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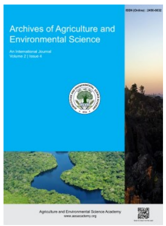

REVIEW ARTICLE

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A review on abiotic stress vulnerability of wheat and its management in Terai, Nepal

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ABSTRACT

Wheat being one of the most important crops of Nepal after rice and maize is prone to abiotic stresses like heat and drought stress. Climate change, increasing temperature and decreasing precipitation is found to be the major cause of drought and heat stress, especially making developing countries like Nepal to be most vulnerable to the negative impacts on productivity and sustainability. Abiotic stress imposes devastating changes on morphology, biochemistry and physiological processes of wheat. Loss in seed vigor, decrease in germination rate, poor crop stand and abnormal embryo are common impact seen due to combined Abiotic stress. Though many trial has been performed on effect of heat and drought, there is a need for trial imposing wheat to combined stress environment. This review especially deals with the impacts of Abiotic stress along with management including tolerant varieties such as Bhrikuti, NL1420, BL4669, NL1350 and NL1368 and agronomic techniques like mulching, use of early varieties, early sowing and incorporation of Biochar.

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INTRODUCTION

Wheat (*Triticum aestivum* L.), the most widely cultivated cereal crop belonging to Poaceae family, is the largest contributor with nearly 30% of the world grain production and 50% of the world grain trade (Akter & Rafiqul Islam, 2017). Wheat is cultivated in 220 million hectares area in the world and has an annual production of 778 million metric tons with a 10% value addition in agriculture (Khan *et al*., 2020). It is an important cereal because of its high nutritive value, high rate of cultivation and high consumption rate (Arzani & Ashraf, 2017). Wheat is the third most important cereal crop of Nepal after Rice and Maize. The total area and production of wheat in Nepal have been reported 716,978 ha and 2,144,568 metric tons where the highest yield is reported in Rupandehi district of Lumbini Province which is 3.91 mt/ha (MoALD, 2023). Wheat is a significant winter cereal crop in Nepal, more than 80% of wheat is grown in rice-wheat cropping pattern (Kandel *et al*., 2018). The annual average productivity of wheat is 3.5 tonnes per hectare and it provides 1.8% fiber, 9.4% protein, 69% carbohydrates, and 2.5% fat (Ahmad *et al*., 2022; Nyaupane *et al*., 2024).

Since 1880, the Earth's temperature has increased at the rate of 0.14° Fahrenheit (0.08° C) every decade but the rate of warming since 1981 is more than double of that which is 0.32° F (0.180° C) per decade (Malakouti, 2023) The long-term weather parameters of Nepal's Terai indicate that the winter season is getting slightly delayed and shorter, while warm summer days are becoming longer causing damage to wheat cultivation throughout the Indo Gangetic area, including Nepal's Terai. Long-duration wheat cultivars are already suffering from early heat during the grain filling stage (Mondal *et al*., 2013). In near future wheat production is predicted to suffer the effects choosing wrong varieties and stagnating farm productivity (Kandel *et al*., 2018). One of the major cereal crop wheat, is subjected to several biotic and abiotic stresses which affect the crop's yield globally and to cope these stresses different mechanisms have been adopted by plants itself and recently with the help of genetic engineering and QTL (Quantitative Trait Loci) methods different stress tolerant inherited genes are developed (Hakeem, 2015). Among different abiotic stresses, the impact of the drought in wheat is high as it causes damage during all the stages of crop growth. Plants that experience drought early on has shown poor seedling stand establishment and less number of tillers per unit area and drought incidence at the mid-stage of growth causes reduction in dry matter production, effective tillers, and grains per plant (Fathi & Tari, 2016; Gani *et al.*, 2016). Stress during the final stage of cool-season may affect numerous physiological and biochemical reactions that may result in low yield and production. The plants possess a good number of adaptive and avoiding mechanisms to sustain the adverse situation (Kumari *et al.*, 2021). The identification and selection of wheat genotypes that are suited to stress conditions over a varied range of environments is influenced by the growing global population and anticipated changes in future climatic circumstances. The main issues with wheat production in many parts of the world, including Nepal, are heat stress and drought. These two environmental stresses are the most prevalent ones that have an impact on plant productivity by changing plant metabolism and gene expression (Poudel *et al.*, 2020) . Research is currently being done to determine the mechanisms that heat stress triggers and how wheat develops thermo-tolerance (Comastri *et al.*, 2018). In the context of developing countries, there has been an estimation to encounter an increase in demand for the ever-increasing population of the world, production of wheat might be increased by 60% in 2050 but at the same time the incidence of abiotic stresses such as drought, salinity, heat, and cold stresses are predicted to reduce wheat production by 20-30% (Hossain *et al.*, 2021).

Stress vulnerability

Drought and heat, significant abiotic stresses, pose a threat to global food security and agricultural sustainability amid the escalating impacts of climate change (Kumari *et al.*, 2021); Lamaoui *et al.*, 2018). Plants exhibit dynamic responses at various levels – morphological, physiological, biochemical and molecular response to cope with adverse environmental conditions as even mild heat and drought stresses adversely impact crop yields, with studies indicating potential reductions of up to 50% (Lamaoui *et al.*, 2018). Nepal is among the most vulnerable nations among countries with respect to climate change, due to higher temperature in recent years (Adhikari, 2018). It is predicted that until the end of the century, both the average annual mean temperature and the average yearly precipitation will rise. By 2100, precipitation may rise by 11–23% and the mean temperature may rise by 1.7–3.6^{0}C. There will probably be fewer wet days in the future and that the winter temperatures will increase at a higher rate than in other seasons. This implies that future water-related hazards will probably increase along with the intensity of the precipitation (Hulme & Sheard, 2019). Drought stress can occur at any time during the wheat growing season, whether early or late, but severe yield reductions occur after anthesis. To address food security concerns, it is necessary to increase wheat productivity in Nepal under rainfed and dry conditions by breeding drought-tolerant cultivars with high yields. High temperatures are threatening wheat production. Temperatures in Nepal vary greatly due to a variety of agro-ecological and agro-climatic factors during wheat cultivation. Nepal's Terai region is falls under ME5 (hot and humid environment) or ME1 (high temperature with low rainfall (Pokhrel *et al.*, 2019).

Wheat as a sensitive crop to Heat stress, as it is estimated that there is a decrease in global wheat production by 6% per 1^{0}C increase in temperature (Karki *et al.*, 2021). Vulnerability to Heat stress is a major concern as the terai is experiencing increasing temperatures and the delayed planting of wheat due to push back of harvesting time of rice in rice- wheat cropping pattern subjects maturation of wheat into periods of the year during which high temperatures are common (Krupnik *et al.*, 2021). Climate change and variability challenges occurring due to global warming is likely to have negative effects on the grain production worldwide, particularly staple crops – Wheat, rice and maize (Ahmad *et al.*, 2018). The heat stress occurs usually for rising of canopy temperature that depends on air and soil temperature, soil and canopy properties, and loss of soil moisture (Akter & Rafiqul Islam, 2017). Heat stress during grain filling is a major constraint to wheat production in the region, with each day delays in wheat seeding after mid-November reducing wheat yield by approximately 50 kg ha−1 d−1. This shifts crop maturation period into the late spring period when temperatures spike (Devkota *et al.*, 2023). Varieties with tolerant alleles has to be identified and deployed to develop varieties that will satisfy the demand of ever-increasing population under climate change (Zahra *et al.*, 2021).

IMPACT OF DROUGHT STRESS ON WHEAT'S GROWTH

Impact on plant morphology

It was reported that wheat on irrigated conditions were taller than that of under drought stress conditions which may be due to decrease in relative turgidity followed by dehydration of protoplasm which is associated with loss due to reduced cell expansion and division (Poudel *et al.*, 2020). Production is severely restricted by drought up to 60% reduction in the yield. Lower thousand grain weight may be due distributed nutrient uptake efficiency and photosynthetic translocation within the plant that produced shriveled grains caused by hastened maturity. This occurs due to the shortage of moisture which forces plant to complete its grain formation in relatively lesser time. (Poudel *et al.*, 2020). Drought Stress condition affects in various reproductive & phenological phases like Days of Booting, Days to Heading, Flowering, anthesis Grain filling, 1000 Kernel weight, Test weight & maturity & overall yield by alternation in Various physiological & metabolic stages & also gene expression (Bhandari *et al.*, 2021).

Impact on plant physiology

Plants imposed to Drought stress suffered significant impact on physiology including the Photosynthesis rate, Transpiration rate and Stomatal conductance (Farooq *et al.*, 2017). The formation of reactive oxygen species (ROS) Degradation of photosynthetic apparatus, thus lowering photosynthetic carbon metabolism, declining net CO_2 assimilation rate (NAR), and eventually reducing dry matter accumulation, is the cause and impact of reduced mean yield under drought conditions (Bhandari *et al.*, 2021). Lack of breeding for drought adaptive traits is leading to low productivity of wheat of 2.85t/ha in Nepal (Bhandari *et al.*, 2021). Different development stages of plant from germination, vegetative and reproductive stage to grain filling and maturation of crop are disturbed when the plant suffers from drought stress. Drought reduces the nutrient uptake efficiency including nitrogen as a main factor and nutrient utilization by plants. The reduction in nutrient uptake capacity is due to impaired membrane permeability and active transport and reduced transpiration rate resulting in decreased root absorbing power (Ahmad *et al.*, 2018). Plants that experience drought at flowering stage showed decrease in photosynthetic C gain, transpiration and stomatal conductance of wheat (Ahmad *et al.*, 2018).

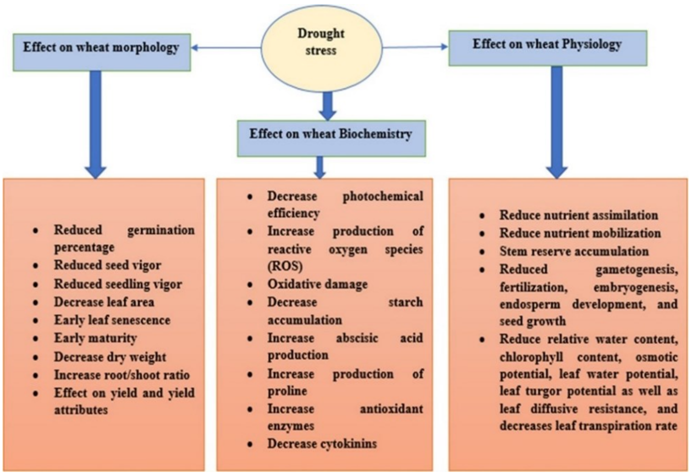

Figure 1. *Effect of drought stress on morphology, physiology, and biochemistry of wheat (Nyaupane et al., 2024).*

Impact on plant biochemistry

Impact of drought significantly reduced chlorophyll content in plant which is the main cause in reduction of photosynthetic activity (Amirjani & Mahdiyeh, 2013). Wheat under water stress conditions showed increment of proline and sugar content (Ahmad *et al.*, 2022) and decrease in N content of leaf leading to C/N imbalance (Amirjani & Mahdiyeh, 2013). Proline content is found to be increased in response to drought condition including additions of certain amino acids and organic acids in Wheat (Zhang *et al.*, 2022).

IMPACT OF HEAT STRESS ON WHEAT'S GROWTH

Impact on plant morphology

Late wheat sowing is a major cause of low grain production. In Nepal, wheat is mostly sown after the harvesting of paddy, which pushes back the appropriate sowing time of wheat, resulting in higher temperature stress during the grain filling period. As a result, wheat yield is very poor (Poudel *et al.*, 2020). Relatively warmer Temperature during crop growth and increased temperature above 30 °C during grain filling, not only had an impact on grain yield but also plant height, days to heading and days to maturity (Mondal *et al.*, 2013). In wheat, the period from spike ignition to flowering is highly sensitive to temperature acceleration, and this appears to be the main reason for the reduction in sink size under high temperature conditions. Heat stress affects wheat productivity by reducing the duration of the grain filling phase, kernel size, biomass, tiller number, and so on (Poudel *et al.*, 2020). There was significant reduction in grain yield indicating that heat stress is one of the major constraints in wheat production. An experiment subjecting seedlings to heat stress concluded a significant reduction in shoot dry mass, reduced length of root and shoot (Gupta *et al.*, 2013).

Impact on plant physiology

Heat stress significantly reduces seed germination and seedling growth, cell turgidity, and plant water-use efficiency whereas, at a cellular level, heat stress disturbs cellular functions through generating excessive reactive oxygen species (ROS), leading to

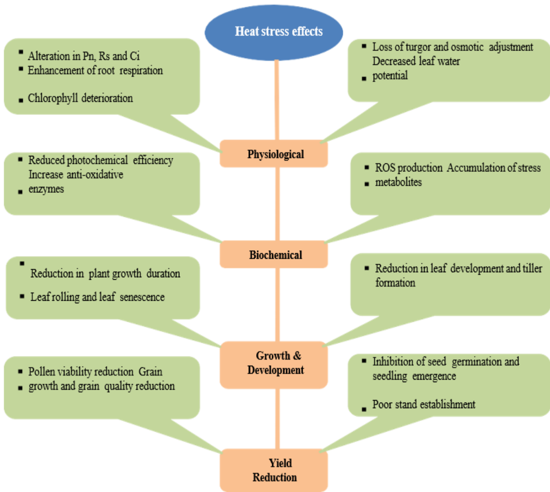

Figure 2. *Schematic diagram showing influence of heat stress in wheat plant (Akter & Rafiqul Islam, 2017).*

oxidative stress. The major responses of wheat to heat stress include the enhancement of leaf senescence, reduction of photosynthesis, deactivation of photosynthetic enzymes, and generation of oxidative damages to the chloroplasts and heat stress also reduces grain number and size by affecting grain setting, assimilate translocation and duration and growth rate of grains (Akter & Rafiqul Islam, 2017). Heat stress has a significant impact on chlorophyll content and leaf area index (LAI) in sensitive genotypes, but proline and malondialdehyde (MDA) levels were higher in tolerant genotypes under late-sown conditions. Wheat genotypes impacted by heat stress were shown to vary in their ability to adapt, and hence tolerance, which could be used as genetic stock to generate wheat tolerant varieties in breeding programs (Dhyani *et al.*, 2013).

Impact on plant biochemistry

The short-term heat stress subjected to a plant shown a significant detrimental effect on the chlorophyll content and reduced membrane stability index with increase of proline content, where proline acts as protector of membrane and accumulates due to its character of zwitter ion without causing any interference with the plant's cellular structure or metabolism. There was significant increase in the activity of catalase, guaiacol peroxidase and superoxide dismutase under stress conditions (Gupta *et al.*, 2013). Wheat starch accumulation is significantly reduces by heat stress during grain filling stage (Comastri *et al.*, 2018). Delayed sowing of wheat influenced the mean starch content percent (%) 3.73 to 2.93. High temperature stress starting from anthesis mainly affects the several traits like, cell membrane injury, proline content, starch content, assimilate availability, translocation of photosynthates to the grain, influence grain development hence lower grain weight spike-1, reduced number of productive tillers plant-1, reduced numbers of grains spike-1 and induced forced maturity resulting in lower grain yield (Amarshettiwar & Berad, 2018); Comastri *et al.*, 2018). According to a trial done by (Amarshettiwar & Berad, 2018) the highest proline content was seen in late sown varieties which can be a result of sharp temperature rise during flag leaf stage.

Combined impact of drought and heat stress

Subjecting both heat and drought stress to wheat involves 34/24^{0}C day/night temperatures and complete withdrawal of water (Zahra *et al.*, 2021) imposing changes in the biochemistry, structure and morphology of yield leading to loss of yield (Ahmad *et al.*, 2018). Seed-filling processes and its components response under separate and combined stress environments to must be understood (Sehgal *et al.*, 2018). Both summer and cool-season crops are experiencing an increase in the frequency of these two stresses occurring together, which is extremely harmful to both the qualitative and quantitative components of production. To understand the diverse ways that different crops respond to these two stresses, it is important to understand and analyze the various components impacting seed-filling processes under both single and combined stress conditions (Comastri *et al.*, 2018). Heat and drought stress negatively impact seed-filling processes in all crop species, leading to worse-quality seeds, lower seed yields and abnormal embryo development (Fábián *et al.*, 2008). Abiotic stresses markedly affect the reproductive development of various crops and, ultimately reduce the final economic yields. Drought and high temperature stress have complex effects on grain yield, including processes such as nutrient assimilation and mobilization to various reproductive organs, stem reserve accumulation, gametogenesis, fertilization, embryogenesis, endosperm, and seed development (Sehgal *et al.*, 2018). Heat and drought stress, alone or in combination, reduced key enzyme activities, including ADP-Glc pyrophosphorylase, granule-bound starch synthase, starch synthases, sucrose synthase, and starch branching enzymes, and genetic expressions linked with the conversion of sucrose to starch, reducing starch content (Lu *et al.*, 2019).

Combined stress has a severe negative effect on wheat grain development, majorly during the early stages such as booting and heading as it hinders meiosis, reduces pollination efficiency, causes ovule abortion, interferes with the natural cycle of anthesis and maturity resulting early maturity of seeds. The stress triggers various physiological processes enabling plant to cope with stress conditions such as deep root systems , cooling canopies, hydraulic conductance, elongation of awns, stomata densing, regulation of circadian, partitioning and remobilization of carbohydrates and assimilate and increase in ROS content (Zahra *et al.*, 2021). Alternation of Planting time, priming of seed (hydropriming), ariel application of nutritients on micro and macro level, application of rhizobacteria are some of the agronomic techniques that are found to reduce detrimental impact of both heat and drought stresses whereas Breeding approaches like trait-based selection, inheritance studies of marker-based selection, genetic approaches using the transcriptome and metabolome are necessary for further future of heat and drought stress mitigation as well as adaptation (Kumari *et al.*, 2021). Genotypes Bhrikuti, NL1420, BL4669, NL1350 and NL1368 had high yield potential under both conditions. Thus, these genotypes can be used for further breeding programs for heat tolerance and/or potential to cultivated in the heat prone areas of Nepal (Poudel *et al.*, 2021). Use of tolerant varieties and agronomic mitigation techniques like biochar incorporation, zeolite, and mulching with nutritious soil especially at anthesis and booting, can increase combined stress tolerance in wheat (Zahra *et al.*, 2021).

Drought management

In drought condition NL1327 had maximum mean yield of 2.0 ton/ha and NL1325 had minimum yield of 1.04 ton/ha (Poudel *et al.*, 2021) also, BL4335 had maximum mean TKW of 47.25 g and NL1244 had minimum TKW of 35 (Poudel *et al.*, 2020). Selection of early mature genotypes has been found to be a successful technique for reducing yield loss caused by terminal drought stress, which reduces crop growth duration (Poudel *et al.*, 2020). To address future drought stress concerns in wheat, new wheat cultivars with water deficit tolerance should be created, as well as developments in cultural methods that increase wheat potential on a long-term basis (Ahmad *et al.*, 2018). Nitrogen deficit combined with drought stress showed a significant reduction in photosynthesis rate, chlorophyll content and ultimately reducing the grain yield whereas plant under drought stress and high Nitrogen showed tolerance mechanisms such as decreased negative leaf water potential, higher chlorophyll, high rubisco content , lower lipid peroxidation with high ascorbate peroxide and superoxide dismutase activity (Ahmad *et al.*, 2018). The simplest way to improve germination is by hydro-priming (use of water); however, under stress conditions, scientists reported that osmopriming (halo-priming, chemo-priming, hormonal priming) is highly effective for improved seedling vigor (Ahmad *et al.*, 2018).

Heat stress management

Vijay (4.06 ton/ha) and Gautam (3.52 ton/ha) are the recommended genotypes that showed promising results in a farmer's field with minimum effect of heat stress in the Terai region of Nepal (Upadhyaya & Bhandari, 2022). The trial performed by (Poudel *et al.*, 2020) concluded better yield of BL4699 with the maximum yield of 2.2 ton/ha in the heat stress conditions. The combination of proline and ethephon application greatly improved photosynthetic qualities and substantially reduced the harmful effects of heat stress (Sehar *et al.*, 2023). Under conditions of terminal heat stress, genotypic diversity was discovered across the genotypes tested for various agronomic traits. While the excellent genotypes NL 1307 (Borlaug 2020), NL 1327 (Zinc Gahun 1), and NL 1369 (Zinc Gahun 2) have been released for terai/plains area in 2020, the earliest maturing genotypes, namely BL4708, NL 1326, BL 4866, NL 1347, NL 1343, BL4818, and NL 1318, were found good under terminal heat stress conditions as they escape the high temperature during grain filling period. The terai region of Nepal may see the release of the pipeline varieties BL4818, NL1202, and BL4335 as a variety for environment with high temperature (Pokhrel *et al.*, 2019). Prior research on controlled research stations found that fertilizer, water management, sowing time, and terminal heat stress were the main variables influencing wheat productivity in Nepal (Krupnik *et al.*, 2021). The seeding date varies with locations, and late seeding beyond the first week of December resulted in a notable decrease in yield. The largest production was achieved between November 1 and November 30, however in most districts the output of wheat decreases after November 15 (Devkota *et al.*, 2024). The main factors influencing variance in wheat yield and profitability were on-farm variations in nitrogen management, followed by temperature stress during grain filling (terminal heat stress) and the frequency of irrigations. A few combinations of agronomic options were found to be more beneficial than the practices of prevailing farmers, including advancing seeding by 7–10 days (from the average farmers' seeding date), line seeding, a slight increase of about 20 kg ha^{-1} of nitrogen fertilizer, and two additional irrigations (Devkota *et al.*, 2024).

Conclusion

Abiotic stresses mediated changes in morphology, biochemistry and physiology in wheat leads to yield loss and affects the quality of grain. A systematic approach including impact study and identification of components causing yield loss is vital for the establishment of better future of staple crop, Wheat. Effective study and use of tolerant mechanism of wheat against stresses with agronomic techniques incorporation will arbitrate a better future for Wheat crop in Developing countries.

DECLARATIONS

Author contribution statement

Conceptualization: B.G; Methodology: B.G.; Software and validation: B.G; Formal analysis and investigation: B.G.; Writing—original draft preparation: B.G.; Writing—review and editing: B.G, S.S and M.R.P; Visualization: B.G; Supervision: B.G, S.S and M.R.P. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Adhikari, S. (2018). Drought impact and adaptation strategies in the mid-hill farming system of western Nepal. *Environments - MDPI*, *5*(9), 1–12. https://doi.org/10.3390/environments5090101

Ahmad, A., Aslam, Z., Javed, T., Hussain, S., Raza, A., Shabbir, R., Mora-Poblete, F., Saeed, T., Zulfiqar, F., Ali, M. M., Nawaz, M., Rafiq, M., Osman, H. S., Albaqami, M., Ahmed, M. A. A., & Tauseef, M. (2022). Screening of Wheat (*Triticum aestivum* L.) Genotypes for Drought Tolerance through Agronomic and Physiological Response. *Agronomy*, *12*(2). https://doi.org/10.3390/agronomy12020287

Ahmad, Z., Waraich, E. A., Akhtar, S., Anjum, S., Ahmad, T., Mahboob, W., Bin, O., Hafeez, A., Tapera, T., Labuschagne, M., & Rizwan, M. (2018). Physiological responses of wheat to drought stress and its mitigation approaches. *Acta Physiologiae Plantarum*, *April*. https://doi.org/10.1007/s11738-018-2651-6

Akter, N., & Rafiqul Islam, M. (2017). Heat stress effects and management in wheat. A review. *Agronomy for Sustainable Development*, *37*(5). https://doi.org/10.1007/s13593-017-0443-9

Amarshettiwar, S. B., & Berad, P. B. (2018). Biochemical and yield responses of wheat genotypes to normal and heat stress condition. *Journal of Pharmacognosy and Phytochemistry*, *7*(1), 2663–2666.

Amirjani, M. R., & Mahdiyeh, M. (2013). *Antioxidative and biochemical responses of wheat*. *8*(4), 291–301.

Arzani, A., & Ashraf, M. (2017). Cultivated Ancient Wheats (Triticum spp.): A Potential Source of Health-Beneficial Food Products. *Comprehensive Reviews in Food Science and Food Safety*, *16*(3), 477–488. https://doi.org/10.1111/1541-4337.12262

Bhandari, R., Gnawali, S., Nyaupane, S., Kharel, S., Poudel, M., & Panth, P. (2021). Effect of Drought & Irrigated Environmental Condition on Yield & Yield Attributing Characteristic of Bread Wheat-a Review. *Reviews in Food and Agriculture*, *2*(2), 59–62. https://doi.org/10.26480/rfna.02.2021.59.62

Comastri, A., Janni, M., Simmonds, J., Uauy, C., Pignone, D., Nguyen, H. T., & Marmiroli, N. (2018). Heat in wheat: exploit reverse genetic techniques to discover new alleles within the triticum durum shsp26 family. *Frontiers in Plant Science*, *9*(September), 1–16. https://doi.org/10.3389/fpls.2018.01337

Devkota, K. P., Devkota, M., Moussadek, R., & Nangia, V. (2023). Genotype × environment × agronomic management interaction to enhance wheat yield in the Mediterranean rainfed environments of Morocco: II. Process based modeling. *European Journal of Agronomy*, *151*(9), 126973. https://doi.org/10.1016/j.eja.2023.126973

Devkota, M., Devkota, K. P., Paudel, G. P., Krupnik, T. J., & McDonald, A. J. (2024). Opportunities to close wheat yield gaps in Nepal's Terai: Insights from field surveys, on-farm experiments, and simulation modeling. *Agricultural Systems*, *213*(February 2023), 103804. https://doi.org/10.1016/j.agsy.2023.103804

Dhyani, K., Ansari, M. W., Rao, Y. R., Verma, R. S., Shukla, A., & Tuteja, N. (2013). Comparative physiological response of wheat genotypes under terminal heat stress. *Plant Signaling and Behavior*, *8*(6). https://doi.org/10.4161/psb.24564

Fábián, A., Jäger, K., & Barnabás, B. (2008). *Effects of drought and combined drought and heat stress on germination ability and seminal root growth of wheat (Triticum aestivum L) seedlings*. *March 2015*, 3–6.

Farooq, M., Nawaz, A., Chaudhary, M. A. M., & Rehman, A. (2017). Foliage-applied sodium nitroprusside and hydrogen peroxide improves resistance against terminal drought in bread wheat. *Journal of Agronomy and Crop Science*, *203* (6), 473–482. https://doi.org/10.1111/jac.12215

Fathi, A., & Tari, D. B. (2016). Effect of Drought Stress and its Mechanism in Plants. *International Journal of Life Sciences*, *10*(1), 1–6. https://doi.org/10.3126/ijls.v10i1.14509

Gani, R., Devi, S., Goundar, S., Reddy, E., Saber, F., Cheng, Y.-L., Lee, C.-Y., Huang, Y.-L., Buckner, C. A., Lafrenie, R. M., Dénommée, J. A., Caswell, J. M., Want, D. A., Gan, G. G., Leong, Y. C., Bee, P. C., Chin, E., Teh, A. K. H., Picco, S., Mathijssen, R. H. J. (2016). We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %. *Intech*, *11*(tourism), 13. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

Gupta, N., Agarwal, V. P., Nathawat, N. S., & Gupta, S. (2013). *Effect of short-term heat stress on growth , physiology and antioxidative defence system in wheat seedlings Effect of short-term heat stress on growth , physiology and antioxidative defence system in wheat seedlings*. *June 2016*. https://doi.org/10.1007/s11738-013-1221-1

Hakeem, K. R. (2015). Crop production and global environmental issues. *Crop Production and Global Environmental Issues*, 1–598. https://doi.org/10.1007/978-3-319-23162-4

Hossain, A., Skalicky, M., Brestic, M., Maitra, S., Alam, M. A., Syed, M. A., Hossain, J., Sarkar, S., Saha, S., Bhadra, P., Shankar, T., Bhatt, R., Chaki, A. K., Sabagh, A. E. L., & Islam, T. (2021). Consequences and mitigation strategies of abiotic stresses in wheat (*Triticum aestivum* l.) under the changing climate. *Agronomy*, *11*(2). https://doi.org/10.3390/agronomy11020241

Hulme, M., & Sheard, N. (2019). Climate Change Scenarios for Mesoamerica. *Wwf*, *February*, 1–6.

Kandel, M., Bastola, A., Sapkota, P., Chaudhary, O., Dhakal, P., Chalise, P., & Shrestha, J. (2018). Analysis of Genetic Diversity among the Different Wheat (*Triticum aestivum* L.) Genotypes. *Türk Tarım ve Doğa Bilimleri Dergisi*, *5*(2), 180–185. https://doi.org/10.30910/turkjans.421363

Karki, P., Subedi, E., Acharya, G., Bashyal, M., Dawadee, N., & Bhattarai, S. (2021). A review on the effect of heat stress in wheat (*Triticum aestivum* L.). *Archives of Agriculture and Environmental Science*, *6*(3), 381–384. https://doi.org/10.26832/24566632.2021.0603018

Khan, M. A. U., Mohammad, F., Khan, F. U., Ahmad, S., Raza, M. A., & Kamal, T. (2020). Comparison among different stability models for yield in bread wheat. *Sarhad Journal of Agriculture*, *36*(1), 282–290. https://doi.org/10.17582/JOURNAL.SJA/2020/36.1.282.290

Krupnik, T. J., Timsina, J., Devkota, K. P., Tripathi, B. P., Karki, T. B., Urfels, A., Gaihre, Y. K., Choudhary, D., Beshir, A. R., Pandey, V. P., Brown, B., Gartaula, H., Shahrin, S., & Ghimire, Y. N. (2021). Agronomic, socio-economic, and environmental challenges and opportunities in Nepal's cereal-based farming systems. In *Advances in Agronomy* (1st ed., Vol. 170). Elsevier Inc. https://doi.org/10.1016/bs.agron.2021.06.004

Kumari, V. V., Roy, A., Vijayan, R., Banerjee, P., Verma, V. C., Nalia, A., Pramanik, M., Mukherjee, B., Ghosh, A., Reja, M. H., Chandran, M. A. S., Nath, R., Skalicky, M., Brestic, M., & Hossain, A. (2021). Drought and heat stress in cool-season food legumes in sub-tropical regions: Consequences, adaptation, and mitigation strategies. *Plants*, *10*(6), 1–21. https://doi.org/10.3390/plants10061038

Lamaoui, M., Jemo, M., Datla, R., & Bekkaoui, F. (2018). Heat and drought stresses in crops and approaches for their mitigation. *Frontiers in Chemistry*, *6* (February), 1–14. https://doi.org/10.3389/fchem.2018.00026

Lu, H., Hu, Y., Wang, C., Liu, W., Ma, G., Han, Q., & Ma, D. (2019). Effects of High Temperature and Drought Stress on the Expression of Gene Encoding Enzymes and the Activity of Key Enzymes Involved in Starch Biosynthesis in Wheat Grains. *Frontiers in Plant Science*, *10*(November), 1–17. https://doi.org/10.3389/fpls.2019.01414

Malakouti, S. M. (2023). Utilizing time series data from 1961 to 2019 recorded around the world and machine learning to create a Global Temperature Change Prediction Model. *Case Studies in Chemical and Environmental Engineering*, *7*(February), 100312. https://doi.org/10.1016/j.cscee.2023.100312

MoALD. (2023). Statistical Information on Nepalese Agriculture 2078/79 (2021/22). *MoALD*, 269. https://medium.com/@arifwicaksanaa/pengertian-use-case-a7e576e1b6bf

Mondal, S., Singh, R. P., Crossa, J., Huerta-Espino, J., Sharma, I., Chatrath, R., Singh, G. P., Sohu, V. S., Mavi, G. S., Sukaru, V. S. P., Kalappanavarg, I. K., Mishra, V. K., Hussain, M., Gautam, N. R., Uddin, J., Barma, N. C. D., Hakim, A., & Joshi, A. K. (2013). Earliness in wheat: A key to adaptation under terminal and continual high temperature stress in South Asia. *Field Crops Research*, *151*, 19–26. https://doi.org/10.1016/j.fcr.2013.06.015

Nyaupane, S., Poudel, M. R., Panthi, B., Dhakal, A., Paudel, H., & Bhandari, R. (2024). Drought stress effect, tolerance, and management in wheat–a review. *Cogent Food and Agriculture*, *10*(1). https://doi.org/10.1080/23311932.2023.2296094

Pokhrel, D., Raj Pant, K., Raman Upadhyay, S., Pandey, D., Raj Gautam, N., Khatri, N., Prasad Yadav, R., Ram Ghimire, B., Prasad Poudel, R., Prasad Poudel, B., Prasad Paudel, G., Raj Yadav, D., & Basnet, R. (2019). *Development of suitable wheat varieties for terminal heat stress environment in Terai region of Nepal*. *January 2022*, 20–21.

Poudel et al. (2020). Evaluation of Wheat Genotypes under Irrigated, Heat Stress and Drought Conditions Corresponding Author*. *Journal of Biology and Today's World*, *9*(1), 1–003.

Poudel, P. B., Poudel, M. R., & Puri, R. R. (2021). Evaluation of heat stress tolerance in spring wheat (Triticum aestivum L.) genotypes using stress tolerance indices in western region of Nepal. *Journal of Agriculture and Food Research*, *5*, 100179. https://doi.org/10.1016/j.jafr.2021.100179

Sehar, Z., Gautam, H., Masood, A., & Khan, N. A. (2023). Ethylene- and Proline-Dependent Regulation of Antioxidant Enzymes to Mitigate Heat Stress and Boost Photosynthetic Efficacy in Wheat Plants. *Journal of Plant Growth Regulation*, *42*(5), 2683–2697. https://doi.org/10.1007/s00344-022-10737-8

Sehgal, A., Sita, K., Siddique, K. H. M., Kumar, R., Bhogireddy, S., Varshney, R. K., HanumanthaRao, B., Nair, R. M., Prasad, P. V. V., & Nayyar, H. (2018). Drought or/and heat-stress effects on seed filling in food crops: Impacts on functional biochemistry, seed yields, and nutritional quality. *Frontiers in Plant Science*, *871*(November), 1–19. https://doi.org/10.3389/fpls.2018.01705

Upadhyaya, N., & Bhandari, K. (2022). Assessment of different genotypes of wheat under late sowing condition. *Heliyon*, *8*(1), e08726. https://doi.org/10.1016/j.heliyon.2022.e08726

Waraich, E. A., Ahmad, R., Halim, A., & Aziz, T. (2012). Alleviation of temperature stress by nutrient management in crop plants: A review. *Journal of Soil Science and Plant Nutrition*, *12*(2), 221–244. https://doi.org/10.4067/S0718-95162012000200003

Zahra, N., Wahid, A., Bilal, M., Ullah, A., Kadambot, H., Siddique, M., & Farooq, M. (2021). Grain development in wheat under combined heat and drought stress: Plant responses and management. *Environmental and Experimental Botany*, *188*(May), 104517. https://doi.org/10.1016/j.envexpbot.2021.104517

Zhang, X., Wang, Z., Li, Y., Guo, R., Liu, E., Liu, X., Gu, F., Yang, Z., Li, S., Zhong, X., & Mei, X. (2022). Wheat genotypes with higher yield sensitivity to drought overproduced proline and lost minor biomass under severer water stress. *Frontiers in Plant Science*, *13*(November), 1–14. https://doi.org/10.3389/fpls.2022.1035038