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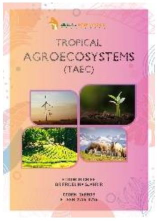

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REVIEW ARTICLE

EFFECT OF DROUGHT ON MORPHOPHYSIOLOGICAL TRAITS OF RICE: A REVIEW

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ABSTRACT

Drought is the condition of prolonged paucity in the water supply, whether atmospheric, surface water, or groundwater. This significant abiotic stress is a severe limiting factor of plant growth and rice productivity, adversely affecting the economic rice production globally. Drought stress has a considerable effect on the rice plant's morphological and physiological traits preventing it from reaching the maximum yield. Morphological alteration in rice includes inhibition of seed germination, reduced tillers, early maturity, reduced biomass while physiological changes involve restricted cell division and elongation, stomatal closure, loss of turgor adjustment, lower photosynthesis, slower growth rate, yield reduction, etc. The stress further brings about a biochemical change by accumulating stress metabolites, increasing Reactive Oxygen Species (ROS) accumulations, increasing antioxidative enzymes and, Abscisic acid (ABA) accumulation. Various mitigation measures are applied to adhere to the effect of drought on rice plants by selecting drought-tolerant cultivars, planting early varieties, sufficient moisture maintenance, conventional breeding, molecular maintenance, and development of varieties with high yielding attributes. Thus, this review aims to assess the complex responses of rice plants to drought in morpho-physiological characters of rice along with its mitigation strategies in adoption to drought stress.

KEYWORDS

Drought, Morphological traits, Physiological traits, Rice.

1. INTRODUCTION

Rice grown worldwide over 165 million ha with 750 million tons (MT) is the indispensable part of agriculture (IRRI, 2019). About 90 percent of the global consumers and producers of rice are concentrated in South Asia (Segal et al., 2019). In context of Nepal, being an agricultural country; rice holds the first rank among cereal crops in the area, production, and livelihood (MOALD, 2020). It has been grown on about 1.49 million ha with a production of 5.61 million tons (MOALD, 2020), accounting for about 20.75% of the total Agricultural GDP of Nepal (CBS, 2019). Rice is the most important staple crop in Nepal, providing nearly 40% of the food calorie intake and 50 percent of the total calories supplement of Nepalese people (Kharel et al., 2018). The production and cultivation of rice rely on the land types, upland and low land, and two water regimes, irrigated and rainfed. Also, the production is highly dependent on the climatic condition accounted by the climate change and has been regarded as the global burning issue. The timely onset of monsoon is significant as the transplanting of rice seedlings depends upon the arrival of monsoon rain. Similarly, rice is transplanted with the monsoon rain in rainfed areas and is harvested from September to November. As a semi-aquatic plant, rice requires a sufficient amount of water. But still, drought, a climatically induced phenomenon that accumulates slowly over a considerable time, has been a problem to about 50 percent of the cultivated rice areas in the world and Nepal.

The figure 1 indicates the fluctuation in the production of rice over the past 6 decades which has been caused by various abiotic and biotic factors. The various abiotic factors (drought, flood, high temperature, and salinity) are serious threats to world food security and have been noted to cause as high as a 70% yield reduction in crop production (Thakur et al., 2010). Among these abiotic factors, drought is the most disruptive, and destructive event of ongoing climate change and occurring mainly in the rainfed ecosystem affecting plants at various levels and stages of their life (Nahar et al., 2016). Generally, the drought is defined on the basis of three parameters i.e., based on meteorological, hydrological and agricultural perspectives (Pandey et. al., 2006). The drought results in depletion of the farmers' productive yield. It has also been recognized as the primary hindrance to rainfed rice production, affecting the crop in its morpho-physio attributes (Ndjiondjop et al., 2018). So proper irrigation is the prerequisite of rice production and for developing countries in Asia, over 80% of freshwater is used for irrigational purpose (IRRI, 2012). In order to produce 1 kg of rice grain currently, about 1900 to 5000 liters of water is required and it is also speculated that, by 2025 almost 10% of irrigated rice will face water scarcity (Tuong et al., 2005).

The plants show different morphological, physiological, and molecular responses under drought stress conditions. Morphologically, reduction in germination, leaf size, leaf numbers, biomass, cell growth, and elongations can be seen in the plants exposed to water stress. Another visible morphological alteration involves leaf rolling, stomata closure, leaf tip drying, and root length reduction (Dash et al., 2018). Similarly, the physiological responses involve a reduction in transpiration, photosynthesis, chlorophyll content, membrane stability, stomatal conductance, photosystem-II activity, and increment in osmo-protectants (Singh, 1993). It indicate that all symptoms and signs lead to the reduction in tillering, the rate in grain filling, delayed flowering, and spikelet fertility,

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resulting in decreased number and size of panicles and grain size and weight, the ultimate reduction in the gram yield (Vibhuti et al., 2015). In this context, this review aims to assess the complex responses of rice plants to drought in morpho-physiological characters of rice along with its mitigation strategies in adoption to drought stress.

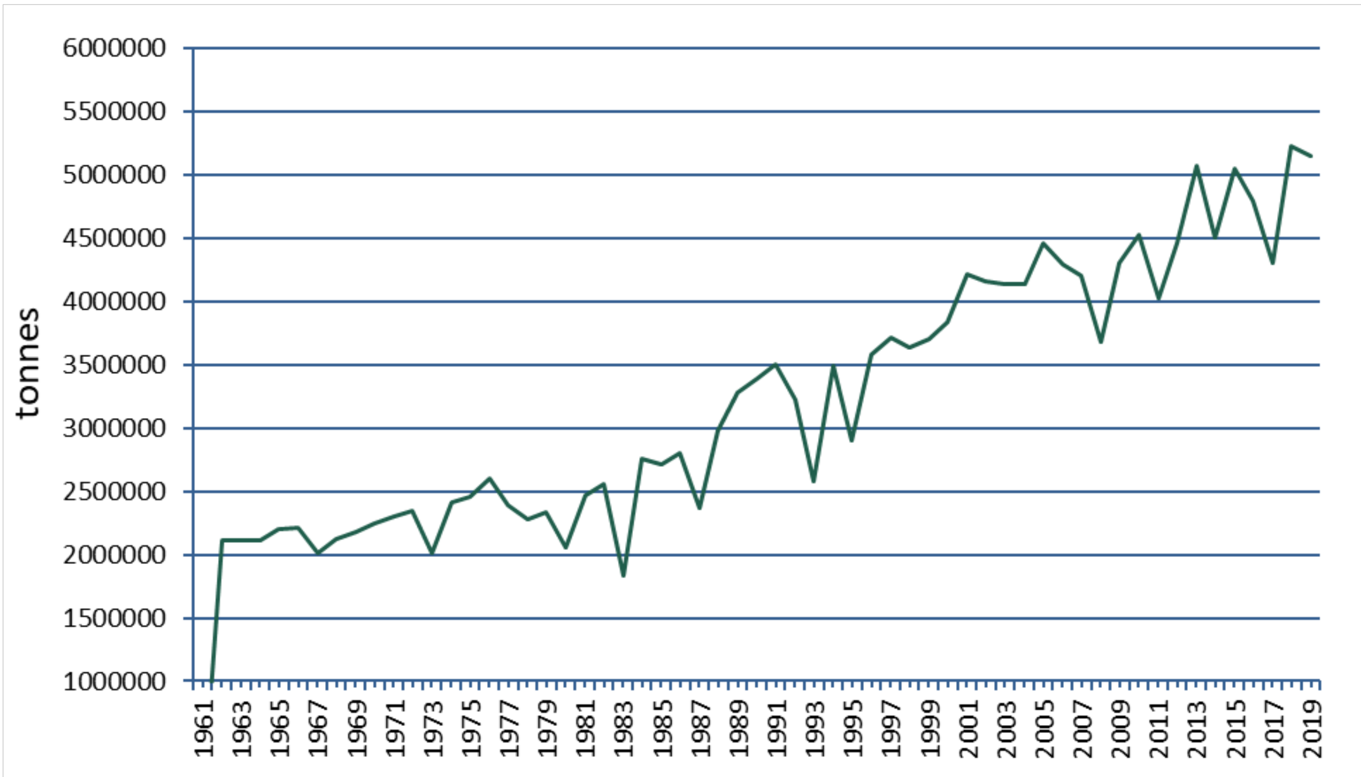

Figure 1: Rice production quantity with reference to time in Nepal. (Source: www.knoema.com/Nepal/Rice-paddyproductionquantity)

2. Literature Review

2.1 Effect on the Morphological Traits

Drought stress has deleterious effects on the overall morphology of the rice plants. This effect ranges from root to the grains and finally the overall yield and biomass of the rice plant. The initial impact of drought stress is inhibiting the growth of rice plants affecting the elongation and expansion of cellular growth (Anjum et al., 2003; Kusaka et al., 2005). Resulting in poor germination and negative impact on seedling development (Kaya et al., 2006; Faroque et al., 2009). Severe reduction in germination and seedling growth is observed under drought stress due to the scarcity of water (Vibhuti et al., 2015). Hindrance in the plant growth and development includes the improper development or the reduction in germination potential, root and shoot dry weight early seedling growth, root length, and vegetative growth. The limiting water condition results in the low or inadequate flow of water on the xylem or nearing cell, ensuring impaired cellular elongation. The morphological changes out-turned by the stress can be seen in root length, leaf size, plant height, stem girth, and biomass.

A timely and optimal germination is the major part for better crop productivity. The drought stress not only affects the germination but also growth reduction of the plant. Rice is extremely sensitive to drought conditions during the germination and early seedling growth stage. In drought condition, the seedling cannot uptake water from soil which results in the reduction of strength of seedling (Vibhuti et al., 2015). Furthermore, drought stress causes water imbalance, impairment of membrane transport, decreases ATP production that finally causes poor seed germination (Sarvestani et al., 2008).

Root characteristics of the plants are the vital attribute for enhancing production under drought stress. Drought stress has a severe impact on the root dry matter. On an average, root dry matter decreases by 5% for vegetative stage drought and similar response was observed at the time of flowering or after flowering (Kim et al., 2020). In case of drought stress, the root length of rice is found to increase due to increment in the abscisic acid concentration in roots (Manivannan et al., 2007). On the contrary, some research found decrement in the root length due to the drought stress. This disparity in the literatures is seen due to differentiation on the crop genotypes, and period and intensity of stress (Kim et al., 2020).

Water deficiency results in the reduction of leaf growth due to limited water potential in drought condition (Sarvestani et al., 2008). Disrupted flow of water towards another cell from xylem, including lower turgor pressure caused by the water deficit responds in form of poor cell development and diminished leaf area in rice (Hussain et al., 2018). The changes in the leaf anatomy and its ultrastructure due to drought include shrinkage of leaf size, reduction in number of stomata, bulky cell wall, cutinisation on leaf surface and poor development of conducting system (Panda et al., 2021). Rolling of leaf and initiation of early senescence are other major characteristics seen under drought stress (Sarvestani et al., 2008).

According to recent study, rice showed a 25.4% yield reduction despite the variations in the response observed in their different studies (Zhang et al., 2018). The total number of filled grain panicle was adversely affected when drought was imposed at the time of flowering (Panda et al., 2021). Though the drought results in the decrement of agronomic traits, the biomass and yield show the most significant decrement. Thus, it is clear that the drought has severe impact on various morphological characteristics of the rice plant including the yield.

2.2 Effect on the Physiological Traits

Drought stress is characterized by reduced water content, diminished leaf water potential, turgor pressure, stomatal activity, and decreased cell enlargement and growth. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, stunted growth, etc.

Drought stress limits crop from achieving threshold yield or maximum yield altering the physiological process of rice. Physiological characters namely diffusive resistance of stomata, closing and opening of stomata, stomata osmotic adjustment, leaf rolling, leaf water retention, and leaf senescence, are associated with drought susceptibility (Singh et al., 1993). Drought stress results in stomata closure which minimizes gaseous exchange. The reduction in soil moisture may have led to lower water content in the leaves, causing guard cells to lose turgor pressure, and hence the size of stomatal pores is reduced (Tezera et al., 2002). Stomata closure decreases the CO2 influx and thereby, leads to the reduction in photosynthetic activity ultimately reducing the metabolic activity in the plant (Haso et al., 1973).

The reduction in moisture causes the leaf of plant of rice to roll frequently and thus the transpiration rate is sharply decreased. This leaf rolling character and death of leaves can be excellent criteria's for determining the level of drought tolerance too (Chang et al., 1974). Various other effects such as disruption of enzyme-catalyzed reactions, reduction in cell enlargement, ion uptake, respiration, formation of growth promoters, source-sink relationship, nutrient metabolism, etc. are affected adversely by the drought stress in the rice plant (Oladosu et al., 2019).

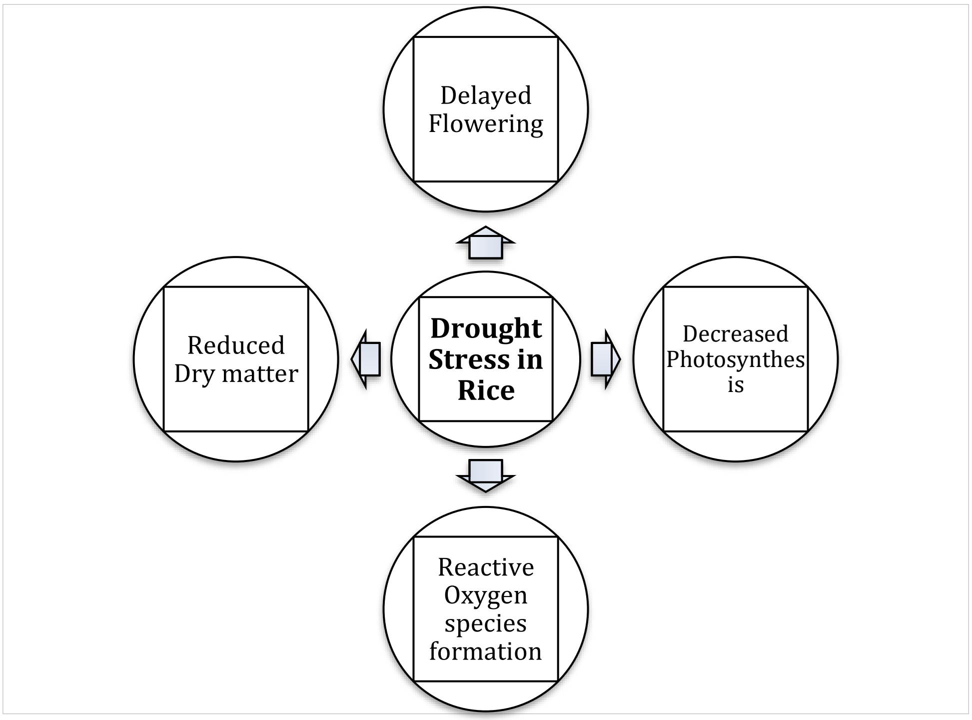

Figure 2: Diagrammatic sketch showing physiological effect of drought in rice.

2.3 Biochemical Responses

Drought stress leads to the accumulation of reactive oxygen species (ROS), generated mostly in chloroplast and to some extend in mitochondria, causing oxidative stress. Major ROS molecules are singlet oxygen, superoxide anion radicals, hydroxyl radicals, and hydrogen peroxide (H2O2) (Lum et al.,2014).

Plants under drought stress display some defense mechanisms to protect themselves from the damaging effect of oxidative stress. Plants with high induced antioxidant levels have better tolerance and resistance to oxidative damage (Parida and Das, 2005). The ROS scavenging mechanism is among the common defense responses against abiotic stresses (Vranova et al., 2002). To detoxify ROS, plants can intrinsically develop different antioxidants, reducing oxidative damage and conferring drought tolerance. The ROS scavengers are antioxidant enzymes containing superoxide dismutase, peroxidase, and catalase. In drought tolerance varieties of rice, the activity of antioxidant enzymes is increased markedly during drought stress. It leads to a marked difference in the accumulation of proline in those varieties. The proline accumulated in plants under water stress can protect the cell by balancing the osmotic potential of cytosol with vacuole and the external environment (Pireivatloum et al., 2010). Thus, to conclude that antioxidant enzymes and proline accumulation activities are associated with dry mass production and the drought tolerance of the upland or drought-resistant varieties. In higher plants, tolerance to drought stress correlates to antioxidant systems and substrates (Athar et al., 2008). Various other biochemical responses such as reduced rubisco efficiency, decrease in photochemical efficiency, Abscisic Acid (ABA) accumulation, proline and polyamines accumulations occurs in rice plant (Oladosu et al., 2019). In order to combat the effects of drought-induced oxidative stress, plants develop a complex mechanism of the antioxidant system. This helps in the drought resistance and tolerance of rice.

2.4 The Growth Stages of Rice in Response to Drought

The different rice varieties have different drought resistance. Keeping this fact aside, the yield attributes of rice production directly depend upon drought and its severeness. The stress can be seen in different growth stages of crop production depending upon the crop's sensitivity and variety. For instance, the yield loss seen during the vegetative stage of crop development is about 21-50.6%, whereas the flowering stage, during the severe drought, bears the reduction in the yield by 42–83.7% (Guan et al., 2010).

Drought stress during the vegetative stage is less important than the reproductive and flowering stage (Fathi and Tari, 2016). Leaf development, stem development and, photosynthesis is of great importance during the vegetative stage impacting the plant and its overall development (Kabiri et al., 2010). According to the study (Lum et al., 2014), rice was seen more sensitive to drought during the reproductive phases, i.e., blooming stage, filling stage, or maturity, than the vegetative phases, including the tillering stage, jointing stage, etc. Also, the yield could be drastically reduced to 60% when the flowering stage encounters drought (Boonjung and Fukai., 1996). This reduction in the flowering stage is because of the crop's nature to hardly recover from the damage suffered. In contrast, the vegetative phase suffers from the limitation of carbohydrate synthesis for cell division and expansion through the stomatal closure, which partially inhibits the photosynthesis and is considered reparable (Barnabás et al., 2008).

The first and foremost effect of drought in the vegetative stage is the impairment of the plant, and poor seed germination and seedling stand, slimming down the opportunity for proper development and growth of the plant. And at the booting, flowering, and grain filling stage, the plant height is significantly affected under about 20% of soil saturation (Islam et al., 1994). This effect might be either due to inhibition of the length of cells or cell division. A study reported that the stress due to drought resulted in a reduction in the tiller number during vegetative stages. In contrast, during the reproductive and grain filling stage, the stress caused decreased grain number and weight (Rahman et al., 2002). Thus, a devastating effect of drought occurs on rice with according to their various growth stages.

2.5 Mitigation Strategies for Drought Stress

Rice being a water-loving semi-aquatic plant, several morphological, physiological, and biochemical pathways are intensively affected by drought. The most prominent metabolic pathways hindered are photosynthesis and carbon metabolism alongside antioxidant defense mechanisms, which play significant roles under drought stress in rice.

Some of the effective strategies used to cope stress are drought tolerance, drought escape and drought resistance, and genetic engineering (Kumar et al., 2017).

Drought tolerance is the complex mechanism of the plants to survive under the minimum level of moisture content in the cytoplasm, i.e., when the water content constitutes ~23% or ~0.3 g of the fresh and dry tissue, respectively (Sahebi et al., 2018). It is also reported to be controlled by polygenes and their expressions and is influenced by various genetic and environmental factors and their interactions (Pereira et al., 2017). The multiple mechanisms of drought tolerance are morphological adaptations, physiological acclimation, and cellular adjustments controlled by genetic factors. The morphological adaptations include thick and lengthy roots, decreased leaf weight and size, reduced epithelial cells. Physiological acclimation consists of higher stomatal density; photosynthesis; change in internal CO2 concentration; internal integrity; water-use efficiency; source to sink reserve mobilization (Pereira et al., 2017); decrement in transpiration rates; reduced and early asynchrony between female and male flowering; and better production, accumulation, and seed and biomass yield partitioning. Cellular adjustments entail increased chlorophyll content, particle numbers, harvest index, and lower osmotic potential (Sahebi et al., 2018). In addition to that, the biochemical responses that help regulate signal transduction and gene expression involve activation of stress metabolites, reduction of antioxidative enzymes, reduction in ROS, polyamines, and osmotic regulation (Pereira et al., 2017).

A lot of variety for drought tolerance of crop species is directly and indirectly improved through two main approaches of Genomics-assisted breeding, i.e., marker-assisted selection (MAS) and genomic selection (GS). Also, identifying donors, mapping, QTLs using marker aided breeding can help develop the crop tolerant varieties. (Khan et al., 2016). Breeding techniques, molecular genetics, genomics, bioinformatics, and low-cost phenotyping programs for drought resistance are now giving the complete spectrum of generating drought-tolerant cultivars with high yielding qualities.

Drought escape is a process that occurs when a plant completes its life cycle before it develops severe soil water shortages. This process is achieved through rapid phenological development and developmental plasticity, and early maturing varieties to escape the drought period. In rapid phenological development, plants can produce flowering plants with minimum vegetative growth, producing seeds on a limited water source. In contrast, developmental plasticity allows plants to create an abundance of seed and vegetative growth in their seasons of abundant rain. This enables desert ephemerals to survive and escape drought (Kumar et al., 2008).

Similarly, drought avoidance refers to the ability of plants to maintain a high-water level even though they do not have enough soil moisture. This avoidance is achieved by either increasing the amount of soil water or reducing the water loss. To increase high water demand during extensive evaporation and growing soil water deficit, the two main options are reducing water loss or maintaining water supply (Pereira et al., 2017). It is also reported as one of the drought resistance mechanisms (Singh et al., 2017).

Another dominant and essential strategy to overcome drought stress includes genetic engineering and breeding strategies. Improving drought resistance by conventional breeding strategies is crucial (Singh et al., 2017). Drought-tolerant rice varieties have a better yield than the presently available cultivars across different locations, environments, seasons, and situations. Developing an improved breeding population helps exploit genetic diversity to identify specific donors and recipients with unique characteristics adaptable to a particular or diverse environment (Pang et al., 2017). The improved varieties involve multiple tolerance donor parents in the background of high-yielding modern improved cultivars to get new combinations of genes with high heritability and performance across variable growing environmental conditions (Capell et al., 2014). Some suitable drought-tolerant donors, PSBRc80, PSBRc68, PSBRc82, Dagaddeshi, Aday Sel, Aus 276, Kali Aus, Kalia, Apo, N22, and Dular IR77298-14-1-2, have been identified at the International Rice Research Institute (IRRI) and used in various complex conventional and marker-assisted breeding programs to improve grain yield under drought condition. For the development of drought-resistant rice varieties to perform or overcome drought stress, the most effective breeding method, heterosis breeding, can help increase yield and associate traits regulating the proper root development as a drought-tolerant variety.

Likewise, other measures involve partial root-zone drying (PRD), which can maintain the water stress in the field (Cheruth et al., 2003). This is a wetting and drying technique, where half of the root system is dry while the other half is irrigated. And the treatment reversed, allowing the previously well-watered side of the root system to dry down while thoroughly irrigating the once dry side—also, proper management for overcoming the drought period to maintain the root traits for good crop performances.

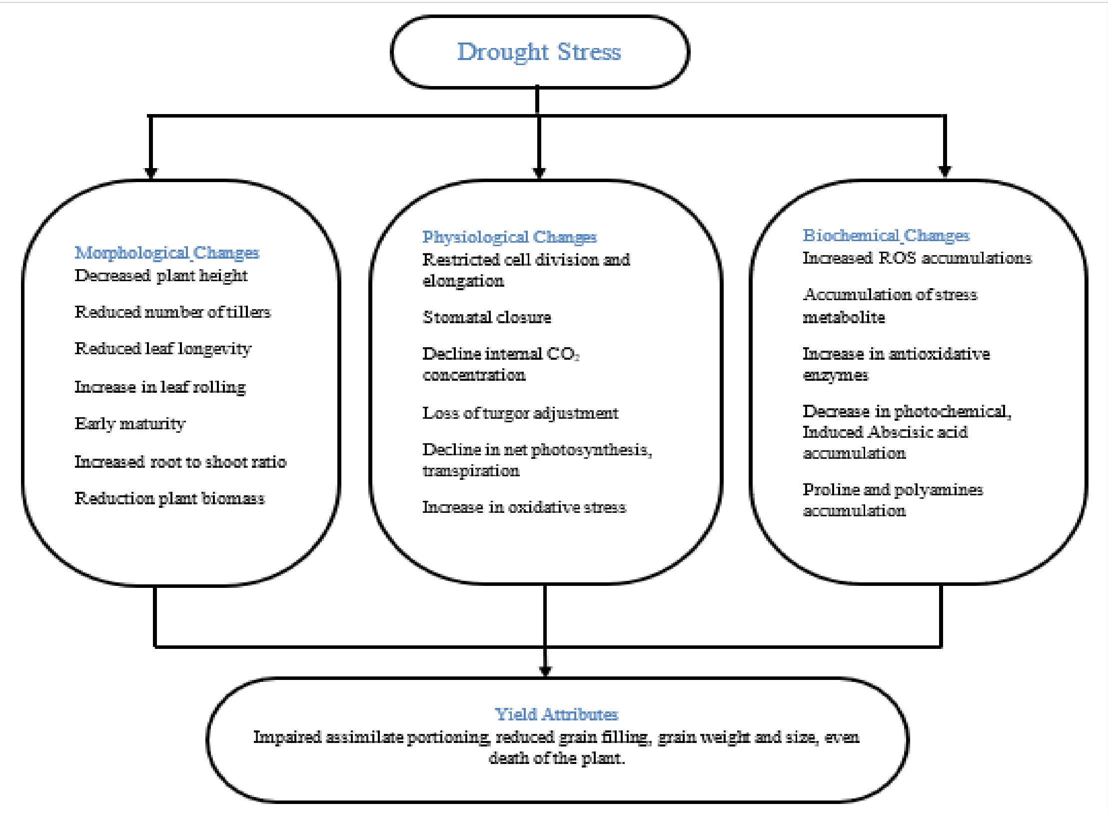

Figure 3: Various Changes brought up by drought on Rice plant (Oladosu et al., 2019).

Table 1: Summarizing the reduction in the rice yield countered during different stages as per various reference

Growth Stages	Level of Severeness	Yield Reduction (%)	References
Vegetative Stage	Severe	50.6	Guan et al., 2010
Vegetative Stage	Moderate	21	Sarvestani et al., 2008
Flowering Stage	Severe	76.7-83.7	Puteh et al., 2013
Flowering Stage	Severe	>70	Shamsuddin et al., 2016
Flowering Stage	Moderate	50	Sarvestani et al., 2008
Reproductive Stage	Severe	63.1	Dixit et al., 2012
Reproductive Stage	Severe	70	Dixit et al., 2012
Reproductive Stage	Moderate	90.6	Dixit et al., 2012
Reproductive Stage	Moderate	51	Swamy et al., 2017
Reproductive Stage	Severe	60	Swamy et al., 2017

2.6 Drought Tolerant Genotypes

Some promising drought-resistant proven varieties of rice which are suitable for the Nepalese environment and topography are IR 83376-B-B-7-1, IR 877761-52-1-2-2, IR 95840-33-3-2-1, IR 82608-B-B-33-2 (Gahatraj et al., 2018).

3. Conclusion and Future Perspective

Drought being one of the primary factors hindering normal function and production is a recurring event that majorly affects the rice's morpho-physio traits. Thus, it becomes mandatory to apply possible mitigation measures to uplift the people's economic standard and raise their social status. Selection of drought-tolerant cultivars, planting of early varieties, and maintaining sufficient moisture on the field seems to be the short-term mitigation strategies. In contrast, various breeding researches are carried out globally, paving pathways for utter change in the farmer fields. Identifying donors, mapping, and using marker-aided breeding of the QTLs and genes affecting performance under stress conditions, conventional breeding, molecular genetics, genomics, bioinformatics, and low-cost phenotyping programs for drought resistance are now providing the full scope of developing drought-tolerant varieties with high yielding attributes. Therefore, special effort is needed to conceptualize, design, and manage phenotyping programs for drought resistance to maximize the chances of identifying donors, QTLs, and breeding lines that will help improve drought resistance in the target environment. Also, a single trait cannot confer drought resistance alone; therefore, the breeding program for drought resistance must consider the aim of pyramiding several relevant traits in a crop. Hence, the consolidation of these innovations and strategies will provide a strong base for fulfilling the obligatory needs of the present farmers and helping to meet the future call of the farmers in drought-prone areas.

References

Barnabás, B., Jäger, K., and Fehér, A., 2008. The effect of drought and heat stress on reproductive processes in cereals. Plant, Cell and Environment, 31 (1), 11–38. https://doi.org/10.1111/J.1365-3040.2007.01727.X

Capell T, Bassie L, Christou P., 2004. Modulation of the polyamine biosynthetic pathway in transgenic rice confers tolerance to drought stress. Proc Natl Acad Sci U S A. 2004 Jun 29;101(26):9909-14. doi: 10.1073/pnas.0306974101. Epub 2004 Jun 14. PMID: 15197268; PMCID: PMC470772.

Chaves M M, Maroco J P, Pereira J S., 2003. Understanding plant responses to drought - from genes to the whole plant. Funct Plant Biol. 2003 Mar; 30 (3), 239-264. doi: 10.1071/FP02076. PMID: 32689007.

Chourasia, K.N., 2017. Resistance/Tolerance mechanism under water deficit (Drought) condition in plants. Int. J. Curr. Microbiol. App. Sci., 6, 66–78.

Dixit S., Singh A., Ma T.S.C., Maturan P.T., Amante M., Kumar A., 2014. Multiple major QTL lead to stable yield performance of rice cultivars across varying drought intensities. BMC Genet. https://bmcgenomdata.biomedcentral.com/articles/10.1186/1471-2156-15-1

Dixit, S., Singh, A., Kumar, A., 2014. Rice Breeding for High Grain Yield under Drought: A Strategic Solution to a Complex Problem. International Journal of Agronomy. 2014. 10.1155/2014/863683.

FAOSTAT. (n.d.). Retrieved June 26, 2021, from http://www.fao.org/faostat/en/#data/QC

Fathi, A., Tari, D. B., 2016. Life Sciences. 10 (1), 1–6.

Gahatraj, S., Jha, R. K., and Singh, O. P., 2018. Impacts of climate change on rice production and strategies for adaptation in Chitwan, Nepal. Journal of Agriculture and Natural Resources, 1 (1), 114–121. https://doi.org/10.3126/JANR.V1I1.22226

Gosal, S.S., Wani, S.H., Kang, M.S., 2009. Biotechnology and drought tolerance. J. Crop Improv. 23, 19–54.

Guan Y.S., Serraj R., Liu S.H., Xu J.L., Ali J., Wang W.S., Venus E., Zhu L.H., Li Z.K., 2010. Simultaneously improving yield under drought stress and non-stress conditions: A case study of rice (Oryza sativa L.) https://academic.oup.com/jxb/article/61/15/4145/426959 https://www.researchgate.net/publication/253008137_Drought_Stress_in_Plants_A_Review_on_Morphological_Characteristics_and_Pigments_Composition

Hu, H.; Xiong, L., 2014. Genetic engineering and breeding of drought-resistant crops. Annu. Rev. Plant Biol., 65, 715–741.

Hussain, H. A., Hussain, S., Khaliq, A., Ashraf, U., Anjum, S. A., Men, S., and Wang, L., 2018. Chilling and Drought Stresses in Crop Plants: Implications, Cross Talk, and Potential Management Opportunities. Frontiers in Plant Science, 0, 393. https://doi.org/10.3389/FPLS.2018.00393

Islam, M.T., M.A. Salam and M. Kauser, 1994. Effect of soil water stress at different growth stages of rice on yield components and yield. https://scialert.net/fulltext/?doi=pjbs.2002.169.172andorg=11Mitigation of plant drought stress in a changing climate. https://www.researchgate.net/publication/267029782_Mitigation_of_plant_dro ught_stress_in_a_changing_climate

Jaleel, C., Manivannan, P., Wahid, A., Farooq, M., Al-Juburi, H., Somasundaram, R., Panneerselvam, R., 2009. Drought Stress in Plants: A Review on Morphological Characteristics and Pigments Composition. International Journal of Agriculture and Biology. 11 (1).

Joshi, N., Maharjan, K., Piya, L., 2011. Production Economics of Rice in Different Development Regions of Nepal. Journal of International Development and Cooperation. 17. 103-112.

Khan, A., Sovero, V., and Gemenet, D., 2016. Bentham Science Send Orders for Reprints to reprints@benthamscience.ae Genome-assisted Breeding For Drought Resistance. Current Genomics, 17, 330–342.

Kim, Y., Chung, Y. S., Lee, E., Tripathi, P., Heo, S., and Kim, K.-H., 2020. Root Response to Drought Stress in Rice (Oryza sativa L.). International Journal of Molecular Sciences 2020, Vol. 21, Page 1513, 21(4), 1513. https://doi.org/10.3390/IJMS21041513

Li, T., Angeles, O., Radanielson, A., Marcaida, M., and Manalo, E., 2015. Drought stress impacts of climate change on rainfed rice in South Asia. Climatic Change, 133 (4), 709–720. https://doi.org/10.1007/s10584-015-1487-y

Liang, X., Zhang, L., Natarajan, S.K., Becker, D.F., 2013. Proline mechanisms of stress survival. Antioxid. Redox Signal, 19, 998–1011.

Lum, M. S., Hanafi, M. M., Rafii, Y. M., Akmar, A. S. N., 2014. Effect of drought stress on growth, proline and antioxidant enzyme activities of upland rice. Journal of Animal and Plant Sciences, 24 (5), 1487–1493.

Manivannan, P., Jaleel, C. A., Sankar, B., Kishorekumar, A., Somasundaram, R., Lakshmanan, G. M. A., and Panneerselvam, R., 2007. Growth, biochemical modifications and proline metabolism in Helianthus annuus L. as induced by drought stress. Colloids and Surfaces B: Biointerfaces, 59 (2), 141–149. https://doi.org/10.1016/J.COLSURFB.2007.05.002

Nahar, S., Kalita, J., Sahoo, L., and Tanti, B., 2016. Morphophysiological and molecular effects of drought stress in rice. Annals of Plant Sciences, 5 (09), 1409. https://doi.org/10.21746/APS.2016.09.001

Nayava, Janak. 2017. Monsoonal rainfall and its impact on rice production in Nepal.

Ndjiondjop, M. N., Wambugu, P. W., Sangare, J. R., and Gnikoua, K., 2018. The effects of drought on rice cultivation in sub-Saharan Africa and its mitigation: A review. African Journal of Agricultural Research, 13 (25), 1257–1271. https://doi.org/10.5897 /AJAR2018.12974

Nezhadahmadi, A.; Prodhan, Z.H.; Faruq, G., 2013. Drought tolerance in wheat. Sci. World J.

Nirmal G., Jiban S., Bhanu P., Mina N.P., 2019. A review on production status and growing environments of rice in Nepal and in the world. Archives of Agriculture and Environmental Science. 4. 83-87. 10.26832/24566632.2019.0401013.

Oladosu, Y., Rafii, M. Y., Samuel, C., Fatai, A., Magaji, U., Kareem, I., Kamarudin, Z. S., Muhammad, I., and Kolapo, K., 2019. Drought Resistance in Rice from Conventional to Molecular Breeding: A Review. International Journal of Molecular Sciences, 20 (14). https://doi.org/10.3390/ijms20143519

Panda, D., Mishra, S. S., and Behera, P. K., 2021. Drought Tolerance in Rice: Focus on Recent Mechanisms and Approaches. Rice Science, 28 (2), 119–132. https://doi.org/10.1016 /J.RSCI.2021.01.002

Pang, Y., Chen, K., Wang, X., Xu, J., Ali, J., Li, Z., 2017. Recurrent selection breeding by dominant male sterility for multiple abiotic stresses tolerant rice cultivars. Euphytica, 213, 268.

Rahman, M. T., Islam, M. T., and Islam, M. O., 2002. Effect of Water Stress at Different Growth Stages on Yield and Yield Contributing Characters of Transplanted Aman Rice. Pakistan Journal of Biological Sciences, 5 (2), 169–172. https://doi.org/10.3923/PJBS.2002.169.172

Rasheed, A., Hassan, M. U., Aamer, M., Batool, M., Fang, S., Wu, Z., And Li, H., 2020. A critical review on the improvement of drought stress tolerance in rice (Oryza sativa L.). Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 48 (4), 1756–1788. https://doi.org/10.15835/NBHA48412128

Rasheed, A., Hassan, M., Aamer, M., Batool, M., Fang, S., Wu, Z., Li, H., 2020. A critical review on the improvement of drought stress tolerance in rice (Oryza sativa L.). Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 48. 1756-1788. 10.15835/nbha48412128.

Sahebi, M., Hanafi, M.M., Rafii, M.Y., Mahmud, T.M.M., Azizi, P., Osman, M., Miah, G., 2018. Improvement of drought tolerance in rice (Oryza sativa L.): Genetics, genomic tools, and the WRKY gene family. BioMed Res. Int. 3158474.

Sarvestani, Z. T., Pirdashti, H., Sanavy, S. A. M. M., and Balouchi, H., 2008. Study of water stress effects in different growth stages on yield and yield components of different rice (Oryza sativa L.) cultivars. Pakistan Journal of Biological Sciences, 11 (10), 1303–1309. https://doi.org/10.3923/pjbs.2008.1303.1309

Shamsun N., Jyotirmay K., Lingaraj S., Bhaben T., 2016. Morphophysiological and molecular effects of drought stress in rice. Annals of Plant Sciences. 5. 1409. 10.21746/aps.2016.09.001.

Singh, C.M., Kumar, B., Mehandi, S., Chandra, K., 2012. Effect of Drought Stress in Rice: A Review on Morphological and Physiological Characteristics. Trends in Biosciences. 5. 261-265.

Singh, S., Prasad, S., Yadav, V., Kumar, A., Jaiswal, B., Kumar, A., Khan, N. A., and Dwivedi, D. K., 2018. Effect of Drought Stress on Yield and Yield Components of Rice (Oryza sativa L.) Genotypes. International Journal of Current Microbiology and Applied Sciences, 7, 2752–2759.

Sonam S., Shambhoo P., Vishwajeet Y., Ajay K., Bandana J., Adesh K., Khan N.A., Dwivedi D.K., 2018. Effect of Drought Stress on Yield and Yield Components of Rice (Oryza sativa L.) Genotypes. https://www.ijcmas.com/ special/7/Sonam%20Singh2,%20et%20al.pdf

Vibhuti, Shahi, C., Bargali, K., and Bargali, S. S., 2015. Seed germination and seedling growth parameters of rice (Oryza sativa) varieties as affected by salt and water stress. Indian Journal of Agricultural Sciences, 85 (1), 102–108.

Wang, Y., Zhang, Q., Zheng, T., Cui, Y., Zhang, W., Xu, J., Li, Z., 2014. Drought-tolerance QTLs commonly detected in two sets of reciprocal introgression lines in rice. Crop Pasture Sci., 65, 171–184.

Yan, W., Zhong, Y., Shangguan, Z., 2016. A meta-analysis of leaf gas exchange and water status responses to drought. Sci Rep 6, 20917.

Zhang, J., Zhang, S., Cheng, M., Jiang, H., Zhang, X., Peng, C., Lu, X., Zhang, M., and Jin, J., 2018. Effect of Drought on Agronomic Traits of Rice and Wheat: A Meta-Analysis. International Journal of Environmental Research and Public Health, 15 (5). https://doi.org/10.3390/IJERPH15050839

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