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REVIEW ARTICLE

DROUGHT STRESS IN NEPAL: IMPACT ON WHEAT AND STRATEGIES FOR MANAGEMENT-A REVIEW

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ABSTRACT

Wheat, a crucial cereal crop, serves over 2.5 billion people globally, with Asia contributing 36.25% of its projected global yield in 2020. In Nepal, it ranks third in cultivation land and productivity, with land covering 716,978 hectares and 2,144,568 metric tons production, with Madesh province having the highest producing province producing 628,909 metric tons in 2078/79. Abiotic stresses, along with global climate change, are the primary factors that restrict global wheat production. The eastern and central regions of Nepal are more prone to drought conditions, owing to water scarcity. Variation in precipitation and temperature over time leads to annual and seasonal drought, causing yield decline, leading to a lower GDP of livelihood. Drought stress affects all plant parts, including the morphology, physiology, and biochemistry of wheat plants. Germination rate, plant turgor, leaf area, nutrient and water assimilation, and various other aspects are affected by drought. At the physiological level, decreased photochemical efficiency, increased production of Reactive Oxygen Species (ROS), enhanced proline production, and decreased starch accumulation are conditions caused by drought stress in wheat. To solve the problem of drought, interdisciplinary approaches such as plant breeding, agronomy, plant physiology, and water engineering have been developed. Water management, nutrient management, soil health, sowing time, and seed priming are major activities related to agronomy for drought stress management. In addition to agronomic methods, the selection of drought-tolerant varieties, transgenic approaches, QTL mapping, and breeding techniques are equally important for drought management in wheat to sustain productivity and improve the AGDP of Nepal.

KEYWORDS

Climate change, Drought, Nepal, Stress, Wheat production

1. INTRODUCTION

Wheat (Triticum aestivum L. 2n = 6x = 42, AABBDD) is vital cereal with direct impact on food security. Globally, more than 2.5 billion people benefit from wheat and its products, and for 35% of the population, wheat is a primary food (Society and Conference, 2022). Wheat is a crucial staple food that is widely cultivated on over 220 million hectares worldwide. In 2020, its projected global yield was 769.31 million tonnes, with Asia contributing 36.25% (278.88 million tonnes) of this total (Kashyap et al., 2022).

In Nepal, it is ranked third in cultivation land and productivity as cultivated in 716,978 hectares, with a productivity of 2,144,568 metric tons, and madesh province being the province with the highest production of 628,909 metric tons during fiscal year 2078/79 (MoALD, 2023). Owing to its high nutritional and calorie value, it is an important aspect of food security (Kashyap et al., 2022). In Nepal, wheat contributes 5.6721% to Agriculture GDP in the fiscal year 2078/79 (MoALD, 2023). If we see data on a global basis, Nepal's wheat productivity is far lower and has been constant over the past ten years (Ram Poudel and Hari Dhakal, 2019).

The majority of Nepal's wheat-growing land is in tropical Terai, where 2.99 tons of wheat are produced on average per hectare under a rice-wheat cropping pattern. Abiotic stress is the primary factor that restricts global cereal production through agriculture (Ram Poudel and Hari Dhakal, 2019) and climate change causes wheat production loss in Nepal (Gairhe et al., 2021). Drought refers to the duration during which a specific area or locality encounters a reduced amount of rainfall compared to the usual levels, and its features and consequences can differ depending on the geographic location (Bista et al., 2021). Drought is a major environmental stress that causes a reduction in cereals and affects half of the agricultural land (Ashraf & Foolad, 2007). Among all stresses, drought stress significantly reduces production by altering several plant stages of growth and development (Tefera et al., 2021). In the near future, global warming is expected to increase the frequency and severity of droughts (Yu et al., 2017). This may result in a shortage of water resources, which affects the morphological, physiological, biochemical, and molecular characteristics of the plants. Both crop output and plant growth are slowed down by these changes. Under drought stress, crops experience negative changes in their morphological and physiological characteristics. The unexpected elements of the environment and the interplay between biotic and abiotic factors make crop response to water scarcity much more complex than the intricacy of the drought itself (Nevo and Chen, 2010). Over the past few years, there has been a decline in the western part of Nepal and an increase in the sensitivity of the central and eastern regions to droughts (Hamal et al., 2020). Rupandehi, Kapilvastu, and many western and far western districts were devastated by agricultural drought in Nepal. The monsoons brought about rain, causing variations in production. In 1992, untimely rain was identified as the primary cause of agricultural drought, which led to a decrease in soil moisture and subsequent crop loss. Although difficult to forecast, the Indian monsoon and ENSO have an impact on drought (Bhandari and Panthi, 2015). One of the main causes of the low grain production in wheat is late seeding. In Nepal, wheat is typically sown after

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paddy is harvested, which delays the ideal sowing season and increases temperature stress during the grain-filling phase, leading to extremely low wheat yields (Poudel et al., 2020a).

2. METHODOLOGY

This review article is based on secondary sources. Various research articles, journals, online sites, and relevant reports were used as references for summarization.

3. RESULTS AND DISCUSSIONS

3.1 Drought In Nepal

The country experiences variations in precipitation and temperature over space and time, leading to the occurrence of both seasonal and annual droughts, which adversely affect crop yields, consequently affecting the nation's GDP and the livelihoods of its people (Hamal et al., 2020). As per the 2009 study conducted by the Nepal Climate Vulnerability Study Team (NCVST), the temperature in Nepal is expected to rise by 0.5ºC to 2.0ºC, with a multi-model mean of 1.4ºC and Global Climate Models (GCMs) anticipate diverse precipitation alterations, particularly in monsoon regions, ranging from a 14% decline to a 40% rise by the 2030 (Sapkota, 2016). Food insecurity and poverty are increasing in developing countries owing to global warming, which affects wheat yield globally. By the mid-century, grain yield was reduced by 15% and 16% in African and South Asian counties, respectively (Pequeno et al., 2021).

Precipitation decline and increased temperature are signs of drought; from 2001 to 2010, precipitation deficits were observed over the western region of Nepal, especially in the Terai region up to the southern Himalayan foothills (Wang et al., 2013). Since 1990, a 1ºC rise in temperature has been observed in western Nepal, and this persistent warming of the Indian Ocean has suppressed rainfall due to increased local Hadley circulation. Recent extended periods of drought in Nepal could be indicative of a combination of natural variability and human-induced factors (Wang et al., 2013).

3.2 Drought And Its Effects On Plants

Alterations in different aspects of plants owing to a lack of water are known as drought stress (Sallam et al., 2019). Stress during drought results in sterile pollen, interrupted photosynthesis, and the transfer of food material to the grains, which can lower the number of grains in a spike and, ultimately, lower the number of spikes per m^2 (Poudel et al., 2020a) . Drought is a frequent environmental stressor that slows plant growth. To adapt to drought stress, plants undergo a variety of morphological, physiological, biochemical, anatomical, and molecular changes, such as stomatal closure, a decrease in photosynthetic activity, root signal detection and turgor pressure loss, osmotic adjustment, a decrease in water potential, a decrease in the rate of CO2 conductance and internal concentration, an increase in the root to shoot ratio, the synthesis of antioxidant species, and the DREBS transcription factor (Rashid et al., 2021). The IPCC (2014) study states that severe water shortage is the primary cause of the decline in yield, productivity, and quality, which poses a serious threat to agriculture. A variety of processes, including nutrient uptake and mobilization to numerous reproductive organs, stem reserve accumulation, gametogenesis, fertilization, embryogenesis, endosperm, and seed growth, are all affected by drought in a complex manner on grain yield. The seed-filling stage is crucial for determining the average seed weight and seed composition because these forces can alter crop output at any stage of development. Consequently, the final quantitative and qualitative yields decrease (Çakir, 2011; Sharma et al., 2022a). "**Error! Reference source not found.** (Hussain et al., 2019)" and "Figure 1 (Nezhadahmadi et al., 2013; Nyaupane et al., 2024)" below shows us about growth of plant under drought and the effects on different aspects of plant due to drought respectively.

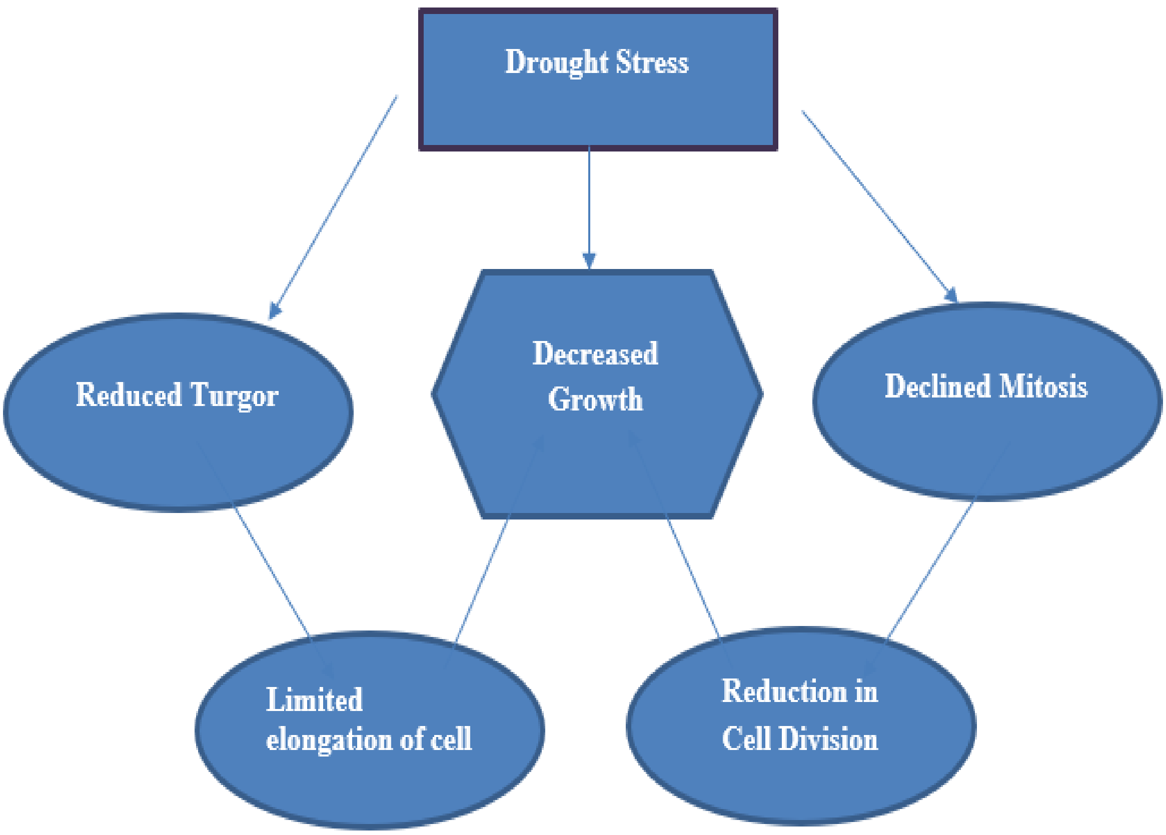

Figure 1: Plant growth reduction under drought condition

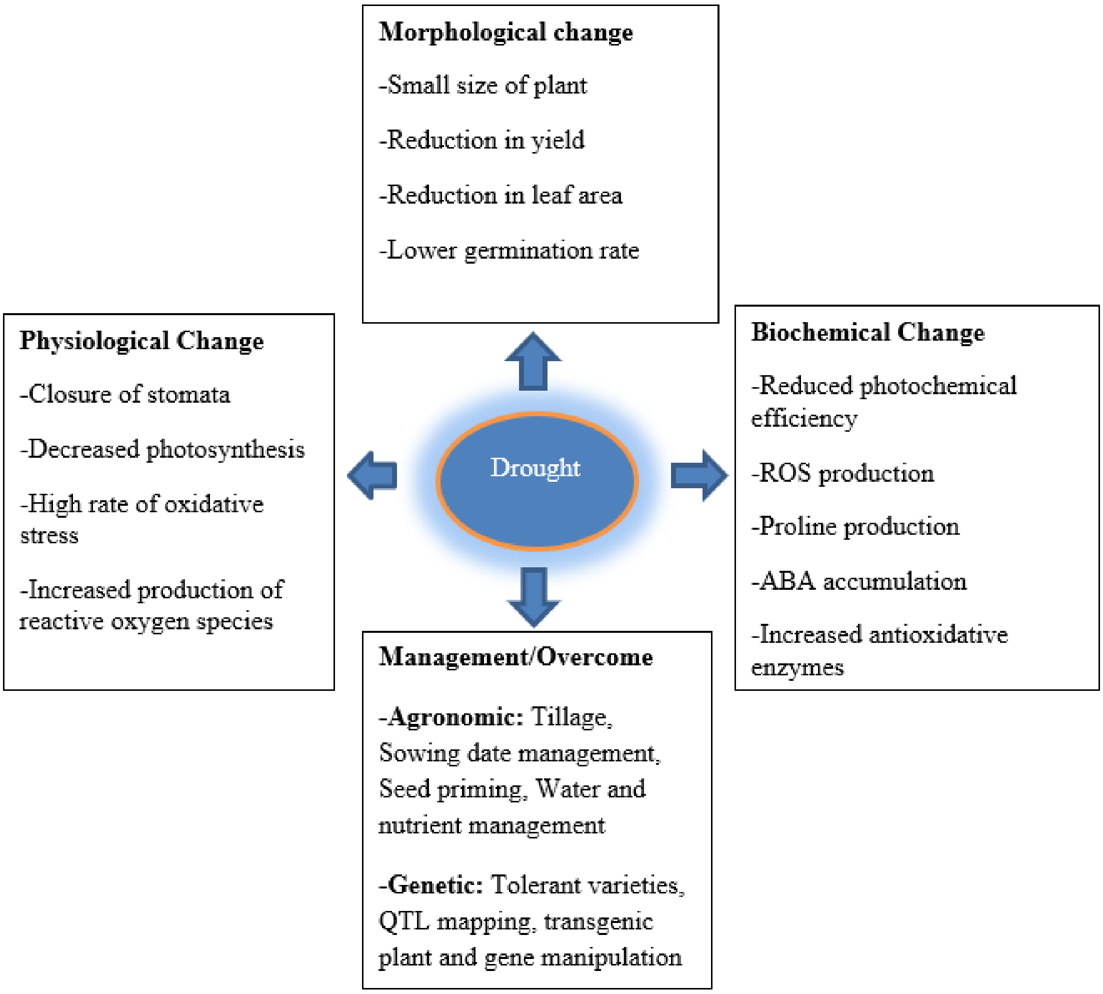

Figure 1: Effect of drought stress on morphology, physiology, and biochemistry of wheat with its management

3.2.1 Morphology of plant

Wheat exhibits morphological adaptations in response to drought stress, with a particular emphasis on certain traits. These traits included leaf shape, expansion, area, size, senescence, pubescence, root dry weight, density, and length. Characteristics such as dwarfism, reduced leaf area, and early maturation are positively correlated with drought (Rizza et al., 2004).

Drought stress alters vital plant growth and developmental processes, such as germination, plant height, stem diameter, number of leaves, size and area of leaves, production and partitioning of dry matter, production of flowers and fruit, and maturity (Anjum et al., 2017). According to (Barnabás et al., 2008) during anthesis, drought causes pollen sterility, which reduces the rate of fertilization and, hence, lowers the productivity and yield of wheat. Drought stress can cause problems with morphological and phenological parameters, such as plant height (Ph), tillers per plant (TPP), number of spikes per meter square (NSPMS), number of spikelets per spike (NSPS), and spike length (SL) (Poudel et al., 2020a).

Drought in wheat causes loss by destroying lipids in the cell membrane and affects the growth of roots and shoots of plants (Vuković et al., 2022). In wheat, seminal roots are developed first;these roots are crucial for early vigor and water intake from deep soil layers, and they remain active throughout the plant's life. A large number of seminal roots descending at a small gravitropic angle is more effective in drawing water from deep soil in drought-prone areas (Manschadi et al., 2008). A study showed that the mid-season water deficit causes more severe damage t roots than the early season water deficit (Asseng et al., 1998). Root characteristics affecting plant productivity under drought include retarded diameter of fine roots, lengthened specific roots, and root length density, especially at the subsurface where water is available (Comas et al., 2013). Drought stress causes a reduction in plant height which might be due to dehydration of the protoplasm, which directly reduces cell division, cell expansion, and loss of turgidity loss (Öztürk et al., 2022; Poudel et al., 2020a). Drought stress reduces plant height resulting in decreased spike length. This could be the reason for reduced grains per spike and grain size since a study showed an average of 15.32% reduction in grain per spike and 10.6% in thousand kernel weight under drought stress (Poudel et al., 2020a).

To combat the stress of low water availability, plants employ a defensive strategy that modifies their morphological processes and stomatal activity to minimize transpiration loss. This involves the rolling of leaves, increased root length, osmotic and hormonal regulation, and late senescence, collectively counteracting the effects of moisture stress (Seleiman et al., 2021).

3.2.2 Physiology of plant

Drought causes oxidative damage to the photoassimilatory apparatus, resulting in diminished rates of carbon fixation and reduced translocation of assimilates, leading to issues such as pollen sterility, impairment of photosynthetic aspects, and damage to the photosynthetic apparatus. (Raza, 2020). Grain yield is severely affected by drought stress because it interferes with several physiological processes, including low nutrient uptake, mobilization, stem reserve building, fertilization, and post-fertilization events (Çakir, 2004). Drought stress causes a reduced transpiration rate due to decreased relative water content and other physiological aspects that interfere with stomata and other plant parts (Ahmad et al., 2022). Numerous factors, such as growth rate, stress intensity, genotype and length of stress, activity of the photosynthetic machinery, transpiration, and respiration, affect how plants respond to drought (Sharma et al., 2022a). One negative aspect of reduced agricultural productivity is pollen sterility caused by drought stress. Water shortage can seriously affect both the meiotic and mitotic stages of the reproductive process in anthers, and if the water potential is lowered, there will be a reduction in plant parts such as leaves and stems, which also reduces the accumulation of food material in wheat plants (Yu et al., 2019). Photosynthesis is affected by drought because of changes in the internal structure of the photosynthetic apparatus and minerals, where major work related to photosynthesis occurs. The destruction of photosystem II (PSII) leads to lipid peroxidation of the cell membrane through the accumulation of reactive oxygen species (Ahmad et al., 2018). Dryness can affect both meiotic and mitotic phases. Tapetal malfunctions cause pollen abortion during drought, which modifies the transport of soluble sugars to microspores. Male sterility results from drought because it reduces sugar supply, GA, and auxin concentrations, and increases ROS and ABA levels in anthers, which hinders anther development. Drought alters the expression of genes involved in anther formation, hormone metabolism, ROS scavenging, and signaling (Yu et al., 2019).

Drought stress leads to a higher accumulation of Reactive Oxygen Species (ROS), causing gradual oxidative damage and eventually cell death (Sharma et al., 2012). ROS(Reactive Oxygen Species) are essential for controlling cell division, seed germination, gravitropism, root hair growth, pollen tube production, and plant senescence in plants (Singh et al., 2016). Plant cells provide oxygen atoms with unpaired valence electrons and their derivatives, also known as reactive oxygen species (ROS), in response to drought. Drought stress disrupts the relationship and stability between ROS production and antioxidant defense mechanisms, leading to the excessive production of ROS and oxidative stress in plants. Under drought conditions, equilibrium is maintained by enzymatic and non-enzymatic antioxidant defence systems in all plants (Hasanuzzaman et al., 2020).

3.2.3 Biochemistry of plant

Abiotic stresses cause various kinds of plant behaviors, such as abnormal gene expression and various levels of metabolism, to alter growth rates and eventually crop production. Drought stress causes various biochemical changes such as decreased stomatal conductance, which results in low CO_2 assimilation (Reddy et al., 2004). During drought stress, the activity and concentration of enzymes that help in the photosynthetic carbon reduction cycle, such as oxygenase and ribulose 1,5-bisphosphate carboxylase, are also reduced and less active (Nyaupane et al., 2024; Reddy et al., 2004). Drought stress during the vegetative phases in plants leads to a decrease in chlorophyll content, an increase in non-photochemical quenching, and a decrease in PSII photochemical efficiency (Li et al., 2019).

A study stated that while drought stress caused oxidative damage to different wheat varieties, as shown by reduced Relative Water Content (RWC), increased lipid peroxidation, accumulation of H_2O_2 and degradation of chlorophyll, it also activated antioxidative mechanisms such as an increase in anti-oxidative enzyme activity and production of other antioxidants, proline, and phenols (Chakraborty and Pradhan, 2012). Drought stress causes changes in the endosperm starch granules in developing wheat kernels and in the constitution and physicochemical properties of starches on mature wheat grains (Yu et al., 2015). The key enzymes responsible for starch accumulation in wheat are soluble starch synthase (SSS), granule-bound starch synthase (GBSS), starch branching enzyme (SBE), and starch debranching enzyme (DBE) (Yi et al., 2014). Drought stress restricts the formation of SSS, GBSS, SBE, and DBE, which directly decreases starch synthesis activity at different levels (Lu et al., 2019).

Water scarcity during wheat growth causes a reduction in ascorbate and chlorophyll concentrations, which are related to an increase in the level of non-enzymatic antioxidants (glutathione, tocopherol, and protective carotenoids) (Herbinger et al., 2002). This causes a reduction in total photosynthesis, stomatal activity, relative water content, 100-grain weight, and eventually, yield in different wheat genotypes (Wasaya et al., 2021).

3.3 Drought Stress Management:

Changes in climate and global warming are continuously affecting agriculture balancing human wants and crop production, and the development of stress-tolerant varieties is necessary. Abiotic stress affects the yield and grain quality of wheat crops. Therefore, the production of drought-tolerant wheat varieties is important in agriculture. Various breeding and agronomic approaches are used to fulfill these needs and manage abiotic stresses (Savyata Kandel, 2021). A multidisciplinary strategy is required to solve the problem of drought stress, including water engineering, agronomy, plant breeding, physiology, and biotechnology (Rakshit et al., 2020). To overcome drought stress, plants perform various mechanisms such as drought tolerance, avoidance, and escape (Hussain et al., 2019)

3.3.1 Genetic Management

Because of innate genetic variation and environmental adaptability, certain wheat crop genotypes can tolerate and flourish under drought stress conditions, leading to the production of drought stress-tolerant varieties. Understanding the physiological, biochemical, genetic, and environmental systems is crucial for the development of drought tolerance variety development (Bapela et al., 2022). Most wheat breeding programs place high importance on breeding for steady output in both the good and poor seasons. Various approaches have been proposed to enhance wheat crop drought resistance, including deep genetic analysis, altering the expression of genes involved in stress responses, focusing on particular physiological features, and direct selection under a variety of stress conditions (Langridge and Reynolds, 2021). The present-day genetic approach assesses adaptability in plants under changing climatic conditions (Kumar et al., 2010; Kumari et al., 2007). Evaluation and assessment can be performed by screening various genotypes to identify novel trait combinations (Langridge and Reynolds, 2021). Genetic engineering and transgenic approaches help develop desirable varieties with desirable characteristics to escape drought stress in wheat (Chapman et al., 2012). The complex trait of drought tolerance is controlled by polygenes and expression of this is influenced by a multitude of environmental variables thus it is very difficult to breed for this trait, and that in order to produce genotypes that are drought-tolerant, new molecular methods like as gene expression patterns, QTL mapping processes, and molecular markers should be used (Poddar et al., 2022).

In Nepal, a study showed that BL4335 had a maximum mean TKW of 47.25 g, NL1327 was high yielding with 2.0 ton/ha and NL1325 yielded a low yielding of 1.04 ton/ha (Poudel et al., 2020b). A second experiment was carried out at a greenhouse to screen 60 distinct genotypes of wheat, which included three international drought-tolerant check cultivars, commercial cultivars, advanced lines derived from CIMMYT and NWRP, and Nepalese landraces. There was a significant variation in the morphology and physiology of wheat under both moisture-stressed and non-stressed conditions. Among Nepalese cultivars, Gautam outperformed Bhrikuti and Vijaya in drought-related characteristics (Pokhrel et al., 2013).

3.3.2 Agronomic Management:

In order to address the issue of drought in crops, agronomic techniques including soil covering, minimum tillage, intercropping, early planting, suitable crop variety selection, and modern irrigation techniques are technically and financially possible (Rakshit et al., 2020). To manage drought, sowing time is an important factor in subtropical, tropical, and rainy environments, as we can escape the dry period during the critical stages (Haefele and Bouman, 2009).

Changing the sowing time, adequate irrigation, and seed priming are the major agronomic practices that can overcome the effects of drought stress in wheat (Hussain et al., 2019). Strategies for managing drought stress must focus on obtaining moisture from the soil as well as crop establishment, biomass, growth, and grain output. Seed priming aids in germination, emergence, and seedling vigor, and its action along with osmoprotectants helps to preserve and repair nucleic acids, improve protein synthesis, and repair cellular membranes (Ahmad et al., 2018). Under drought stress, seed priming preserves the ideal plant population and enhances output by increasing seedling vigor and germination percentage (Sharma et al., 2022b). Similarly, it is believed that bacterial priming is a useful strategy for reducing the impact of drought on wheat. The inoculation of wheat with endophytic actinobacteria activated hormone production in plants, which increased soil mineralization and nitrogen availability during droughts (Yandigeri et al., 2012). In addition to hydropriming, auxin priming, halo priming ($CaSO_4$), chemical priming (KH_2PO_4, H_2O_2, SNP), and gibberellic acid (GA_3) priming are also effective in developing drought (Hussain et al., 2019). Nitrogen (N) and zinc (Zn) application enhances leaf area, crop growth rate, biomass, and grain yield of wheat under combined heat (late planting) and drought stress, which helps in the management of stress (Kibe et al., 2006). The use of organic manure enhances the water retention capacity of the soil. Thus, the application of organic manure also helps improvedrought tolerance in wheat (Carter, 2002). Plants are protected from drought stress by the exogenous application of different drought stress protectors, such as phytohormones, osmoprotectants, signaling molecules, and trace elements, which reduce the harmful effects drought (Nyaupane et al., 2024; Sharma et al., 2012). "**Error! Reference source not found.** (Cheng et al., 2016)" gives us the idea about management of drought through agronomic measures.

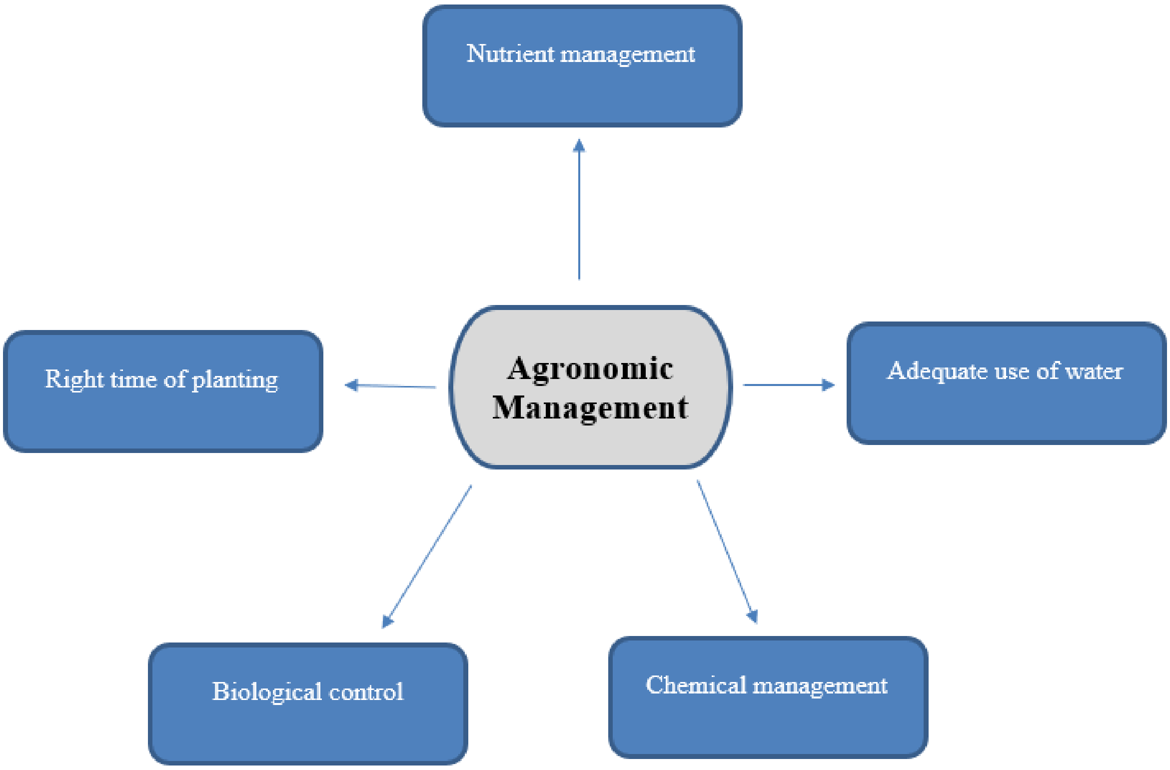

Figure 3: Agronomic management practices for drought mitigation

4. Conclusion

Drought stress is one of the primary factors restricting wheat crop production. Drought stress and climate change can reduce the global wheat production and supply. Progress in developing drought tolerance and management is slow and has not been done properly. Thus, to manage drought in wheat, we must understand the morphology, physiology, and biochemistry of wheat plants. By understanding these aspects, we can obtain information on plant regulatory mechanisms and stress management according to need. For the management of abiotic stresses, we need to know about the escape, tolerance, and avoidance of stress in wheat. Improved cultivars and varieties with enhanced tolerance to drought play a vital role in coping with stress. Genetic management should be the main concern of breeders in managing drought stress, whereas agronomic management processes also help to cope with stress to some extent. Thus, the information from this review can be used to understand different aspects of wheat plants to manage drought stress and produce drought resistant crop varieties for the purpose of stable wheat production.

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