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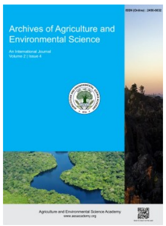

REVIEW ARTICLE

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A comprehensive review on drought stress in wheat: Causes, mechanism and management practices

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ABSTRACT

Plant health is cornerstone for agricultue productivity and food security. Severe impacts have been observed in wheat crop including physiological, morphological and bio chemical components as a result of water insufficiency. Seedling growth aspects such as seedling length, length of primary roots, seedling dry weight, and germination percentage are also affected whenever water scarcity prevails in the soil. Early flag leaf senescence decreased the grain yield of wheat while a delay in flag leaf senescence enhanced the grain yield of wheat under drought stress. Physiological phenomena like chlorophyll content, photosynthesis rate, rate of evapotranspiration, and relative water content in wheat are affected by water scarcity in soil. Proline content, osmotic adjustment, and abscisic acid accumulations are affected in periods of water deficit in wheat. Escape, avoidance, recovery, and tolerance meachanism appear in the wheat crop to sort out drought stress. More effective and suitable drought-resistant wheat cultivars producing through advanced techniques are pivotal to combat against drought stress as well as for higher yield and sustainability purposes. In this paper we discussed the causes, mechanism and management practices of drought stress in wheat.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the world's most important cereal crops in the Poaceae family (Poudel *et al*., 2020). It is the most planted crop globally occupying a total area of 216 million hectares with an average yield in 2021-22 of 768.9 million metric tons (Dhakal *et al*., 2021). In Nepal, Wheat is grown on a total of 711,067 hectares and total production is 2,127,276 Metric tons in the year 2021/22 (Ministry of Agriculture and Livestock Development, 2021). They are more appropriate than maize as a source of energy when used in the concentrates, and in addition to this, sunflowers can be used as a replacement for the grain because they can supply more protein per unit of weight than the grain or maize. Wheat is significant in the feed and Livestock industry. Wheat straw could be used as a binder to feed cows with developing diets that might allow manufacturers to get the most from their better-quality feed ingredients (Tufail *et al*., 2021). Due to the ever-increasing world population, the desire for wheat in the world has risen; therefore, it has been estimated that grain production in the world should increase by 60 percent by 2050 to meet the requirements of the world's 9 billion population (Borisjuk *et al*., 2019). All ecological pressures are unfavorable to wheat development and its formation, of all loads, drought loading is the most lethal to yield (Sattar *et al*., 2023). Drought therefore is assumed to be the most abiotic stress factor that affects plant growth and food production (Zhang *et al*., 2018). Wheat crop water requirement is estimated to be 266.8-500 mm, which is considerably higher than other crops like maize (Poudel *et al*., 2020). The permanent wilting point of wheat is about -1.5 Mpa or -15 bar/atmosphere. A permanent wilting point is a point at which the crop plant has access to no water and displays wilting or death signs and cannot be rehabilitated even with water. Irrigation is only installed in 346,895 thousand hectares of the total land area, while the remaining area relies solely on rainfall. Elevated atmospheric CO_2 level means a change in the climate and also the pattern of rainfall and seasonal dry period (Zaheer *et al.*, 2021). The increase in the temperature of the earth is 0.06 °C every year while the average rainfall reduces to 16.09 mm (Nyaupane *et al.*, 2024). The future incidences of water stress are very realistic because of changes in climate for the whole world and the reduction of water availability for agricultural purposes (Stevens & Madani, 2016). Climate change was estimated to reduce global production of wheat by −1.9% in mid -century (Pequeno *et al.*, 2021). Out of all the fresh water available globally, about 70% of it goes to agricultural use hence presenting an opportunity to have technologies that can help to properly utilize this water (Zia *et al.*, 2021). Growing drought-tolerant wheat genotypes may be a sustainable option to increase wheat productivity under drought-stress conditions (Ahmad *et al.*, 2022). In summary, the major goal of this study is an approach that attempts to understand drought stress, the morphological, biochemical, and physiologic impacts of drought stress, different mechanisms of drought resistance observed, and management strategies that can assist the plant breachers in finding ways that can help to mitigate the effects of drought stress on food crops and ensure food and nutritional security around the world. Stress is classified into two classifications biotic and abiotic and their main cause of minimizing yields. Amelioration between abiotic and biotic stress enhances plant performance by decreasing the probability of biotic stress from diseases' pathogens (Ben Rejeb *et al.*, 2014).

ABIOTIC STRESS IN WHEAT

Abiotic stress includes extreme temperature stress, flooding stress, salinity stress, metal stress, nutrient stress, and drought stress (Zhang *et al.*, 2023). High temperature, water stress, deficiency, and toxicity of plant nutrients result in an overall yield loss of (51–82)% of crop production across the world (Teshome *et al.*, 2020). Osmotic stress due to salinity can be considered as one of the major abiotic stresses affecting crops along with causing cellular dehydration, and the secondary metabolites such as terpenoids, flavonoids, alkaloids, steroids, and phenolic compounds are the defense mechanisms in plants against salt stress (Jan *et al.*, 2021). 'Law of diminishing yield increment' postulates that if the specific nutrient is continuously supplied, they have tendency to hold other nutrients and genetic potentiality of successive crops in low yield. Yield in crops is lowered by such factors like physiological factors, toxicity, and imbalance leading to over availability of any particular nutrient in the soil (Zhang *et al.*, 2023).

Drought stress

Technically, drought stress can be described as a deficiency of water that leads to phenomenal changes at market, biochemical, physiological, and molecular levels (Sallam *et al.*, 2019). It takes place when the available soil moisture fails to meet the plant requirement because of low precipitation, high evapotranspiration, and low water capacity in the rhizosphere zone (Mwamahonje *et al.*, 2021). Meteorological drought deals with the dryness of a particular place for a certain period of time depending on the region (Mwamahonje *et al.*, 2021). The kind of stress that develops when plants cannot effectively take water from the soil although the soil has effective moisture is referred to as pseudo drought stress or physiological drought stress (Seleiman *et al.*, 2021). Among the total districts affected by droughts, 33% get a mean annual rainfall of less than 750 mm, these areas are termed as 'chronically drought-prone' while 35% get a mean annual rainfall of 750- 1125 mm and are termed as 'drought-prone' (Seleiman *et al.*, 2021). Rising temperatures and changes in precipitation patterns lead to increasing incidence and intensity of drought events. climate change will increase the frequency of droughts and floods, both of which will be problematic for food production.

EFFECT OF DROUGHT STRESS ON WHEAT MORPHOLOGY

Figure 1 showing drought stress elicits morphological, physiological, biochemical, cell, and molecular changes altogether (Ilyas *et al.*, 2021). Wheat seedling goes through various developmental stages such as the germination phase, seedling development phase, tillering phase, stem extension phase, booting phase, heading phase, flowering phase, and grain filling phase (Khadka *et al.*, 2020). Among them, plants may be drought-stressed at any developmental stage at different levels of intensity (Sallam *et al.*, 2019).

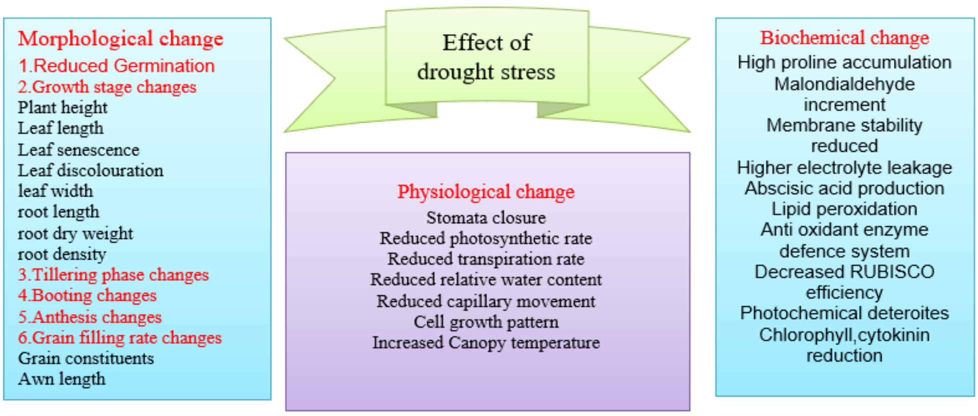

Figure 1. *Effect on wheat Morphology, physiology, and biochemistry (Source: Nyaupane et al., 2024).*

Seed germination and seedling growth stage

Seed germination begins with the intake of water by the seed but when water is limited the seeds do not intake enough water and thus affect the rate of germination as well as the population density per unit area. In water-deficit conditions, seed germination declines to 32.83-53.50% (Mahpara *et al.*, 2022). The extent by which morphological adaptation has occurred can be grouped into two categories namely; shoot parts and root parts. The shoot parts include changes in leaf shape, leaf expansion, leaf size, leaf area, cuticle tolerance, leaf pubescence, reduction in plant height, Leaf discoloration, and leaf senescence, Whereas, the lower root parts include changes in root dry weight, root density, and root length (Sahani *et al.*, 2021). When grown under drought conditions, the maximum mean plant height achieved for the BL4335 genotype was 73.25 cm (Poudel *et al.*, 2020). When water is scarce the leaves turn yellow, this stalls the photosynthesis process and leads to the last phase of a leaf's life, senescence (Sharma *et al.*, 2022). Lack of water reduces the intake of nitrogen by the crops, and hence Nitrogen is remobilized from the leaves and stems to the seeds leading to early loss of leaves (Hasanuzzaman *et al.*, 2020). The flag leaf is the main photosynthetic organ, meaning it is responsible for providing the crop with the energy it requires to go around the cycle (Nardino *et al.*, 2022). In wheat, early flag leaf senescence reduced the grain yield while delayed flag leaf senescence increased the grain yield under drought stress (Khadka *et al.*, 2020). Damage to Photosystem II occurs at the early senescence stage which consequently alters the structure, metabolism, and gene of the photosynthetic cell and reduces cellular chlorophyll content (Khadka *et al.*, 2020).

Tillering stage and flowering stage

It has an impact on different levels such as plant stand density in the establishment phase, tiller population per plant in the tillering phase, and plant height in the stretching phase. Drought was found to decrease the wheat biomass the most by 34.4% at the tillering stage (Bhandari *et al.*, 2021). During the flowering stage, the processes included in fertilization and grain fixation are most influenced and the number of plantable seeds per unit area reduces during droughts. Pollen sterility ranged from 1.1 to 9.1% under normal conditions and 5.7 to 11.7% under drought stress conditions (Lonbani & Arzani, 2011).

Grain filling stage and its constituents

Thousand-grain weight, grain area, grain perimeter, grain length, the length-to-width ratio of the grain, grain diameter, grain roundness, grain color (Green and Blue), and awn length all being higher order grain traits, are influenced by drought stress. Both drought stress and nitrogen levels affected the grain compositions containing the starch protein including gliadins gluten and fibers (Rakszegi *et al.*, 2019).

Grain weight and awn length

In the grain formation stage, the leaf's ability to utilize and transport the assimilates to the grain is most disoriented and so the grain weight is affected (Sarto *et al.*, 2017). similarly, maximum mean number of grains per spike of NL1244 was greater 46 and minimum of NL1247 was 29.25 (Poudel *et al.*, 2020). At low water availability, ear biomass and spikelet number decreased to a greater extent in the tetraploid and hexaploid species of wheat compared to the diploid species (Wang *et al.*, 2017). The awn length can be measured with reference to the spike tip or with reference to the longest awn. Awns had a relatively higher relative water content and photosynthetic electron transport rate under drought stress than the flag leaf, showing their ability to survive in low soil water levels (Khadka *et al.*, 2020). It was also found that awn length had a highly significant positive correlation with grain yield (Khadka *et al.*, 2020).

EFFECT ON WHEAT PHYSIOLOGY

It has been established that water deficit stress conditions elicit some changes in the cell division pattern, chlorophyll factory, rate of photosynthesis, rate of evapotranspiration, membranous stability condition, relative water content, gamete formation, fertilization, and temperature of canopy (Ilyas *et al.*, 2021).

Evapotranspiration and photosynthetic rate

It also causes deactivation of gibberellin acid in guard cells during the early stages of dry weather and interferes with production of gibberellin acid in the leaves to control canopy development and size of the transpiring surface (Shohat *et al.*, 2021). Maximum crop evapotranspiration occurs from heading to flowering and that particular stage of the crop is most sensitive to water deficits (Sarto *et al.*, 2017). Soil drought conditions lead to early stomata closure, which in turn reduces the CO_2 diffusion rate, and accounts for turgor pressure, lower activity of different photosynthetic enzymes, a reduction of biochemical components, formation of triose-phosphate and lowering down of photochemical efficiency of photosystem II (Pandey and Shukla, 2015). It affects the chlorophyll content and is said to cause photoinhibition of the photosynthesis process during a dry spell (Rijal *et al.*, 2020). Because of the changes in energy absorption, trapping, and electron transport, the drought stress led to the impairment of the electron of chlorophyll a transformation to the PSII reaction center, and thus a decrease in the photosynthetic PSII efficiency (Faseela *et al.*, 2020).

Gametogenesis and fertilization

The reproductive organs exposed to drought stress represent meiotic defects due to the morphological, structural, and metabolic alterations that raise the chances of premature gametes and reproductive sterility. Such stress also reduces the water availability in plant reproductive organs such as style and stigma as well as reduces pollen viability leading to poor fertilization (Nyaupane *et al.*, 2024).

Canopy temperature

Canopy temperature has been a good measure of plant water status as it can be used in order to estimate the changes in stomatal conductance using a non-destructive technique that is contactless. The difference in air temperature and canopy temperature is called Canopy Temperature Depression. In water-insufficient conditions, this leads to a reduction of water transpiration accompanied by an increase in plant canopy or surface temperature (Ahmed *et al.*, 2020). Canopy temperature can be obtained using an infra-red thermometer and this was done within two hours of mid-day, and with sun angle directed to the South (Tasmina *et al.*, 2017).

EFFECTS ON WHEAT BIOCHEMISTRY

Proline content, antioxidant enzymes defense system, osmotic adjustment, production, lipid peroxidation, photochemical efficiency, ROS, chlorophyll content, cytokinin, ABA, cysteine content, MDA, electrolyte leakages, membrane stability are affected by water deficient (Sarto *et al.*, 2017).

Membrane stability, electrolyte leakage, and malondialdehyde content

Membrane stability and electrolyte leakage are inversely related in that high electrolyte leakage is indicative of low stability of the cellular membrane. The increases in oxidative stress characterized by Malondialdehyde (MDA), high electrolyte leakage, and a decline in membrane stability are also noticed in water-inadequate situation (Ahmed *et al.*, 2019).

Proline content

Proline increases simultaneously with the formation of water pressure and dissolves quickly after pressure is released due to changes in cytosolic synthesis and mitochondrial breakdown (Sharma *et al.*, 2022).

Reactive oxygen species

The oxygen molecule is the last acceptor protein in the series of oxidation-reduction reactions of the electron transport chain. Stomatal closure under drought stress results in a disruption between electron excitation and photosynthetic consumption thereby generating ROS such as superoxide and hydroxyl radical (Sharma *et al.*, 2022). Formation of H_2O_2 leads to the peroxidation of cellular membrane lipids and degradation of enzyme proteins and nucleic acid in Organelles including Chloroplast and mitochondria. Hence, such condition creates oxidative stress on the yields (Hussain *et al.*, 2019).

Abscisic acid and cysteine content

A major stress signal formed during drought is abscisic acid which leads to a decrease in cytokinin contents in plants (Nyaupane *et al.*, 2024). Stomata closure during water deficit is controlled by the hormone abscisic acid which results in the inhibition of xylem transport, and reduction of turgor pressure and in turn, affects root growth (Osmolovskaya *et al.*, 2018). Cysteine is present in the wheat organs found in the leaves. In water-insufficient conditions, its contribution to proteolysis activity increases (Poddar *et al.*, 2022).

DROUGHT RESISTANCE AND TOLERANCE MECHANISM

Drought resistance is the capacity to yield its economic product with a minor reduction in a water deficit environment vis a water-free constraint environment (Rijal *et al.*, 2020). Drought resistance in plants involves mainly 4 mechanisms- drought avoidance, drought tolerance, drought escape, and drought recovery (Fang & Xiong, 2015). Figure 2. The process of shortening the life cycle or growing season of plants to avoid dry environmental conditions is known as drought escape (Rijal *et al.*, 2020). Reduced time to flowering and a shorter time in the vegetative phase can be highly beneficial to wheat seedlings during the drought as this will reduce the time that it will take to be exposed to drought during the flowering and post-flowering grain fill periods (Shavrukov *et al.*, 2017). A short vegetative phase will lead to low plant biomass because less time is available to produce photosynthates and to fill seeds with nutrients (Shavrukov *et al.*, 2017). Drought avoidance is the capacity of plants to retain relatively high tissue water potential in order to support physiological activities despite a lack of water in the root zone. It is the mechanism of slow plant growth, apertures closure, decreased rate of photosynthesis and transpiration, minimal root system formation, and change in many other bodily processes (Shavrukov *et al.*, 2017). Leaf rolling is one of the most general forms of protection against water loss (Chutia & Borah, 2012). Some adaptive features of plant roots to drought include long root length, dense root mass, and high root mass density. A Denser root system also absorbs a relatively bigger amount of water than thin roots because more roots could touch with a relatively bigger amount of water vapor that exists in the soil (Comas *et al.*, 2013). Drought tolerance refers to a plant's ability to withstand conditions of water deficit through physiological activities like the production of osmoprotectant, through morphological activities like enhanced root spread, through the formation of the waxy layer, and through biochemical activities like build up of proline and soluble sugars (Nyaupane *et al.*, 2024). Thus, the stress tolerance of wheat can be identified by determining the stress tolerance indices of wheat crops (Poudel *et al.*, 2023). The NL1327 genotype had a maximum mean yield of 2.0 tons per hectare in drought conditions (Poudel *et al.*, 2020). The morphological tolerance responses that wheat acclimatizes when experiencing drought stress include enhanced root penetration into the soil, enhanced root density, enhanced root-to-shoot ratio, presence of trichomes, and cuticular wax (Rijal *et al.*, 2020).

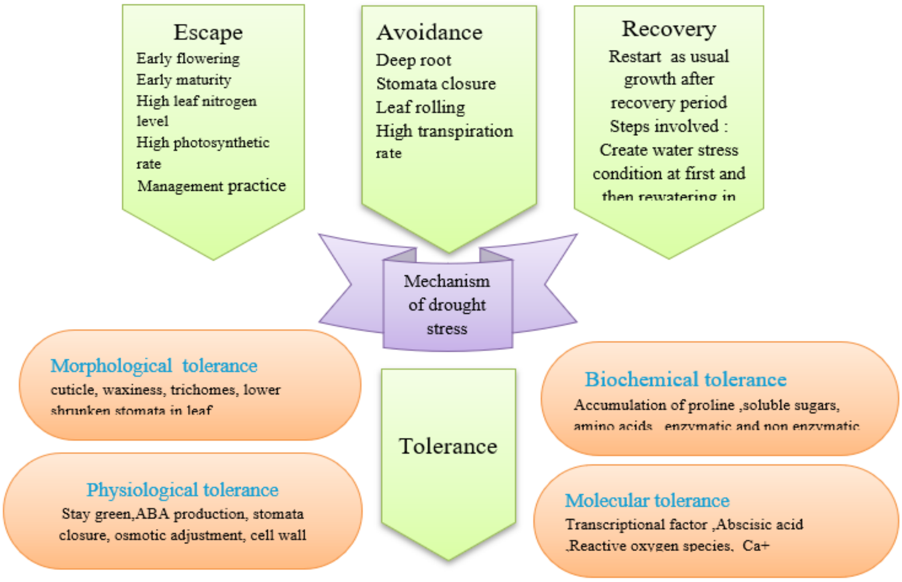

Figure 2. *Mechanism of drought resistance in wheat (Source: Nyaupane et al., 2024).*

Cuticular wax and trichomes presence

The cuticular membrane is thin, ranges from 0.1–10 μm in thickness, and consists of polyester and a single hydrocarbon chain (Bi *et al.*, 2017). Crops grown in drought conditions develop cuticular wax as a protective mechanism to minimize the decrease in leaf water potential, which is crucial for high photosynthesis rate and relatively high yield under drought stress (Guo *et al.*, 2016). The degree of waxiness is generally estimated visually determining the part of bluish-white colored wax on the surface of the shoot and spikes during field phenotyping. The degree of waxiness is generally estimated visually determining the part of bluish-white colored wax on the surface of the shoot and spikes during field phenotyping. Contrary to this, qualitative analysis of cuticular waxes reveals that those genotypes with higher β-diketones, one of the two main constituents of wax with alkanes being the other, are more drought resistant (Bi *et al.*, 2017). Trichomes are present on the outer epidermal layer of plants and help to add to the layer's depth, aiding in protection from drought stress.

Physiological drought tolerance

Other aspects of physiological drought tolerance are kept throughout the stay-green, alterations in the Leaf water potential, abscisic acid, osmotic adjustment, cell wall elastic adjustment, dehydrin, and transpiration efficiency.

Stay green

Stay-green is therefore the ability that enables plants to maintain green leaves under conditions of physiological drought stress in order to allow photosynthesis for the synthesis of energy and other nutrients in the wheat crops (Mwamahonje *et al.*, 2021). Delayed senescence and appearance of greenness are considered the stay-green trait of flag leaf under drought conditions and are involved in altering cytokinin and ethylene activities under drought conditions (Khadka *et al.*, 2020). Qualitative scores on the leaf color can be used to record the degree of flag leaf senescence.

Leaf water potential

Plants can regulate the amount of water that is present in the leaf through stomatal hole as a short-term strategy to water deficiency and also different strategies of root architecture as part of root development plans due to water pressure (Biel *et al.*, 2021). In those genotypes that sustained a higher rate of photosynthesis, the leaf water potential was most realised at the tillering stage of the crop (Abid *et al.*, 2018).

Abscisic acid production

ABA is one of the root signaling hormones synthesized during water deficit conditions and has a major role for reduction of stomatal conductance for transpiration as well as involved in the promotion of nHRS (Kong *et al.*, 2021).

Osmotic adjustment and cell wall elasticity

The process by which plant cells accumulate solutes up to a total concentration higher than the external soil solution and promote water from the soil into the cell in water-stress condition is known as osmotic adjustment (Hou *et al.*, 2021). Such solutes shield the cells architecture, catalyze their function, enhance osmosis, and avert dehydration damages by preserving cell turgidity. Cell wall elastic adjustment property increases during water stress conditions in order to avoid the decrease in water potential due to cell shrinkage and, consequently, the reduction of cell size (DaCosta & Huang, 2006).

Dehydrin and transpiration efficiency

Dehydrin is one of the hydrophilic proteins created as a drought tolerance option and has the capacity to increase the shoot dry matter production in wheat crops through increased water holding capacity, increased chlorophyll content, maintains photosynthesis and synthesis of compatible solutes (Hassan *et al.*, 2015). The rate of transpiration was reduced at higher extent than that of the rate of leaf net CO_2 assimilation under moisture stress conditions (Changhai *et al.*, 2010).

Bio chemical drought tolerance

Dissolvable sugars, cysteine, proline content, Glycine betaine, mannitol, Jasmonic acid Ethylene, Cytokinin, amino acids, chlorophyll content (Guizani *et al.*, 2023), enzymatic and non-enzymatic antioxidant activities, are synthesize inside the plant as a stress defense when confronted to drought (Rijal *et al.*, 2020). In the leaf and roots maximum concentration of water soluble carbohydrates of glucose, galactose, rhamnose and xylose content in drought tolerant genotypes were higher than that of sensitive genotypes (Samaneh *et al.*, 2020).

Cysteine and proline

The cysteine has been identified as a wheat antioxidant that guards against the oxidative stress caused by the water stress conditions by synthesizing the glutathione (Elkelish *et al.*, 2021). Proline works as an antioxidant and scavenges reactive oxygen species, protects the denaturation of macromolecules (Marthandan *et al.*, 2020). proline brings antioxidant properties and eliminates ROS, prevents the denaturation of macromolecules and controls cytosolic activity (Khan *et al.*, 2019).

Glycine betaine and mannitol

Glycine betaine is involved in osmoprotection due to drought stress by stabilizing osmotic potential and quaternarily structured proteins (Ahmed *et al.*, 2019). Mannitol is a sugar-alcohol that is involved in osmoregulation as a coenzyme regulator and scavenging of reactive oxygen species as compatible osmolytes to support cell turgor and beneficial plant water relations for the conservation of biological functions and soil water acquisition (El Habti *et al.*, 2020).

Jasmonic acid, cytokinin, and Ethylene

Jasmonic acid (JA) enhances the antioxidants activity, Cytokinin delays the senescence of leaves and Ethylene leads to stomatal closure and SodERF3 gene expression (Zia *et al.*, 2021) that cause tolerance to drought stress (Ilyas *et al.*, 2021).

Reactive oxygen species

Drought stress is one of the dreadful factors that lead to the enhancement of Reactive oxygen species which include singlet oxygen, hydrogen peroxide, superoxide, hydroxyl radicals, however, kept controlled by the antioxidant system in plants (Kaur & Asthir, 2017). Antioxidant enzyme catalaise and Ascorbate peroxidase of the cells neutralize reactive oxygen species including H_2O_2 by converting it to O_2 and H_2O. Nonenzymatic antioxidant activities take place through glutathione and carotenoids. Glutathione protects the chloroplast from the toxic effect of H_2O_2 by enhancing the ratio of the oxidized and reduced glutathione and carotenoid and detoxifies the integrant of the photosystem through dissipating excessive light energy to heat (Figure 3).

Molecular defence mechanism

Secondary messengers such as Ca^{2+}, ROS and ABA have crucial function in the signal-transmitting pathway (Kaur & Asthir, 2017). MAPK (Mittogen activated protein Kinase) phosphorylation results in activation of transcription factors and synthesis of drought tolerance protein which lowers moisture stress in wheat crop (Nykiel *et al.*, 2022). Several transcription factors genes including bZIP, DREB, DOF, HSF, MYB, NAC, and WRKY involved in drought tolerance protein formation (Hrmova & Hussain, 2021). There were two sets of genes in plants under drought stress: the ABA-responsive genes including bZIP, HSF, MYB, and WRKY and the non-ABA-responsive gene including HSF, WRKY, ERF, and NAC (Hrmova & Hussain, 2021). The target proteins of drought-responsive genes are the proteins that belong to signalizing and transcription regulation (protein kinases, phosphatases, and transcription factors), protect cytomembrane, and other LEA proteins, antioxidants, osmoprotectants, aquaporines and sugar transporters. Plants manage the genes expressing some antioxidant enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidases which are involved in combating ROS thereby minimizing oxidative injury. Increases of abscisic acid in roots in response to drought induce different stress responsive genes (Muhammad Aslam *et al.*, 2022). This leads to the build up of compatible solutes, LEA proteins, dehydrins and shock proteins, chitinases glucanases and other protective proteins (Figure 4). Heat shock protein such products enable plant to adjust osmotic potential of the leaf and retain higher level of relative water in the leaf at low leaf water potential under drought (Nykiel *et al.*, 2022).

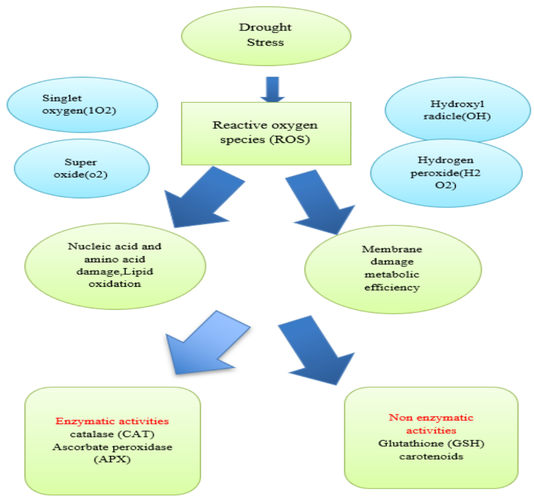

Figure 3. *Biochemical drought tolerance mechanism in wheat.*

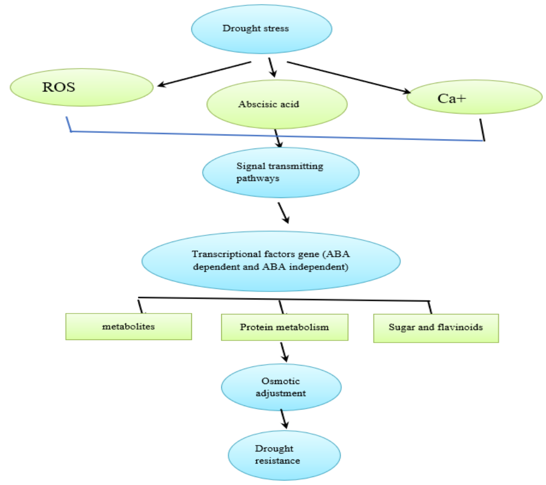

Figure 4. *ABA involved in molecular drought tolerance.*

Drought recovery

Drought recovery is the capacity of the plant to resume growth following exposure to severe drought stress (Ilyas *et al.*, 2021). Restoration capacity is important for genetic advancement and production of improved drought-tolerant type of crop species. Leaf respiration of three wheat genotypes was observed by exposing them to drought stress and rapid recovery was observed in the Katya genotype by rewatering which is considered as most drought tolerant. Leaf respiration experiment was conducted on three wheat genotypes with and without drought stress, quick recovery of photosynthesis was noted in Katya genotype by rewatering thinking it most tolerant to drought (Vassileva *et al.*, 2011). Post-drought recovery is possible through proline accumulation in such conditions.

MANAGEMENT PRACTICES FOR DROUGHT STRESS IN WHEAT

Drought stress can be managed by the production of the appropriate wheat genotypes using various genetic technologies along with the adjustment of agronomic practices.

Genetic management

The plant growth should be minimized in farms and crops should only be grown under conditions of drought stress. New-generation drought-tolerant wheat cultivars are being produced by employing modern techniques like physiological trait-based breeding, QTL, transgenic technology, and the application of different chemical substances like nitric oxide, glycine, proline, antioxidants, and microorganisms like fungi, and bacteria (Ilyas *et al.*, 2021), Genome editing, Genetic marker-assisted backcrossing (Sharma *et al.*, 2022). CRISPR/Cas9 is preferred over other conventional genome editing because of two main advantages (Sami *et al.*, 2021), First is that sgRNAs can function with the same Cas9 protein at different locations and second the target DNA specificity can be easily changed by reprogramming the sgRNA sequence (Sami *et al.*, 2021). QTLs may be transferred to wheat using CriSpr-Cas9 technology that produces transgenic wheat with potential for drought stress tolerance of physiological traits like net photosynthesis, relative water content, and cell membrane stability undiscovered by previous methods (Poddar *et al.*, 2022). Transgenic approach points out the genes, microRNA, and transcription factors that would help introduce the desired characteristics into transgenic plants (Anwar & Kim, 2020). Gene encoding elements like bZIP, bHLH, ERF, NAC, HD-ZIP and WRKY are employed as drought tolerance tools in wheat. MicroRNAs (miRNA) are a complex of small single-strand RNA with a length of (21 – 24) nucletides that are involved in specific regulation of gene expression during the plant defense response toward the biotic and abiotic stress stimuli (Anwar & Kim, 2020). A marker is a segment of DNA that links that specific site within the genome to a particular location and is used for the identification of stress –resistance traits. Pcr and non Pcr based molecular markers such as restriction fragment length polymorphisms (RFLP), AFLP, Simple Sequence Repeat (SSR), and Single nucleotide polymorphism (SNP) are employed to track stress resistance traits (Younis *et al.*, 2020). Some of the adaptation strategies developed through genetic and phenotypic variations by the plants to defend themselves against the abiotic stress include; molecular crosstalk, epigenetic memories, ROS signaling, plant hormone build up including salicylic acid, ethylene, jasmonic acid and abscisic acid, change in redox status, inorganic ion defense, R gene resistance and systemic acquired resistance (SAR) (Ghorbanpour & Varma, 2017). Genetic engineering for Water Use Efficiency (WUE) includes use of genes for compatible osmolytes such as sugar, and amino acids and overexpression of embryonic proteins for dehydration tolerance (Bagale, 2021).

Agronomic practices

Some of the management practices of drought stress, include seed treatment; seed priming; foliar spraying; application of organic matter; intercropping; provision of silage; construction of rain water harvesting structures; and use of micro irrigation techniques. When grown under conditions of water unavailability (Yadav *et al.*, 2023), seed priming with glycine betaine or with water minimized the level of electrolyte leakage and thereby enhanced the cellular membrane stability index (Ahmed *et al.*, 2019). Seed Ethephon application occupies the leaf water during tillering and stimulates the root volume and dry weight under drought stress (Yang *et al.*, 2021). There should be attempts to alter the flowering time; there should be breeding systems for the short or the long-dwelling crops; and there should be contamination screenings of tolerant germplasm (Dolferus *et al.*, 2011). Mulches prevent weed growth by denying them access to light into the soil while at the same time enhancing access to water in reducing plants in dry seasons (Nyaupane *et al.*, 2024). For improvement in the result, the diversification of the crop, water conservation, water harvesting, and watershed development should be given importance. Among the plant growth substances salicylic acid, cytokinin and Abscisic acid application enhance the water potential and chlorophyll content to minimize water stress in wheat plant, However it can be controlled by exogenous application of silicon (Lamaoui *et al.*, 2018). It was established that the ridge and furrows method and raised bed sowing used 20-30% less irrigation water and improves water use efficiency. The use of nitrogenous potassium fertilizer at the grain filling stage accelerates the rate of photosynthesis so as to enhance the dry matter translocation to veins and hence increase the grain weight through compensating for the effects of drought.

Effective management of irrigation water

Irrigation scheduling is the determination of the time and the rate at which irrigation should be practiced (Ahmad & Kumar, 2015). Schedule irrigation is one important factor that have been known to affect the efficient use of water, energy and other production inputs in the crop production system. It is suggested that water should be provided on the field soon after sowing the wheat seeds. In case of a shortage of water, wheat should be irrigated in it's critical stages such as the Crown Root Initiation Stage, the heading stage and the grain filling stage (Aryal *et al*., 2021). These stages are very critical stages where water supply is very crucial (Aryal *et al*., 2021). Based on the growing period, climate, and requirement of soil, wheat needs around 400-650 mm of water for best production (Pareek *et al*., 2023). Tensiometer in 35 cm depth at 50 Kpa tension recorded maximum grain yield of 3184 kg/ha in 2013/2014, while minimum grain yield was observed at tensiometer in 20 cm depth with 20 Kpa tension at 2502 kg/ha in 2013/2014.Performance of tensiometer in 35 cm depth with 50 Kpa tension in 2014/15 (Sah *et al*., 2017). In the case of the wheat, the plants took the largest amounts of soil water from the 0 to 45 cm soil profile. Thus, only 0 – 45 cm of the soil profile needs to be taken for scheduling irrigation water for wheat crops grown in sandy soil. Full supplemental irrigation treatments should only be initiated once the available soil water is at 50 percent of the total amount of water.

Application of organic amendments (Biochar)

Biochar is an organic soil conditioner which is used to enhance the content of carbon and organics in the soil, the capacity of the soil to conserve moisture, proper soil structure and fertility, and the porosity of the soil to improve the capacity of the soil to impound polyvalent cations (Zaheer *et al*., 2021). It gives a higher yield such as fertile tiler (19.50%), spikelet length (6.52%), number of grains per spikelet (3.07%), thousand grain weight (6.42%), biological yield (9.43%) and economic yield (13.92%) compared with the controlled condition of drought stress in wheat crop (Haider *et al*., 2020).

Conclusion

Plants suffer from drought stress at any phase of their lifecycle. Drought stress shows morphological effects on Germination, number of tillers, flag leaf, and root length. Similarly, Physiological processes such as relative water content, photosynthetic rate, and chlorophyll content vary with water availability in soil. Biochemical constituents like Proline content, Antioxidant enzymes defense system, osmotic adjustment, Abscisic acid production, and lipid peroxidation are also affected by water scarcity in soil. Basic physiological, morphological, and biochemical processes need to be studied well to clarify the defense mechanism of wheat crops. Mainly four main defense mechanisms escape, avoidance, recovery, and tolerance are shown by plants. Leaf respiration can be continued well by frequent watering after passing through drought soil conditions. Knowledge of these basic concepts helps researchers to find new drought-tolerant drought-drought-tolerant drought wheat cultivars using modern technology like Molecular markers, genome editing, and transcriptase factors.

DECLARATIONS

Author contribution statement

Conceptualization: S.S., S.B., Methodology, Software and validation: S.S., S.B., S.K.B.Y., M.P.; Resources: S.S., S.B., S.K.B.Y., M.P.; Data curation: S.S., S.B., S.K.B.Y., M.P.; Writing—original draft preparation, review and editing: S.S., S.B., S.K.B.Y., M.P.; Visualization, Supervision: S.S., S.B. Project administration: S.S.. All authors have read and agreed to the published version of the manuscript.

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