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Drought responses and its management in rice: A review

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Abstract

Rice (*Oryza sativa* L.) is one of the oldest crops cultivated over 117 countries and it is staple food for about half of the world's population. But rice production is severely affected by drought and other climate change threats. Drought affects yield as well as biochemical, physiological and morphological functioning of plant. Drought will affect not only rice yield but also will shift cropping systems away from rice cultivation towards more cultivable crops with adequate temperature range. Therefore managing drought for sustaining rice cultivation and yield is very important. Application of silica, proline, biochar, designer seed technology and some other methods are briefly discussed in this review as an attempt to mitigate drought stress. The aim of this review is to highlight the rice responses to temperature and drought stress and also to suggest crop sustaining adaptation measures for this.

Keywords: Drought stress, rice, drought responses, drought management

Introduction

Rice is staple food for half of the world's population and it is cultivated is spread over 168 million hectares all over the globe. But the production of rice is not enough to meet the growing population. Rice production must be increased about 60% to meet dietary needs by the year 2050 to meet the needs of increasing population. Furthermore environmental stress and climate change impose serious threats to global rice production. Due to rice's sensitivity to climate changes, particularly rising temperatures and prolonged droughts, meeting future global demand for rice presents a significant challenge, Reduced water availability caused by rising temperatures is also posing threat to rice cultivation and it will not only impact rice production but also lead to shift in cropping systems favoring crops better suited to the changing temperature conditions. Drought stress is a significant limitation to rice production, especially in water-scarce environments like upland rice cultivation areas. Evenson reported that drought causes an average annual global reduction in rice production of 18 Mt. Given the current and anticipated water scarcity challenges, irrigation offers only limited relief for drought-related issues in rainfed rice-growing systems. Therefore, it is essential that agronomic and genetic strategies prioritize proper utilization of available soil moisture to support crop growth, and yield. In drought-prone rainfed regions, rice yields remain low, ranging from 1.0 to 2.5 t ha^{-1}, and are often unstable due to irregular and unpredictable rainfall. Enhancing drought resilience through the development of drought-tolerant rice varieties, along with complementary practices such as water conservation using soil amendments plays critical role in mitigating drought effects and alleviating poverty. Further extraneous application of foliar sprays and seed hardening enhances drought tolerance in rice. The aim of this review is to highlight the response of rice to drought stress and to suggest suitable measures sustain yield and productivity. The effects of drought stress on rice will be discussed briefly in the coming sections.

Morphological, biochemical and physiological responses of drought stress in rice

Drought affects morphological and physiological characteristics of rice in so many ways, all resulting in either yield reductions, especially in rainfed cropping systems. More particularly, stomata closure and the leaf carbon dioxide oxygen ratio is reduced under drought stress conditions resulting in inhibition of photosynthesis.

Stress at early seedlings and tillering stages either result in wilting or drying of leaves, which directly affect plant stature, tillering as well as source partitioning. Early formed tillers (30-50 DAS) directly contribute towards grain yield but tillers produced later stages doesn't have much impact on grain yield. Physiological changes were noticed by Ramakrishnayya and Swain (2002) [23] in rice that increasing the severity of stress during the vegetative stage (21–35 DAS) reduces leaf water potential and relative water content, further affecting plant growth and productivity. If drought stress occurs later during meiotic division or at anthesis, then sterility of flowrets is increased and consequently there is a lower percentage of filled grains. At the time of flowering occurrence of moisture stress reported reduced shoot and culm dry matter which resulted in less total dry matter indicating the ill effects of soil moisture stress on translocation of photosynthates from shoot to panicle. Thus moisture stress at different growth stages affects crop yield in one way or other. Reduced tillering, reduced grain filing, delayed flowering, spikelet infertility are some common symptoms of drought stress found in rice.

Stress lasting for a longer period during initial stage cause prolonged crop duration than stress occurring at later stages. Leaf rolling was the most identifiable symptom of moisture stress however shoot growth of rice was more susceptible to water deficit than leaf rolling. Furthermore a negative correlation between leaf transpiration and photosynthesis was found in upland rice. Wassmann reported that photosynthetic pigments such as chlorophyll concentrations and total soluble proteins were severely affected by drought stress and it reduced photosynthetic primary products and sucrose-phosphate synthase activity. Further drought impacts were less severe for plants grown at elevated CO_2 levels as leaf photosynthesis was maintained longer under drought conditions when rice plants were grown at elevated than at ambient CO_2. Findings on anthesis due to drought stress was that in rice, low water potentials around the time of anthesis may lead to a failure of anther dehiscence which leads to male sterility.

Drought stress is a critical abiotic factor affecting plant growth by altering morphological, physiological, and molecular traits. Early seedling and tillering stages are particularly vulnerable, where reduced water availability leads to wilting and leaf drying, which directly impairs photosynthesis and nutrient uptake. Studies by Upadhyaya and Panda (2019) [29] emphasized that moisture stress not only affects leaf water content but also hampers nutrient mobilization, critical for grain filling during the reproductive phase. Additionally, drought-induced stomatal closure limits CO_2 uptake, reducing photosynthetic efficiency and biomass accumulation. Long-term drought may also lead to structural changes in root systems, often promoting deeper rooting to access residual moisture.

Drought and temperature stress responses on rice yield

Low rainfall leads to drought that could result in permanent damage to plant growth and development. Temperature stress is very much similar to drought stress and the raise in temperature cause stress in plants that are non distinguishable with drought stress. Both these stress cause damage to plants but when these combines it cause severe damage that is more difficult to manage. Even 1°C slight increase in daytime temperature from 28°C to 34°C reported a rice yield reduction of about 78%. More number of findings has predicted yield reductions due to temperature increase and it is causing much hardship to farmers. For example the yield of recent rice varieties in South Japan is reduced by up to 40%. Also sub-Saharan area has already seen decline in per capita agricultural output in recent decades, especially for staple foods including rice production. Further study conducted by Monsoon and Tariqul (2017) in different rice genotypes found that occurrence of drought at panicle initiation stage resulted increased spikelet sterility (40% FC) resulting low grain yield.

Many findings have brought the negative impact of high night temperature on yield since the diurnal variation is very important for rice growth. Drought stress also hinder swelling of pollen grains resulting in poor dehiscence which reduce pollination and finally cause reduction in no. of productive tillers, Hasanuzzaman *et al*., (2018) [13]. Rice is likely being affected by raise in temperature such as increased floret sterility and the severity is even worse when temperature raise is continuing.

Increased no. of chaffy grains was reported by Lisle when rice was grown in a glasshouse at 38/21 °C compared to rice grown at 26/15 °C day/night temperature. One of the reasons for chaffy grains is the loose packing of amyloplasts it was presented in study conducted by Krishnan in high temperature stress study. reported detrimental effects of increased temperatures on the grain quality of some *Oryza Japonica* varieties under field conditions that grain where either not fully filled or it was chaffy. Likewise, high-temperature stress during ripening resulted in poor grain filling in study conducted by Morita and it was damaged without any day night difference.

Reduced tillering, delayed flowering, reduced spikelet fertility, reduction in number of panicles, reduced grain filling rate, reduction in grain size and weight are some of the common symptoms of drought stress that is mainly leading to reduced grain yield. Rice growth and functioning is severely affected by drought and temperature stress throughout its growth stages finally resulting in yield reduction.

Effects of temperature increases on quantitative and qualitative attributes of rice yield

Yield is severely affected under drought situation but increased temperatures will also affect the grain quality of rice. Drought generally decrease the dry biomass of all plant organs and shortens the life cycle of the plants causing yield reduction. But major contribution to yield reduction due to strong effects of drought on grain yield is spikelet infertility and panicle exsertion. Drought during the initial stage i.e., vegetative stage before the onset of flowering reduce rice yield by reducing the growth of photosynthetic and storage organs. Drought occurring at the time of flowering may reduce pollen viability, stigma receptivity, and seed set. Now it's evident that drought affects all stages of rice growth and development but water stress during occurring at the time of flowering stage depresses grain formation more than drought occurring at any other stages. The drought-induced inhibition of panicle exertion is due to reduction in peduncle elongation that usually account for 70-75% spikelet sterility under water deficit period. Inhibition of reproductive organ development such as ovary and pollen at meiosis along with process inhibition e.g. anther dehiscence, pollen shedding, pollen germination, and fertilization due to drought have been observed and recorded.

Drought mitigation approaches

Role of silicon in drought stress mitigation

Silicon (Si) plays an indispensable role in alleviating drought stress by enhancing the structural integrity of plant cell walls and regulating water loss through reduced transpiration. Studies by Kim demonstrated that Si supplementation in rice increases plant resistance to water deficit by forming a silica cuticle layer on leaves, reducing water loss. Furthermore, Gholami and Falah (2013) [12] highlighted the improvement in root architecture, aiding water uptake. Despite its abundance, the low solubility of Si from natural sources limits its availability in the soil. Intensive cultivation in regions like India has exacerbated Si depletion, necessitating the incorporation of Si fertilizers or Si-enriched amendments like rice husk ash. This not only addresses deficiencies but also enhances water-use efficiency under drought conditions.

Role of potassium in stress tolerance

Potassium (K) is a key nutrient influencing plant responses to drought through its role in stomatal regulation, osmotic adjustment, and enzyme activation. Mohd Zain and Ismail (2015) [18] demonstrated that K application improves drought tolerance by increasing proline levels, an osmoprotectant, while reducing oxidative damage through catalase activity modulation. Higher potassium levels enable efficient water utilization by maintaining turgor pressure and enhancing root hydraulic conductivity. Additionally, K-induced improvements in photosynthetic efficiency and carbon assimilation contribute to better growth and yield, even under moisture stress conditions.

Designer seed technology

Designer seed technology, which integrates bioactive compounds and beneficial microbes, is a breakthrough in enhancing seed resilience to environmental stress. Demonstrated that treating seeds with a combination of PPFM, polymers, and beneficial microbes significantly boosted seedling vigor and pest resistance. For example, Azospirillum, a nitrogen-fixing bacterium, enhances root growth and nutrient uptake, while *Trichoderma viride* provides disease resistance. Such priming strategies not only ensure uniform germination and early growth under drought but also reduce the reliance on chemical inputs, fostering environmentally friendly agriculture.

Biochar and hydrogel for enhanced water use efficiency

Biochar is a carbon product derived from pyrolysis process and it has shown improvement in soil moisture retention and crop performance under water-limited conditions. Xi Chen *et a.* (2021) [5] found that biochar applications in rice improved plant height, the number of tillers, and yield components by increasing soil organic matter and water-holding capacity. Similarly, hydrogel, a polymer-based product, has been specifically designed for moisture-stress agriculture. It acts as a reservoir for water and nutrients, releasing them gradually to plants. Research by Saini and Umesh showed a significant enhancement in rice yields with the application of 4 kg ha^{-1} hydrogel in furrow-sown fields. Such technologies not only enhance productivity but also support sustainable water management practices, particularly in semi-arid regions.

Plant Growth-Promoting Rhizobacteria (PGPR) and Endophytes

PGPR and endophytes like *Piriformospora indica* has an important role in promoting plant resilience under drought conditions. These microorganisms colonize the rhizosphere and facilitate nutrient uptake by solubilizing phosphates and synthesizing plant growth promoter phytohormones such as auxins and gibberellins found that *Piriformospora indica* increases root surface area and chlorophyll content, promoting better water uptake and photosynthesis. Moreover, PGPR-induced production of stress-alleviating compounds like ACC deaminase reduces ethylene levels, mitigating drought-induced senescence.

Proline and oxidative stress management

Proline accumulation is an important antioxidant which allows plant adapt to drought stress, playing a dual role in osmotic adjustment and reactive oxygen species (ROS) scavenging. Hasanuzzaman *et a*. (2012) [13] highlighted that proline stabilizes membranes and proteins while protecting cellular organelles from oxidative damage. Exogenous application of proline enhances the activity of antioxidant enzymes such as superoxide dismutase (SOD), catalase, and peroxidase, enabling plants to combat oxidative stress. Its protective effects have been particularly evident in rice and wheat under prolonged water deficit conditions.

Seed Priming and anti-transpirant applications

Seed priming techniques like hydro-priming and chemical priming, significantly improve seed germination and seedling establishment. Matsunami *et al*. (2022) [17] observed that primed seeds germinate faster and develop more robust seedlings compared to non-primed controls. Antitranspirants reduce the transpiration and helps to maintain the moisture content in leaf tissues which further reduce dehydration of plants. Kaolin spray, a reflective particle film, mitigates the impact of high temperatures and water loss by reducing leaf temperature and enhancing radiation use efficiency. Studies by Patel found that Phenyl Mercuric Acetate (PMA) applications increased nutrient uptake, photosynthetic activity, and dry matter production in water-stressed rice fields.

Seed hardening

Low-cost methods such as seed hardening or priming should be seriously considered for managing occasional moisture stress (Pathak *et al*., 1999) [22]. When dry seeds are soaked in water or a chemical solution, the innate cells become hydrated, initiating the germination process. Drying the seeds at this stage temporarily halts germination, which resumes once soil moisture is available after sowing. This physiological pre-conditioning, involving imbibition, drying, and subsequent rehydration upon sowing, enhances plant resilience, equipping them to withstand adverse conditions such as high temperatures, low relative humidity, and phytotoxicity caused by insecticide residues (Dawson, 1965; Thakuria & Choudhary, 1995) [7, 28].

Research indicates that seed hardening can improve drought tolerance especially with potassium salts (Chinoy *et al*., 1970) [6]. For example study conducted at Assam Agricultural University found that among different potassium salts, KCl was the most effective for seed treatment compared to K_2SO_4, KNO_3, and K_2HPO_4 (Borgohain, 1988) [4]. Experiments revealed that seed hardening with 4% KCl, combined with higher potassium fertilizer application (60 kg K_2O/ha) and spraying 50 ppm paraquat as an anti-transpirant at the tillering stage of direct-seeded upland rice, led to an increase in the number of effective tillers, enhanced root volume, improved water use efficiency, and provided better drought resistance (Thakuria & Choudhry, 1995; Pathak *et al*., 1999; Pathak & Choudhry, 2001; Khatua, 2002) [28, 22, 21, 16].

Besides potassium salts, other seed treatments such as bioinoculants have been found to enhance stress tolerance in rice. Treating seeds with FYM slurry at 25 kg/ha improved yield and related attributes in upland rice compared to untreated seeds (Dinesh Chandra *et al*., 1991) [8]. Additionally, treating seeds with a 1% $CaCl_2$ solution resulted in better crop establishment and survival under drought conditions (Ananda *et al*., 2002) [2].

Pre-soaking seeds in a 385 ppm sodium phosphate ($Na_2 HPO_4$) solution for 12–14 hours improved germination and seedling uniformity even under moisture stress. This treatment increased grain yield from 2.3 t/ha to 2.5 t/ha (Singh & Chatterjee, 1980) [25]. Further studies by Singh and Chatterjee (1981) [26] reported that seeds treated with water (soaked for 48 hours) and solutions of Na_2HPO_4, $Al(NO_3)_2$, NaCl, and $Co(NO_3)_2$ resulted in a 13–26% increase in grain yield compared to untreated seeds.

Mulching

As rising temperatures intensify, evapotranspiration becomes the primary cause of water loss in croplands. Around 30–60% of the total applied water that is not directly absorbed by crops is lost as unproductive evaporation. Reducing this soil evaporation is a crucial strategy for enhancing water-use efficiency. Bare soil exposed to heat and wind experiences greater water loss through evaporation. Mulching has been shown to improve water-use efficiency by 10–20% (Ossom *et al*., 2001; Ramakrishna *et al*., 2006; Kazemia & Safaria, 2018; Waraich *et al*., 2011) [20, 23, 15, 31]. It enhances water-use efficiency by increasing the infiltration rate and minimizing evaporation losses (Kar & Singh, 2004; Ramakrishna *et al*., 2006) [14, 23], runoff, and temperature fluctuations (Ranjan *et al*., 2017) [24]. observed improved water-use efficiency, higher relative water content in leaves, and reduced weed populations under mulch treatment compared to non-mulched conditions during water stress. Similarly, Teame *et al*. (2017) [27] reported an increase in sesame yield with mulching. Weeds compete with crops for essential resources like water and nutrients, significantly depleting available soil moisture. In fact, weeds require more water than many crop plants to produce an equivalent amount of dry matter, leading to considerable yield losses Verma *et al*., (2015) [30]. Mulching effectively suppresses weed growth by limiting light penetration into the soil, thereby improving water availability for crops, particularly under drought conditions. Given its affordability and effectiveness, mulching serves as a cost-efficient strategy to prevent crop failure during dry periods.

Integrating advanced practices for drought resilience

The integration of advanced drought management strategies, such as biochar and hydrogel application, potassium fertilization, seed priming, and microbial inoculation, offers a holistic approach to sustaining crop productivity. Combined with technologies like designer seeds and PGPR, these methods provide synergistic benefits, enabling plants to thrive under adverse conditions. Continued research and adoption of such practices will be crucial in addressing global food security challenges in the face of increasing climate variability.

Conclusion

Drought is a significant climatic hazard that continues to impact various regions. As a recurring phenomenon, it severely affects agriculture and disrupts the livelihoods of millions of farmers and agricultural laborers. The socio-economic consequences of drought are substantial, leading to considerable financial losses both during drought periods and from missed opportunities for economic growth. Additionally, drought directly exacerbates poverty by increasing its prevalence and severity. To safeguard agricultural productivity and promote environmental sustainability, it is essential to develop and implement effective strategies to mitigate the adverse effects of drought.

References

1. Ajaykumar R, Krishnaswamy SM. Effect of PPFM and PGRs on crop growth rate in transplanted rice under moisture stress condition. J Pharmacol Phytochem. 2018;7(4):2366-2368.
2. Ananda MG, Reddy VC. Effect of sowing methods and seed treatments on grain yield of rainfed lowland paddy varieties. Mysore J Agric Sci. 2002;36:231-236.
3. Roychoudhury A, editor. Biology and Biotechnology of Environmental Stress Tolerance in Plants: Volume 2: Trace Elements in Environmental Stress Tolerance. CRC Press; 2023.
4. Borgohain B. Effect of seed treatment, antitranspirants, and potassium on direct-seeded rainfed rice [Ph.D. thesis]. Jorhat: Assam Agricultural University; 1988.
5. Chen X, Yang S, Ding J, Jiang Z, Sun X. Effects of biochar addition on rice growth and yield under water-saving irrigation. Water. 2021;13(2):209.
6. Chinoy JJ, Abraham PG, Pandya RB, Sensens OP, Dave IC. Effect of pre-sowing treatment of Triticum seeds with ascorbic acid and sucrose on growth, development, and yield characters. Indian J Plant Physiol. 1970;13:40-8.
7. Dawson MJ. Effect of seed soaking on the growth and development of crop plants. Indian J Plant Physiol. 1965;8(1):53-5.
8. Dinesh C, Moorthy BTS, Jha KP, Manna GB. Agronomic practices for augmenting rice production in the rainfed upland ecosystem of Orissa. Indian J Agron. 1991;24:199-202.
9. Emam MM, Khattab EH, Helal MM, Deraz EA. Effect of selenium and silicon on yield quality of rice plant grown under drought stress. Aust J Crop Sci. 2014;8:596-605.
10. Farooq M, Basra SM, Wahid A, Ahmad N. Changes in nutrient homeostasis and reserve metabolism during rice seed priming: consequences for seedling emergence and growth. Agric Sci China. 2010;9(2):191-8.
11. Garg NK, Maheshwari CH, Changan SSK, Vaibhav A, Kumar AM, Singh AR, *et al*. Paclobutrazol-induced physio-biochemical manifestations to ameliorate water deficit stress in rice (*Oryza sativa*). Indian J Agric Sci. 2019;89(11):80-4.
12. Gholami Y, Falah A. Effects of two different sources of silicon on dry matter production, yield, and yield components of rice (Tarom Hashemi variety and 843 lines). Int J Agric Crop Sci. 2013;5:227-31.
13. Hasanuzzaman M, Hossain MA, da Silva JAT, Fujita M. Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. In: Venkateswarlu B, Shanker A, Shanker C, Maheswari M, editors. Crop stress strategies. Dordrecht: Springer; 2012. p. 261-315.
14. Kar G, Singh R. Soil water retention-transmission studies and enhancing water use efficiency of winter crops through soil surface modification. Indian J Soil Conserv. 2004;8:18-23.
15. Kazemi F, Safari N. Effect of mulches on some characteristics of a drought-tolerant flowering plant for urban landscaping. Desert. 2018;23(1):75-84.
16. Khatua S. Studies on drought management in upland rice [M.Sc. (Ag) thesis]. Bhubaneswar: Department of Agronomy, OUAT; 2002.
17. Matsunami M, Hayashi H, Murai-Hatano M, Ishikawa-Sakurai J. Effect of hydropriming on germination and aquaporin gene expression in rice. Plant Growth Regul. 2022;97(2):263-70.
18. Mohd Zain NA, Ismail MR. Effect of potassium rates and types on growth, leaf exchange, and biochemical changes in rice (Oryza sativa) grown under water stress conditions in

Inceptisol of Varanasi, U.P. Int J Crop Sci. 2016;7(6):1327-31.
19. Moonmoon S, Islam MT. Effect of drought stress at different growth stages on yield and yield components of six rice (*Oryza sativa* L.) genotypes. Fundam Appl Agric. 2017;2(3):285-9.
20. Ossom EM, Pace PF, Rhykerd RL, Rhykerd CL. Effect of mulch on weed infestation, soil temperature, nutrient concentration, and tuber yield in *Ipomoea batatas* (L.) Lam. in Papua New Guinea. Trop Agric. 2001;78:144-51.
21. Pathak K, Choudhry AK. Water and weed management studies in direct-seeded upland rice. IRRN. 2001;26:55-7.
22. Pathak K, Saikia M, Chaudhary AK. Drought management in direct-seeded upland rice in Northeast India—a review. Agric Rev. 1999;20(3-4):239-42.
23. Ramakrishna A, Tam HM, Wani SP, Long TD. Effect of mulch on soil temperature, moisture, weed infestation, and yield of groundnut in northern Vietnam. Field Crop Res. 2006;95(2):115-25.
24. Ranjan P, Patle GT, Prem M, Solanke KR. Organic mulching—a water-saving technique to increase the production of fruits and vegetables. Curr Agric Res J. 2017;5(3):371-80.
25. Singh AI, Chaterjee BN. Upland rice production with pre-treated seeds. Indian J Agron. 1980;25:479-86.
26. Singh AI, Chaterjee BN. Upland rice production with pre-treated seeds. Indian J Agric Sci. 1981;51(6):393-402.
27. Teame G, Tsegay A, Abrha B. Effect of organic mulching on soil moisture, yield, and yield-contributing components of sesame (*Sesamum indicum* L.). Int J Agron. 2017;2(7):1-6.
28. Thakuria RK, Choudhry JK. Effect of seed priming on dry-seeded Ahu rice (summer rice). Indian J Agron. 1995;40(3):412-4.
29. Upadhyaya H, Panda SK. Drought stress responses and its management in rice. In: Advances in rice research for abiotic stress tolerance. Woodland Publishing; 2019. p. 177-200.
30. Verma SK, Singh SB, Prasad SK, Meena RN, Meena RS. Influence of irrigation regimes and weed management practices on water use and nutrient uptake in wheat (*Triticum aestivum* L. emend. Fiori and Paol.). Bangladesh J Bot. 2015;44(3):437-42.
31. Waraich EA, Ahmad R, Ashraf MY, Saifullah, Ahmad M. Improving agricultural water use efficiency by nutrient management in crop plants. Agric Soil Plant Sci. 2011;61(4):291-304.