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Review Article

EXPLORING NEW TECHNIQUES AND STRATEGIES FOR ENHANCING RICE DROUGHT TOLERANCE

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Abstract: *Drought stress harms rice production and results in significant economic losses. The severity of the global climate change issue is rising. Given the current and projected levels of global food demand, it is imperative to boost agricultural output in rain-fed, drought-prone areas. Because they are crucial to achieving the production goal in rainfed regions, drought-tolerant rice varieties are in great demand. Future research on genetic improvement for drought resistance should be given top priority. A recent study has shown that several genetic and physiological factors affect how well rice manages drought. This information has been used to make better rice varieties that can manage drought. In addition, new techniques like marker-assisted selection and gene editing are being used to make rice even more resistant to drought.*

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Introduction

Rice is one of the most important staple crops in the world. More than half of the world's people get their food and nutrition from rice. It is an important part of the global food chain, and its production is very vulnerable to climate change and extreme weather events like drought. Drought is a major abiotic stressor that affects the growth and output of rice crops, leading to big drops in yield and quality. To keep food security and agricultural production up, we need to develop rice varieties that can handle drought stress better. Multigenic control of drought-tolerant traits would be a big problem for the work (Chakraborti *et al*., 2021). Asia is the first place that makes and eats the most rice. From 2016 to 2017, the FAO predicts that the usual amount of rice that will be produced will be 5.0 108 t, but that the amount of rice that will be needed will rise to 2.0 * 109 t by 2030 because the population will have grown. Crop yields in places with less favorable rain must be greatly increased to fix the present and future food shortages worldwide. Climate change is a big problem for agriculture, especially in poor countries. It changes how often and how much water changes and puts much outside pressure on plants (Chaudhry and Sidhu 2022; dos Santos *et al*., 2022). Drought is one of the most important non-living things that stop the rice from growing in rain-fed settings. A drought is a time of low average rainfall, bad rain, or higher evaporation rates that damage crop growth and productivity (McHugh, *et al*., 2007). How bad a drought depends on several factors, such as how often it rains, how much water evaporates, and how much water is in the land (Sheffield and Wood, 2008; Panda *et al*. 2021) More than a third of the land used for farming around the world is in a drought-stressed state (Singh and Sood, 2020). Of that area, emerging countries take up 33%, rich countries take up 25%, and underdeveloped states take up 42%. Singh, *et al*. (2016) found that breeding rice cultivars that can handle drought stress is a safe and cost-effective way to boost rice production.

Researchers have tried to grow drought-tolerant rice plants in the past, but they haven't made much progress because they haven't been able to find drought-tolerant donors. After looking at thousands of genetic samples from different parts of the world to see if they were resistant to drought, only a few drought-tolerant types have been found so far. Kumar *et al*., (2018) think that rice plants' responses to drought are difficult and involve several stresses on their bodies. This review talks about the effects of drought stress and highlights current studies on how organisms adapt at cellular, molecular, and physiological levels. This study aims to find and test new ways to improve rice plants' ability to survive in dry conditions. A thorough examination of the literature will be done to find out what is known about the mechanisms and methods used to make rice more resistant to drought. This study will look at studies focusing on the physiological, biochemical, and molecular bases of drought tolerance and different ways to improve drought tolerance, such as genetic engineering, drought-tolerant cultivars, and agronomic practices. The review will also give an account of the current problems with rice's ability to handle drought and some ideas for how to make rice better at handling drought.

Various research methods, such as field experiments, molecular analyses, and computer simulations, will be used to find the best ways and processes to make rice more drought-resistant. These tests and analyses will be used to develop new ways to make rice more resistant to drought. The study will also look at how well existing drought-tolerant rice varieties work and look for ways to make traditional varieties more resistant to drought. The results of this study will be very helpful in coming up with ways to make rice more resistant to drought, which will help improve global food security and agricultural sustainability. The study will also give important information about how rice is made more resistant to drought, which can be used to help other crops. Rice is the most important food crop in the world and helps a lot with food security worldwide. In recent years, droughts have become more common in many parts of the world. This has caused rice crops to drop and food security to get worse. To solve this problem, a study has been done to find new ways to make rice more resistant to drought to better handle the effects of drought and keep food secure (Reynolds *et al*., 2015).

The first step in making rice more resistant to drought is to learn what happens to physiological and molecular changes when it is stressed by drought. Studies have shown that the reaction of rice plants to drought stress involves more than one gene and that these genes can be used to make rice plants more resistant to drought. For example, new studies have found several genes involved in how rice plants respond to drought stress. For example, genes controlling stomata closing can help plants use water more efficiently. Also, the study has shown that the expression of certain genes, like those that control how the plant uses ABA, can make rice plants more resistant to drought (Kumar *et al*., 2018). Creating new breeding techniques is another important part of making rice more drought-resistant. Traditional ways of breeding have been used for a long time to find plants with desirable traits, such as a better ability to handle drought.

On the other hand, recent improvements in genomics and molecular breeding have made it possible to find and choose plants with better drought tolerance more efficiently and effectively. For example, high-throughput sequencing and genomic selection have made it possible to create rice types that can handle drought better (Andleeb *et al*., 2017). Furthermore, there are several scientific ways to make rice better manage drought. These methods use genetic engineering or gene editing to change the genes of rice plants to give them new traits. For example, genetic engineering has been used to add genes that make plants better able to handle drought, such as those that control ABA metabolism. Also, gene editing has been used to change genes already present in rice plants, such as those that control the closing of stomata, to make them more resistant to dryness (Sen 2018). Researchers have found several ways to make rice more resistant to drought. These include finding the genes involved in how rice plants respond to drought stress, using standard and new breeding methods, and using biotechnological processes. These methods have the potential to make rice much more resistant to drought and ensure food security in a world where droughts are becoming more regular (Handa *et al*., 2019).

Morphological Adaptations to Water Scarcity

Drought resistance is a plant's ability to make the most money using the least water (Bott and Benites, 2005). It is a complex trait that rests on how different biochemical, physiological, and morphological responses work together. (Theodosis, Poulain, and the others, 2008). The crop growth factors are effect by the drought, which leads to less food being made. Changes in plants' biochemical, molecular, physiological, and morphological functions and their reactions to drought stress are signs of bad effects. (Anjum, Xie *et al*. 2011).

Impacts of Drought Stress on Seed Germination and Seedling Development

When there isn't enough water for the rice to grow, the shape of the grain changes. Normal productivity rests on the crop standing in the right way and at the right time. The major effects of drought stress are that seeds don't sprout and plants grow too slowly. During dry stress, when there isn't enough water, seedlings' germination and growth slow down a lot. (Dornbos *et al*., 1989) Compared to many other crops, rice is very sensitive to dryness during seedlings' sprouting and early growth stages. (Ramakrishna, Tam, *et al*., 2006) For a seed to sprout, it needs the right temperature, humidity, and soil. Drought stress kills metabolic processes at the cellular level and throws off the water balance. It also slows down the process of making ATP and breathing, which makes it hard for seeds to germinate (Salehi-Lisar and Bakhshayeshan-Agdam, 2016). Several sources say that water stress causes plants to lose weight, leaf area, and height (Li *et al*. 2009).

Impacts of Drought on Leaf Characteristics

When there isn't enough water, water flow from the xylem to another cell is slowed down, which slows leaf growth (Ge *et al*., 2012). When there isn't enough water, turgor pressure drops, slows water flow from the xylem to another cell and lowers turgor pressure (Yadav, Modi, *et al*., 2020). Drought stress changes the ultrastructure and design of the leaf (Fu *et al*., 2013). As the leaf gets smaller, there are fewer stomata, thicker cell walls, less use of the leaf surface, and the conducting system isn't growing as it should. Some important signs of drought stress in plants are leaf rolling and the start of early senescence (Anjum *et al*., 2017). Leaf pigment content, higher flag leaf area, leaf area index, and leaf relative water content are some of the leaf characteristics used to identify drought-tolerant varieties (Maghsoudi *et al*., 2016).

Root Traits and Their Response to Drought Stress

When plants are stressed by drought, they need certain qualities in their roots to produce more. In general, rice types with a deep root system and lots of roots are more drought-resistant (Nguyen *et al*., 1997), and drought resistance in rice depends on genotypes that have a deep root system, coarse roots, the ability to grow many branches, and a high root-to-shoot ratio. The shape and function of rice roots greatly affect shoot growth and total grain yield when the plant is stressed by drought (Bhandari *et al*. 2023)

Physical Responses to Drought Stress

Drought stress hurts many parts of a plant's body, and plants respond to it to get used to bad conditions. Before breeding programs, it is important to improve physiological factors and processes to increase yield in dry conditions (Richards, Rebetzke, *et al*., 2002). Water shortage harms many physiological traits of rice, including transpiration rate, stomatal conductance, water use efficiency, internal carbon dioxide concentration, membrane stability index, photosystem II (PSII) activity, and relative water content (Xu *et al*., 2010).

The Impact of Antioxidants Under Drought Stress

Plants have an antioxidant defence system that helps them fight off damage caused by oxidation. It comprises enzyme- and non-enzyme-based antioxidants (Hasanuzzaman *et al*., 2012). The enzyme antioxidants are glutathione reductase (GR), dehydroascorbate reductase (DHAR), ascorbate peroxidase (APX), catalase (CAT), superoxide dismutase (SOD) and superoxide dismutase (SOD), etc. Ascorbate (AsA) and glutathione (GSH) are two antioxidants not made by enzymes. Increasing the production of the antioxidant system is a way to protect rice from oxidative stress and make it better able to deal with drought. (Hasan, Skalicky, *et al*., 2021) SOD is the first line of defense against oxidative stress, affecting almost all living things' biological parts.

The increased activity of these enzymes is thought to be one of the most important ways rice plants deal with reactive stress during drought. (Sharma, Jha, *et al*., 2012) Also, the increase in ascorbic acid and GSH in rice plants under drought stress is directly related to the increase in the As A-GSH cycle activity. (El-Beltagi *et al*., 2020). There have been many studies that have shown the importance of this pathway in fighting water shortage. The age in rice. Studied rice's biomarker for yield loss (Chaves and Oliveira, 2004). The increase in ascorbic acid content is highly related to oxidative tolerance in rice (Roy *et al*. 2016) and hence broadly used as an important screening parameter for drought tolerance in rice plants.GSH is highly important against drought stress and the over-production of ROS. GSH works all the time to eliminate free radicals and protect DNA, proteins, and lipids. Much research has been done on how drought affects GSH in rice plants, and a surprising rise was seen (Sahoo *et al*., 2022).

Molecular Basis of Drought Tolerance: After membrane sensors that haven't fully developed yet pick up on drought signals in the environment, the signals are sent down through different signal transduction pathways. This leads to the release of drought-responsive traits with the right gene functions and tolerance to drought. (Huang, Ma *et al*. 2012)). A drought is a complicated event. So, breeding and selection can't give exact results regarding how well plants can handle drought. But DNA markers can make molecular studies faster and provide more accurate results. (Upadhyaya *et al*., 2006) These genetic markers can help choose drought-tolerant germplasm from a group and use it in upcoming crop development projects.

Identification of Quantitative Trait Loci Related to Drought Tolerance in Rice: Several genes in a plant's genome, called QTLs, have quantitative traits that are very exact. Due to poor mapping resolution and a small effect on phenotype, earlier molecular genetic studies (Foolad, 2007) found many QTLs linked to many physiological and biochemical variables. Still, they were unable to find the genes that control these traits. Finding these QTLs linked to certain traits helps plant stress screening programs (Koyama, Levesley, *et al*., 2001). Many QTLs are linked to different physiological and developmental traits under drought. Most of the QTLs found so far for drought resistance in rice come from non-elite genotypes. When drought stresses rice plants, the QTL qDTY1.1 is often used as a yield trait.

Biswal and his colleagues (2017) said these QTLs are also linked to other SSR markers. The quick and exact way the rice lines were shaped. In their research on the genetic mapping of morpho-physiological traits linked to reproductive stage drought tolerance in rice, Panda *et al*., (2019) found five QTLs that control, in this order, spikelet fertility, harvest index, leaf rolling, leaf drying, and relative water content under reproductive stage drought stress. These QTLs are qLR9.1, qLD9.1, qHI9.1, qSF9.1, and qRWC9.1 (Panda *et al*. 2021)

Exploring Genes and Transgenic Strategies for Drought Tolerance in Rice

After the rice is exposed to drought stress, different genes are produced differently. About 5000 genes are turned up and 6000 are turned down (Todaka *et al*., 2015). There are three main groups of these genes: those that move molecules across membranes, send signals, or control how genes are made. Their expression controls most biochemical, physiological, and molecular processes in rice when it is stressed by drought. Most genes that are changed by drought are changed by ABA, both because of ABA and on their own. Also, some genes are linked to osmoregulation and late embryogenesis abundant (LEA) proteins, which give rice water shortage tolerance. Other genes, like OsPYL/RCAR5 and EcNAC67, stop rice leaves from rolling and cause more roots and shoots to grow when there isn't enough water. Guseman, Webb, *et al*. (2017) found that the gene DRO1 makes modified rice roots grow longer and go deeper. When drought stresses rice, excess OsDREB2B, CYP735A, and OsDREB1F also improves the roots' appearance. (Kim, Chung *et al*. 2020). Huang *et al*. (2018) found that rice has a DREB2-like gene called OsDRAP1, making the plant more drought-resistant. During droughts, it is important to increase the grain yield of rice. Transgenic methods are used to introduce certain genes, such as OsNAC5. Overexpressing OsDREB2A helps transgenic plants survive in situations of extreme drought and saltiness. (Cui, Zhang, *et al*. 2011). CDPK7 and CIPK03/CIPK12 control rice's several regulatory proteins, signaling networks, and protein kinases.

When drought stresses rice, OsITPK2 has lower amounts of inositol triphosphate and ROS homeostasis. The WRKY genes react to stress from drought and are essential for plant growth. Many genes have been tested using genetic techniques in a lab or glass house to see if they can make rice resistant to drought. (Oladosu, Rafii, *et al*., 2019) Because of this, these genes need to be tested in the field before they can be used in genetic breeding programs.

MicroRNA Contribution to Drought Stress Tolerance in Rice: MicroRNAs (miRNAs) are small non-coding regulatory RNAs that change gene expression in response to abiotic stress. Also, several miRNAs give rice drought resistance by altering gene expression (Yang, Liu, *et al*., 2022). Also, miR393 controls the transcriptional factors OsAUX1 and OsTIR1 to control tiller number increase, early flowering, and auxin hypersensitivity in rice (Liu, Wang, *et al*., 2017). Thirty miRNAs have been found in rice, of which eleven are down-regulated and eight are up-regulated in response to environmental stress. Increased stomatal closure and reduced stomatal density, controlled by ROS homeostatic genes and then by DST-a miRNA, make plants more resistant to drought. (Panda, Mishra, *et al*. 2021). Osa-miR169-3p and Osa-miR166e-3p control the over-expression of UDP-glucose-4-epimerase, which controls root growth, cell wall formation, and carbohydrate metabolism. It is possible to change the genes of these miRNAs to make the body more resistant to stress. MiRNAs control several processes that have to do with drought, suggesting that drought-resistant rice types could be bred. (Ahmad, Wang *et al*. 2022).

Breeding Strategies to Increase Drought Tolerance in Rice: Rice is natural genotypic diversity that can be studied to find new genotypes with desirable drought-tolerant traits and the genes/loci that are linked to them. Using marker-assisted selection, these new genotypes can be added to traditional breeding attempts to make rice varieties that survive drought. Before cultivars can be used in agriculture, breeding aims to make lines that produce more and are of better quality. Researchers have previously studied the breeding of drought-tolerant rice genotypes (Sandhu and Kumar, 2017). Over the past ten years, the International Rice Research Institute has used marker-assisted breeding techniques to create drought-resistant rice varieties (Dixit *et al*., 2020).

The leading rice cultivars have multiple QTLs for drought tolerance built into them using marker-assisted breeding techniques. In the past, scientists have looked into breeding drought-tolerant rice genotypes (Kumar, Dixit, *et al*., 2014), but the success rate has been much lower than expected. This is because it is hard to find donors with a high tolerance level, and the rice is also very sensitive to its surroundings. (González, Butković *et al*. 2020) . With the help of marker-assisted breeding, many QTLs that make rice more resistant to drought have been added to the best types. Drought has only become an important problem, and so far, no practical steps have been taken to make drought-tolerant rice varieties. Most high-yielding varieties, like Swarna, Samba-Mansuri, and IR36, which were once suggested for growing in fields with water, have been used in the drought breeding program. Because high-yielding varieties can't handle a lot of droughts, farmers lose a lot of rice when they plant these varieties in rain-fed areas with a lot of droughts. So, improved special rice varieties with high yields during drought and the ability to adjust to a wide range of unfavourable climate conditions in the future need more attention. (Wassmann, Jagadish, *et al*., 2009)

Perspective

It is hard to make rice more resistant to drought and to do so, you need to know a lot about its physical, biological, physiological, and molecular characteristics. Even though marker-assisted breeding has made a lot of progress, molecular breeding of rice for drought resistance still faces several big problems. Transgenic technologies must be used to improve rice's agronomic and output traits. This would also help with breeding for drought tolerance. It is important to know how these genes respond to drought in the field because several genes have been studied in the lab to see if they can make rice more resistant to drought. Even though many basic studies are being done, we still only know a little about how the whole plant responds to stress. So, we must determine how different cells, tissues, and systems respond to stress and make sense of the information. Crop breeding can use discoveries in crop physiology, molecular genetics, and breeding techniques to help us learn more about how plants deal with drought and help improve the genes of rice types so they can handle drought better. With this investigation's condensed knowledge, it will be easier to research the signalling mechanisms that make rice resistant to drought and to create genotypes with high yields.

Conflict of interest

The authors declared absence of conflict of interest.

References

Ahmad, H. M., Wang, X., Ijaz, M., Oranab, S., Ali, M. A., & Fiaz, S. (2022). Molecular aspects of microRNAs and phytohormonal signaling in response to drought stress: A Review. *Current Issues in Molecular Biology*, **44**(8), 3695-3710.

Andleeb, T., Shah, T., Nawaz, R., Munir, I., Munsif, F., & Jalal, A. (2020). QTL mapping for drought stress tolerance in plants. *Salt and Drought Stress Tolerance in Plants: Signaling Networks and Adaptive Mechanisms*, 383-403.

Anjum, S. A., Ashraf, U., Zohaib, A., Tanveer, M., Naeem, M., Ali, I., ... & Nazir, U. (2017). Growth and development responses of crop plants under drought stress: a review. *Zemdirbyste*, **104**(3), 267-276.

Anjum, S. A., Xie, X., Wang, L. C., Saleem, M. F., Man, C., & Lei, W. (2011). Morphological, physiological and biochemical responses of plants to drought stress. *African Journal of Agricultural Research*, ***6***(9), 2026-2032.

Bhandari, U., Gajurel, A., Khadka, B., Thapa, I., Chand, I., Bhatta, D., ... & Shrestha, J. (2023). Morpho-physiological and biochemical response of rice (Oryza sativa L.) to drought stress: A review. *Heliyon*.

Biswal, A. K., Shamim, M. D., Cruzado, K., Soriano, G., Ghatak, A., Toleco, M., & Vikram, P. (2017). Role of biotechnology in rice production. *Rice Production Worldwide*, 487-547.

Bot, A., & Benites, J. (2005). *The importance of soil organic matter: Key to drought-resistant soil and sustained food production* (No. 80). Food & Agriculture Org..

Chaudhry, S., & Sidhu, G. P. S. (2022). Climate change regulated abiotic stress mechanisms in plants: A comprehensive review. *Plant Cell Reports*, **41**(1), 1-31.

Chakraborti, M., Anilkumar, C., Verma, R. L., Abdul Fiyaz, R., Reshmi Raj, K. R., Patra, B. C., ... & Subba Rao, L. V. (2021). Rice breeding in India: eight decades of journey towards enhancing the genetic gain for yield, nutritional quality, and commodity value. *Oryza*. **58** (Special Issue) 2021 (69-88) DOI https://doi.org/10.35709/ory.2021.58.spl.2

Chaves, M. M., & Oliveira, M. M. (2004). Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *Journal of Experimental Botany*, ***55***(407), 2365-2384.

Cui, M., Zhang, W., Zhang, Q., Xu, Z., Zhu, Z., Duan, F., & Wu, R. (2011). Induced over-expression of the transcription factor OsDREB2A improves drought tolerance in rice. *Plant Physiology and Biochemistry*, **49**(12), 1384-1391.

Dixit, S., Singh, U. M., Singh, A. K., Alam, S., Venkateshwarlu, C., Nachimuthu, V. V., ... & Kumar, A. (2020). Marker assisted forward breeding to combine multiple biotic-abiotic stress resistance/tolerance in rice. *Rice*, *13*, 1-15.

Dornbos Jr, D. L., Mullen, R. E., & Shibles, R. E. (1989). Drought stress effects during seed fill on soybean seed germination and vigor. *Crop Science*, **29**(2), 476-480.

dos Santos, T. B., Ribas, A. F., de Souza, S. G. H., Budzinski, I. G. F., & Domingues, D. S. (2022). Physiological responses to drought, salinity, and heat stress in plants: a review. *Stresses*, **2**(1), 113-135.

El-Beltagi, H. S., Mohamed, H. I., & Sofy, M. R. (2020). Role of ascorbic acid, glutathione and proline applied as singly or in sequence combination in improving chickpea plant through physiological change and antioxidant defense under different levels of irrigation intervals. *Molecules*, **25**(7), 1702.

Foolad, M. R. (2007). Genome mapping and molecular breeding of tomato. *International journal of plant genomics*, *2007*.

Fu, Q. S., Yang, R. C., Wang, H. S., Zhao, B., Zhou, C. L., Ren, S. X., & Guo, Y. D. (2013). Leaf morphological and ultrastructural performance of eggplant (Solanum melongena L.) in response to water stress. *Photosynthetica*, **51**, 109-114.

Ge, T., Sui, F., Bai, L., Tong, C., & Sun, N. (2012). Effects of water stress on growth, biomass partitioning, and water-use efficiency in summer maize (Zea mays L.) throughout the growth cycle. *Acta Physiologiae Plantarum*, **34**, 1043-1053.

González, R., Butković, A., & Elena, S. F. (2020). From foes to friends: Viral infections expand the limits of host phenotypic plasticity. *Advances in Virus Research*, **106**, 85-121.

Guseman, J. M., Webb, K., Srinivasan, C., & Dardick, C. (2017). DRO 1 influences root system architecture in Arabidopsis and Prunus species. *The Plant Journal*, **89**(6), 1093-1105.

Handa, A. K., Gupta, A., & Kumar, R. (2019). Drought-tolerant rice: current progress and future prospects. *Frontiers in Plant Science*, ***10***, 990.

Hasan, M. M., Skalicky, M., Jahan, M. S., Hossain, M. N., Anwar, Z., Nie, Z. F., ... & Fang, X. W. (2021). Spermine: its emerging role in regulating drought stress responses in plants. *Cells*, **10**(2), 261.

Hasanuzzaman, M., Hossain, M. A., da Silva, J. A. T., & Fujita, M. (2012). Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. *Crop stress and its management: perspectives and strategies*, 261-315.

Huang, G. T., Ma, S. L., Bai, L. P., Zhang, L., Ma, H., Jia, P., ... & Guo, Z. F. (2012). Signal transduction during cold, salt, and drought stresses in plants. *Molecular Biology Reports*, **39**, 969-987.

Kim, Y., Chung, Y. S., Lee, E., Tripathi, P., Heo, S., & Kim, K. H. (2020). Root response to drought stress in rice (Oryza sativa L.). *International Journal of Molecular Sciences*, **21**(4), 1513.

Koyama, M. L., Levesley, A., Koebner, R. M., Flowers, T. J., & Yeo, A. R. (2001). Quantitative trait loci for component physiological traits determining salt tolerance in rice. *Plant Physiology*, **125**(1), 406-422.

Kumar, S., Sachdeva, S., Bhat, K. V., & Vats, S. (2018). Plant responses to drought stress: physiological, biochemical and molecular basis. *Biotic and Abiotic Stress Tolerance in Plants*, 1-25.

Li, F. L., Bao, W. K., & Wu, N. (2009). Effects of water stress on growth, dry matter allocation and water-use efficiency of a leguminous species, Sophora davidii. *Agroforestry Systems*, **77**, 193-201.

Liu, Y., Wang, K., Li, D., Yan, J., & Zhang, W. (2017). Enhanced cold tolerance and tillering in switchgrass (Panicum virgatum L.) by heterologous expression of Osa-miR393a. *Plant and Cell Physiology*, **58**(12), 2226-2240.

Maghsoudi, K., Emam, Y., & Pessarakli, M. (2016). Effect of silicon on photosynthetic gas exchange, photosynthetic pigments, cell membrane stability and relative water content of different wheat cultivars under drought stress conditions. *Journal of Plant Nutrition*, **39**(7), 1001-1015.

Marathe, A., Krishnan, V., Vinutha, T., Dahuja, A., Jolly, M., & Sachdev, A. (2018). Exploring the role of Inositol 1, 3, 4-trisphosphate 5/6 kinase-2 (GmITPK2) as a dehydration and salinity stress regulator in Glycine max (L.) Merr. through heterologous expression in E. coli. *Plant Physiology and Biochemistry*, **123**, 331-341.

McHugh, O. V., Steenhuis, T. S., Abebe, B., & Fernandes, E. C. (2007). Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. *Soil and Tillage Research*, **97**(1), 19-36.

Nguyen, H. T., Babu, R. C., & Blum, A. (1997). Breeding for drought resistance in rice: physiology and molecular genetics considerations. *Crop Science*, **37**(5), 1426-1434.

Oladosu, Y., Rafii, M. Y., Samuel, C., Fatai, A., Magaji, U., Kareem, I., ... & Kolapo, K. (2019). Drought resistance in rice from conventional to molecular breeding: a review. *International journal of molecular Sciences*, ***20***(14), 3519.

Panda, D., Mishra, S. S., & Behera, P. K. (2021). Drought tolerance in rice: focus on recent mechanisms and approaches. *Rice Science*, **28**(2), 119-132.

Ramakrishna, A., Tam, H. M., Wani, S. P., & Long, T. D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Research*, **95**(2-3), 115-125.

Reynolds, M. P., Quilligan, E., Aggarwal, P. K., Bansal, K. C., Cavalieri, A. J., Chapman, S. C., ... & Yadav, O. P. (2016). An integrated approach to maintaining cereal productivity under climate change. *Global Food Security*, **8**, 9-18.

Richards, R. A., Rebetzke, G. J., Condon, A. G., & Van Herwaarden, A. (2002). Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Science*, **42**(1), 111-121.

Roy, P. R., Tahjib-Ul-Arif, M., Akter, T., Ray, S. R., & Sayed, M. A. (2016). Exogenous ascorbic acid and hydrogen peroxide alleviates salt-induced oxidative stress in rice (Oryza sativa L.) by enhancing antioxidant enzyme activities and proline content. *Advances in Environmental Biology*, **10**(10), 148-155.

Sahoo, J. P., Mishra, P., Mishra, A. P., Panda, K. K., & Samal, K. C. (2022). Physiological, biochemical, and molecular responses of rice (Oryza sativa L.) towards elevated ozone tolerance. *Cereal Research Communications*, 1-10.

Salehi-Lisar, S. Y., & Bakhshayeshan-Agdam, H. (2016). Drought stress in plants: causes, consequences, and tolerance. *Drought Stress Tolerance in Plants, Vol* **1***: Physiology and Biochemistry*, 1-16.

Sandhu, N., & Kumar, A. (2017). Bridging the rice yield gaps under drought: QTLs, genes, and their use in breeding programs. *Agronomy*, **7**(2), 27.

Sen, S. (2018). Many Faces of Resource Management: Blueprint for Sustainable Conservation.

Sharma, P., Jha, A. B., Dubey, R. S., & Pessarakli, M. (2012). Reactive oxygen species, oxidative damage, and antioxidative defense mechanism in plants under stressful conditions. *Journal of Botany*, *2012*.

Sheffield, J., & Wood, E. F. (2008). Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. *Climate dynamics*, **31**, 79-105.

Singh, M., & Sood, S. (Eds.). (2020). *Millets and pseudo cereals: genetic resources and breeding advancements*. Woodhead Publishing.

Singh, R., Singh, Y., Xalaxo, S., Verulkar, S., Yadav, N., Singh, S., ... & Singh, N. K. (2016). 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**, 278-287.

Theodosis, D. T., Poulain, D. A., & Oliet, S. H. (2008). Activity-dependent structural and functional plasticity of astrocyte-neuron interactions. *Physiological Reviews*, **88**(3), 983-1008.

Todaka, D., Shinozaki, K., & Yamaguchi-Shinozaki, K. (2015). Recent advances in the dissection of drought-stress regulatory networks and strategies for development of drought-tolerant transgenic rice plants. *Frontiers in Plant Science*, **6**, 84.

Upadhyaya, H. D., Gowda, C. L. L., Buhariwalla, H. K., & Crouch, J. H. (2006). Efficient use of crop germplasm resources: identifying useful germplasm for crop improvement through core and mini-core collections and molecular marker approaches. *Plant Genetic Resources*, **4**(1), 25-35.

Wassmann, R., Jagadish, S. V. K., Heuer, S., Ismail, A., Redona, E., Serraj, R., ... & Sumfleth, K. (2009). Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. *Advances in Agronomy*, **101**, 59-122.

Xu, Z., Zhou, G., & Shimizu, H. (2010). Plant responses to drought and rewatering. *Plant Signaling & Behavior*, **5**(6), 649-654.

Yadav, S., Modi, P., Dave, A., Vijapura, A., Patel, D., & Patel, M. (2020). Effect of abiotic stress on crops. *Sustainable crop production*, **3**.

Yang, X., Liu, C., Niu, X., Wang, L., Li, L., Yuan, Q., & Pei, X. (2022). Research on lncRNA related to drought resistance of Shanlan upland rice. *BMC Genomics*, **23**(1), 336.

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