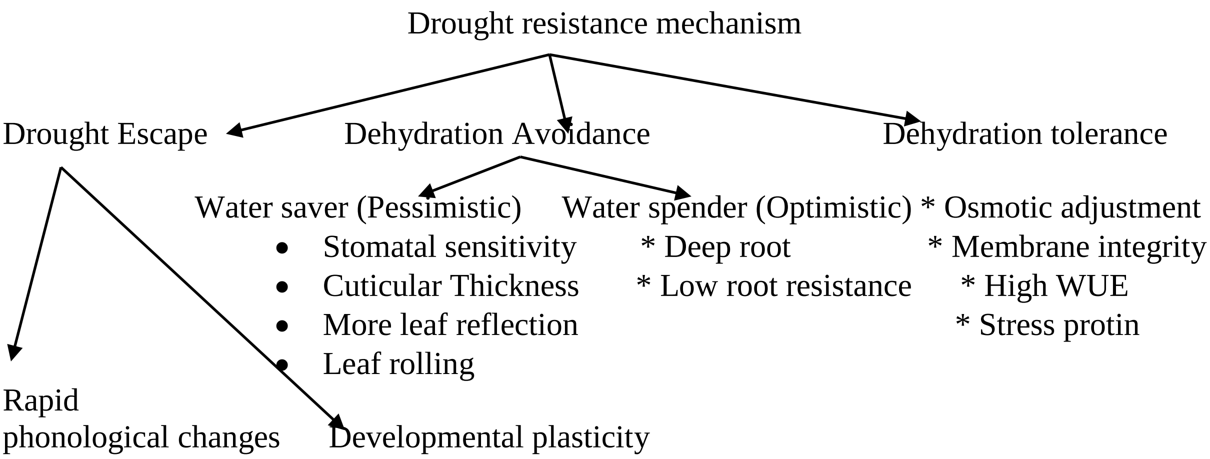

Fig. 1: General mechanism adopted by plant for drought resistance.

Salinity stress: Rice is a salt sensitive crop with threshold level 3dS m^{-1} beyond this level, yield stability start decline[19]. Despite its high sensitivity to salinity, considerable variation exist depend on age of plant, phenological stage and genotypes. Sensitivity to salinity in rice varies with the stage of development being tolerant during germination, active tillering and maturity and sensitive during early seedling stage, panicle initiation, pollination and fertilization[2]. Damage to plant could results from water deficit due to low osmotic potential imposed externally or internally. Ion toxicity could results from excess ion entry, fails to compartmentalization, and exclusion. Frageria[9] observed a decline in P and K in the shoot of two rice cultivars with increasing salinity.

Numerous abnormalities were noted in rice due to salt injury as stunted growth, rolling of leaves, white leaf tip, poor root growth, reduced survival, and spike sterility[29]. Salinity tolerance in rice is confirmed by the sum of a number of contrasting traits; the most are presented in **Table 2**.

Sr. No.	Mechanism	Trait	Referances
1.	High growth rate	Vigorous seedling vigor	Yeo *et al*[39].,
2.	Salt exclusion	Root membrane selectivity, Na Transportes	Yeo and Flower[38]
3.	Compartmentalization	Leaf to leaf compartmetalization	Yeo and Flower[37]
4.	Tolerance	Tissue tolerance	Yeo *et al*[39].,
5.	Accumulation of organic Solutes	Proline	Munn[23]

Submergence Stress: Rice is the only crop plant adapted to aquatic environments and can grow well under waterlogged condition. This adaptation arises from well-developed arenchyma tissue that facilitates oxygen diffusion through continuous air spaces from shoot to root and avoid anoxia or hypoxia development in root. Although rice is well developed to waterlogged conditions, long time flooding can adversely affect plant growth and development. More than 16% of rice lands of the world in lowland and deepwater rice areas are unfavorably affected by flooding due to complete submergence[18]. Characterization of floodwater environment in most rice growing areas pointed to gas diffusion as the major limiting factor[31]. This is because gas diffusion is 10^4 fold less in water than air[4]. Carbon assimilation supply is needed for maintenance and growth process under submergence. Mechanisms of submergence tolerance are illustrated in **Table 3**.

Sr. No.	Mechanism	Traits	References
1	Enhanced growth	Fast shoot and leaf elongation	Kende *et al*[17].,
2	Improvement of oxygen and carbohydrate resource	Thin leaf cuticle, low resistance to diffusion, Higher SLA,	Jensen *et al*[33].,
3	Improvement of internal gas diffusion	Aerenchyma formation	Visser *et al*[35].,
4.	Over expression of Pyruvate Dehydrogenas	Alcoholic fermentation	Ram *et al*[31].,
5.	Antioxidant defence	Glutathion reductase	Kawaano *et al*[16].,

Low temperature: Low temperature stress is a major problem for rice production particularly in temperate zone. It is major constrain to crop production for crop grown at higher elevation[20]. Both cool weather and cold irrigation water are damaging to rice and losses of more than 50% in grain yield. Response of rice to low temperature varies with the temperature pattern of the locality and stage and age of plant.

Effect of low temperature on vegetative stage: Chilling temperature at sowing reduces germination, delay emergence, discoloration of leaves, stunted growth, reduced tiller number, and decrease in seedling vigor[7].

Effect of cold temperature during reproductive stage: Rice is more sensitive to low temperature during reproductive development. The young microspore stage and the booting stage are particularly more sensitive. Low temperature during microsporogenesis causes immature pollen , anthesis indehiscence and reduces viable pollen number leading to male sterility[34]. Varieties that develop long anther are more tolerant to low temperature. Low temperature during flowering reduces pollination, and pollen germination. Low temperatures at flowering also inhibit complete exertion of the panicle from the flag leaf sheath[14]. During grain filling, low temperature causes irregular synchronization in maturity, reduce grain weight and poor quality grain.

Multiple abiotic stress response in rice: As sessile organism, plants have evolve many trailblazing mechanism to adopt, cope, sensing and responding diverse abiotic stresses such as drought, flood, heat, chilling, high or low light, mineral deficiency or toxicity and heavy metal toxicity under natural grown field conditions. It is estimated that abiotic stress such as drought, salinity and extreme temperatures, which usually cause primary crop losses worldwide, lead to an average yield loss of >50% for most major crop plants[5]. Multiple abiotic stresses can directly or indirectly affect the physiological, biochemical and molecular status of an organism by altering its metabolism, growth, and development. For these reasons, understanding the mechanisms underlying plant abiotic stress responses and the generation of stress tolerant plants has received much attention in recent years. However, because of the complexity of stress tolerance traits, conventional approaches are less effective at directly connecting tolerance traits to the determinant genes that play key roles in the stress response. Multiple abiotic stresses and their tolerance mechanism are illustrated in **Fig. 2**.

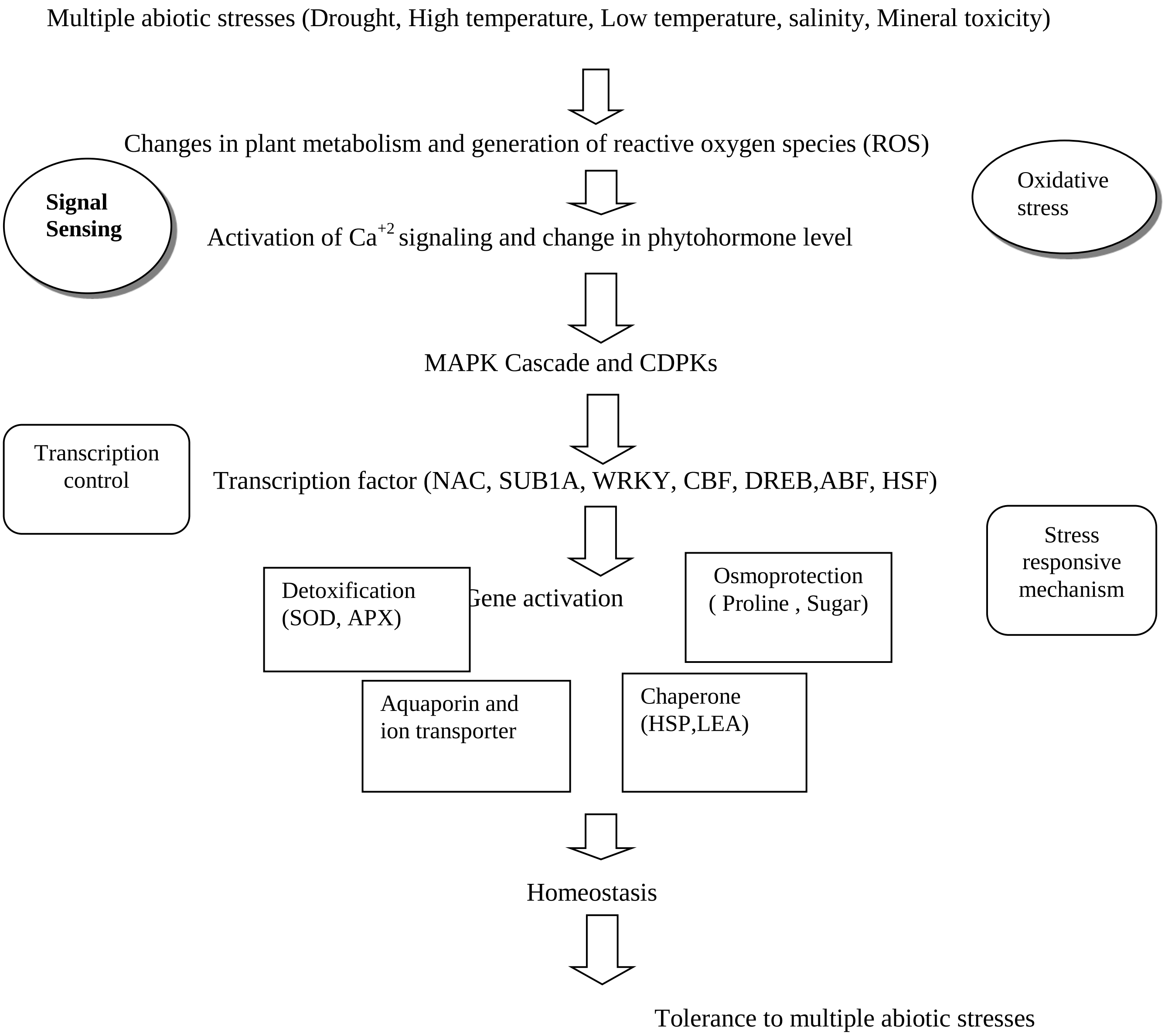

Fig. 2: General mechanism of plant responds to multiple sbiotic stresses

MAPK(Mitogen activated protein kinase), **CDPKs**(Calcium dependent protein kinases), **NAC**(No apical meristem ATAF & cup shaped cotyledons), **CBF**(C- repeat binding factor), **DREB**(Dehydration responsive element binding protein), **SOD(**Super oxide dismutase), **ABF**
(Abscisic binding factor), **LEA**(Late embryogenesis abundant protein), **HSP**(Heat shock protein), **HSF**(Heat shock factor) and **APX(**Ascorbic peroxidase).

Summary

Further increase in world rice production relies both on enhancing yields potential of favorable environment and on improving yield stability in less favorable environment. Under field situations plant faces multiple stresses at a time however their effect varies with age, genotype and stage of growth of plant. Abiotic stress effects on plant are complex in nature and impact of multiple abiotic stresses are more compared to single stress. Therefore, understanding the dynamics of multiple stresses is a major challenge for agriculturist. Selection and identification of new trait, which can enhance the adaptability in various stresses and can reduce yield penalty. Identification of quantative trait loci (QTL), signaling mechanism, and stress protein, over expression of gene, indentification of new pathways, transcription factor, gene family and regulatory protein can accelerate the mechanism of tolerance. Furthermore, complet understanding the complex mechanism of stresses and there tolerance mechanism will be helpful in achieving our goal in near future

REFERENCES

1. Ahuja, I., de Vos, R.C., Bones, A.M. and Hall, R.D., Plant molecular stress responses face climate change. *Trends in plant science*, **15(12):** 664-674 (2010).
2. Akbar, M., Yabuno, T. and Nakao, S., Breeding for saline resistant varieties of rice I. Variability for salt tolerance among some rice varieties. *Jpn J. Breed*, **22:** 277-284 (1972).
3. Armenta-Soto, J., Chang, T.T., Loresto, G.C. and O'Toole, J.C., Genetic analysis of root characters in rice. *SABRAO J*., **15:** 103-116 (1983).
4. Armstrong, W., Aeration in higher plants. In: Woolhouse, H.W. (Ed.), *Adv. Bot. Res*., **7:** 225–331 (1979).
5. Bray, E.A., Responses to abiotic stresses. *Biochemistry and molecular biology of plants*, 1158-1249 (2000).
6. Chen, J.Q., Meng, X.P., Zhang, Y., Xia, M. and Wang, X.P., Over-expression of OsDREB genes lead to enhanced drought tolerance in rice. *Biotechnology letters*, **30(12):** 2191-2198 (2008).
7. Chung, G.S., Vergara, B.S. and Heu, M.H., Breeding strategis for development of cold tolerance and rice varieties. International Rice Research, Project review no. 14 IRRI Institute, Los Banos, Laguna, Philippines, 18-22 Apr.
8. Ekanayake, I.J., De Datta, S.K. and Steponkus, P.L., Spikelet sterility and flowering response of rice to water stress at anthesis. *Ann Bot*., **63:** 257-264 (1989).
9. Fageria, N.K., Salt tolerance of rice cultivars. *Plant Soil*., **88:** 237-243(1985)
10. Fukai, S. and Cooper, M., Development of drought resistant cultivars using physiomorphological traits in rice. *Field Crops Res*., **40:** 67-86 (1995).
11. Hall, A.E., Crop Responses to Environment. New Yark: CRC Press LLC. (2000).
12. IRRI. Terminology for Rice- Growing Environments. Manila, Philippines, International Rice Research Institute. (1984).
13. IRRI. Programme report. Manila, Philippines, International Rice Research Institute. (1995).
14. Kaneda, C. and Beachell, H.M., Breeding rice for cold tolerance. Saturday Seminar Paper 9. Los Banos, Philippines. *International Rice Research Institute (IRRI)*, (1974).
15. Kato, Y., Abe, J., Kamoshita, A., and Yamagishi, J., Genotypic variation in root growth angle in rice (Oryza sativa L.) and its association with deep root development in upland fields with different water regimes. *Plant and Soil*, **287(1):** 117-129 (2006).
16. Kawano, T., Roles of the reactive oxygen species-generating peroxidase reactions in plant defense and growth induction. *Plant cell reports*, **21(9):** 829-837 (2003).
17. Kende, H., Van Der Knaap, E. and Cho, H.T., Deepwater rice: a model plant to study stem elongation. *Plant Physiol.*, **118:** 1105–10 (1998).

18. Khush, G.S., Terminology for Rice-Growing Environments. Manila, Philippines, International Rice Research Institute, (1984).
19. Maas, E.V., Salt tolerance of plants. *Apple Agric Res*., **1:** 12-26 (1986)
20. Mackill, D.J., Zhang, Z., Redona, E.D. and Colowit, P.M., Level of polymorphism and genetic mapping of AFLP markers in rice. *Genome*, **39(5):** 969-977 (1996).
21. McWilliams, D., Drought Strategies for Cotton, Cooperative Extension Service Circular 582, College of Agriculture and Home Economics, New Mexico State University, USA (2003).
22. Mohan kumar., Association Mapping for Drought Tolerance Traits Like Root Traits and Water use Efficiency in Rice Germplasm Accessions. Paper presented at the *National symposium on genomics and crop improvement: relevance and reservations*, Angru, Hyderabad, India, February 25–27 (2010).
23. Munns, R. and Tester, M., Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol.*, *59*, 651-681 (2008).
24. Naguyen, H.T., Babu, R.C. and Blum, A., Breeding for drought resistant in rice: physiology and molecular genetics consideration. *Crop Sci*., **37:** 1426-1434 (1997).
25. O' Toole, J.C. and Chang, T.T., Drought resistant in cereals-rice: a case study In: Mussel H, Staples RC, eds. Stress Physiology in Crop Plants. New Yark: Jahn Willy and Sons 373-405 (1979).
26. O'toole, J.C. and Bland, W.L., Genotypic variation in crop plant root systems. *Advances in Agronomy*, **41:** 91-145 (1987).
27. Pantuwan, G., Fukai, S., Cooper, M., Rajatasereekul, S. and O'Toole, J.C., Yield response of rice (Oryza sativa L.) genotypes to different types of drought under rainfed lowlands: Part 1. Grain yield and yield components.*Field Crops Research*, **73(2):** 153-168 (2002).
28. Ponnamperuma, F.N., Physiochemical Properties of Submerged Soils in Relation to Fertility. IRRI Res. Paper Ser No. 5 Manila: IRRI. (1977).
29. Ponnamperuma, F.N. and Bandyopadhyay, A.K., Extent of salt-affected soils and their management. In *Proc. Int. Symp. Priorities for Alleviating Soil-related Constraints to Food Production in the Tropics, Los Banos, Philippines, IRRI, Philippines* (pp. 3-19) (1980).
30. Premachandra, G.S., Saneoka, H., Kanaya, M. and Ogata, S., Cell membrane stability and leaf surface wax content as affected by increasing water deficits in maize, *J. Exp. Bot*., 42, 167–171 (1991).
31. Ram, P.C., Singh, B.B., Singh, A.K., Ram, P. and Singh, P.N., Annual Report for the Rainfed Lowland Rice Research Consortium, 1999/2000. Narendra Dev University of Agriculture and Technology, Kumarganj, UP, India, (2000).
32. Rosegrant, M.W., Agcaoili-Sombilla, M.C. and Perez, N.D., *Global food projections to 2020: Implications for investment* (No. 5). Diane Publishing (1995).
33. Sand-Jensen, K. and Frost-Christensen, H., Plant growth and photosynthesis in the transient effect of water temperature and nitrogen application before the critical stage on the sterility induced by cooling at the critical stage. *Japanese Journal of Crop Science*, **56(3):** 404-410 (1999).
34. Satake, T., lee, S.Y., koike, S., and kariya, K., Male Sterility Caused by Cooling Treatment at the Young Microspore Stage in Rice Plants: XXVII. (1987).
35. Visser, E.J.W., Colmer, T.D., Blom, C.W.P.M. and Voesenek, L.A.C.J., Changes in growth, porosity, and radial oxygen loss from adventitious roots of selected mono- and dicotyledonous wetland species with contrasting types of aerenchyma. *Plant Cell Environ.*, **23:** 1237– 45 (2000).
36. Weston, D.J., Gunter, L.E., Rogers, A. and Wullschleger, S.D., Connecting genes, coexpression modules, and molecular signatures to environmental stress

phenotypes in plants. *BMC Systems Biology*, **2(1):** 16 (2008).
37. Yeo, A.R. and Flowers, T.J., Accumulation and localisation of sodium ions within the shoots of rice (Oryza sativa) varieties differing in salinity resistance. *Physiologia plantarum*, **56(3):** 343-348 (1982).
38. Yeo, A.R., and Flowers, T.J., The absence of an effect of the na/ca ratio on sodium chloride uptake by rice (Oryza sativa l.). *New Phytologist*, **99(1):** 81-90 (1985).
39. Yeo, A.R., Yeo, M.E., Flowers, S.A. and Flowers, T.J., Screening of rice (Oryza sativa L.) genotypes for physiological characters contributing to salinity resistance, and their relationship to overall performance. *TAG Theoretical and Applied Genetics*, **79(3):** 377-384 (1990).