Review on Effect, Mechanism and Management Methods of Drought Resistance in Wheat

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Abstract

Wheat is considered as limiting factor for crop productivity and food security. Morphological, physiological and bio chemical phenomena are affected by water unavailability in soil. Morphological changes like seedling length, primary roots length, seedling fresh weight, seedling dry weight, shoot dry weight, germination rate occur during drought condition in soil. Changes in physiological phenomena like cell growth pattern, chlorophyll content and photosynthetic rate, evapotranspiration rate, membranous stability, relative water content occurs by water scarcity in soil. Bio chemical changes in proline content, Anti-oxidant enzymes defence system, osmotic adjustment, abscisic acid production, lipid peroxidation occurs at water deficient period in wheat. Despite of these all causes, 4 mechanism of drought tolerance *i.e.*, escape, avoidance, recovery, tolerance are present in wheat crop are studied in this review. Drought-tolerant wheat cultivars should be developed using modern approaches such as physiological trait-based breeding, molecular breeding, marker-assisted backcrossing, genome editing, transcriptase factors.

Keywords: Abiotic stress • Morphology • Reactive oxygen species • Osmotic adjustment • Abscisic acid

Introduction

Wheat (*Triticum aestivum* L.) is one of the world's most important cereal crops, belonging to the Poaceae family. It is the most planted crop in the world, covering 216 million hectares with an average production in year 2021-22 was 768.9 million metric tonnes. In Nepal, wheat is cultivated altogether in 711,067-hectare area along with total productions of 2,127,276 metric tons in year 2078/79. Wheat grain consists of excellent source of starch 60%-70%, protein 6-26%, fibre, carbohydrates, minerals 2.1%, fat 2.10 vitamins [1]. It can replace maize as a high-energy ingredient in concentrates, with extra advantages that it requires less protein supplementation than maize due to its higher protein content. Wheat significance has been expanding much more due to often encountering food shortages in human diet. It has a major contribution to the animal feed and livestock industry too. Wheat straw might be utilized as a fixing in cows developing diets to assist makers with achieving most extreme use from their higher quality feedstuffs. The constantly raising population of the world has increased the demand for wheat in the world, so it has been estimated production of wheat in the world should increase by 60% by 2050 fulfilling requirement of 9 billion population of the world.

All ecological stresses adversely affect the development of wheat and its creation, among every burdens, drought stress has demonstrated more deadly to yield [2]. Drought is considered as most limiting factors for crops productivity and food security. Wheat seedling passes through different phase like germination, seedling growth stage, tillering stage, stem elongation, booting, heading, anthesis, grain filling stage, among them plant may suffered from drought stress at any phase of their lifecycle at varying degree of severity. Water prerequisite of wheat crop is assessed to be 266.8-500 mm which is a lot higher when compared with water necessity of different yields including maize. Globally, only 346,895 thousand hectares of land area is under irrigation and the rest fully depends upon the natural rainfall. Annually, the temperature of the earth rises at the rate of 0.06°C with a decline in precipitation of 16.09 mm. The possibility of water stress in the future is high due to global climate changes and a decrease in water resources for agriculture. Climate change is projected to decrease global wheat production by -1.9% by mid-century [3]. Approximately 70% of the global fresh water supply is used in agriculture, creating a great opportunity for technology to provide solutions for effective use of the available water.

Growing drought-tolerant wheat genotypes may be a sustainable option to increase wheat productivity under drought stress conditions. Drought tolerance is defined as the ability of a crop plant to produce its economic product with minimum loss in a water-deficit environment relative to the water-constraint-free management. Overall, the major objective of this study is an approach that aims to study drought stress, its morphological, biochemical and physiological consequences, various drought resistance mechanisms observed as well as management methods that helps plant breeders search for various ways that can help to cope the effect of drought stress in food crops and provide worldwide food and nutritional security.

Literature Review

Stress is ordered into two classifications biotic and abiotic and these are the significant reason for the reduction in yields [4]. Interaction between abiotic and biotic stress have a positive effect on plant performance by reducing the susceptibility to biotic stress such as resistance to the infection from pathogen.

Biotic stress

Pests, parasites and pathogens like fungi, nematodes, virus infect plants and induces biotic stress. A global survey on the major food crops found that pathogens, insect pests and weeds cause average yield losses ranging from 17.2%-30% [5].

Abiotic stress

Abiotic stress includes extreme temperature stress, flooding stress, salinity stress, metal stress, nutrient stress, drought stress. High temperature, water stress, deficiency and toxicity of plant nutrients cause 51%-82% annual loss of crop yield in the world. Salinity is one of major abiotic stress in crop that causes cellular dehydration, osmotic pressure and also leads to the accumulation of specific secondary metabolites like terpenoids, flavonoids, alkaloids, steroids and phenolic that act as plant defensive tool against salt stress. Yield in crops is reduced due to physiological factors, toxicity as well as over availability of a certain nutrients in soil. 'Law of diminishing yield increment' states that if there is a continuous provision of a particular nutrient, it will limit the availability of other nutrients and genetic potential of crops resulting in reduction of yield [6].

Plants suffered from drought mainly by high evaporative demand, low water availability and low water holding capacity around the rhizosphere. The condition in which plant are unable to absorb moisture from soil although there is efficient moisture in soil is termed as pseudo drought stress or physiological drought stress. Out of total drought affected areas, 33% receives less than 750 mm of mean annual rainfall and is classified as "chronically drought-prone" while 35% which receive mean annual rainfall of 750 m-1125 mm is classified as "drought-prone". Morphological, physiological, biochemical, cellular and molecular consequences are observed under drought stress.

Effect on wheat morphology

Morphological response of wheat can be classified into two types *i.e.*, shoot parts and root parts. The shoot parts include changes in leaf shape, leaf expansion, leaf size, leaf area, leaf senescence, cuticle tolerance, leaf pubescence and reduction in shoot length. Whereas, the lower root parts include changes in root dry weight, root density and root length. Seed germination starts as the seed imbibes water but when there is scarcity of water, seeds do not imbibe sufficient water which reduces germination rate as well as overall plant population per unit area. Seed germination is reduced by 32.83 to 53.50% under water scarce condition [7]. The dehydration of protoplasm, which ultimately reduces cell division, cell expansion and loss of cell turbidity, may be the cause of the significant reduction in plant height. Absence of water diminishes the nitrogen take-up by the crops which causes the remobilization of nitrogen from leaves and stems to seeds resulting early leaf senescence.

The drought affects the plant density in the initial phase, tiller number per plant in the tillering phase and plant height in the stretching phase extremely. Drought was found to decrease the wheat biomass the most by 34.4% at the tillering stage. At the flowering stage, the processes related to fertilization and fixation of grain are most severely affected and the number of viable seeds per area decreases. In the grain formation stage, the ability of the leaf to use and translocate the assimilates to the grain is most severely affected, thus affecting the grain weight. In drought condition BL4335 genotype had maximum mean plant height of 73.25 cm, similarly, NL1244 had maximum mean number of grain per spike of 46 and NL1247 had minimum number of grain per spike of 29.25. Drought stress increased the days to maturity, flag leaf length, maximum quantum yield of photosystem II by 2.05%, 1.42 % and 3.56 %. Under water scarce conditions, above ground biomass, ear biomass, spikelet number, tiller number, plant height reduced more in the tetraploid and hexaploid species of wheat than in the diploid [8].

Effect on wheat physiology

Water deficient condition brings physiological effects in cell growth pattern, chlorophyll content and photosynthetic rate, evapotranspiration rate, membranous stability condition, relative water content, gametogenesis, fertilization. Drought leads to gibberellin acid deactivation in guard cells, contributes to stomatal closure at the early stages of soil dehydration and inhibition of GA synthesis in leaves suppresses canopy growth as well as restricts transpiration area. The crop evapotranspiration increases maximum from heading to flowering which is the most sensitive stage of the crop to drought. Drought condition in soil causes early stomata closure which limits the CO_2 diffusion rate and results in loss of turgor, reduced activity of different photosynthetic enzymes, decrease of biochemical components as well as help in the formation triose-phosphate and reduction in the photochemical efficiency of photosystem II. Drought decreases chlorophyll content and responsible for photo inhibition in photosynthesis process. The drought stress caused the impaired electron of chlorophyll a transformation to PSII reaction centre due to the changes in energy absorption, trapping, electron transport which results in reduction of photosynthetic efficiency of PSII. The reproductive organs exposed to drought stress represent meiotic defects due to the morphological, structural and metabolic alterations that raises the chances of premature gametes and reproductive sterility. Such stress also reduces the water availability in the plant reproductive parts such as style, stigma and reduces pollen viability which raises poor fertilization.

Effect on wheat biochemistry

Proline content, antioxidant enzymes defence system, osmotic adjustment, production, lipid peroxidation, photochemical efficiency, Reactive Oxygen Species (ROS), chlorophyll content, cytokinin, abscisic acid, cysteine content are influenced by insufficiency of water [9]. Proline expansions occurs along with creation of water pressure and disperses rapidly after the pressure is eased because of contrasts in cytosolic synthesis and mitochondrial breakdown. Genotypes having maximum proline content would be able to protects the membranes from damage under stress and capable for surviving under drought stress conditions. The oxygen molecule is the final destination of the electron transport chain's series of proteins that are involved in oxidation-reduction reactions. Drought stress causes an imbalance between electron excitation and photosynthetic consumption, leading to the formation of Reactive Oxygen Species (ROS) like superoxide and hydrogen peroxide. 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, mitochondria, hence such condition creates oxidative stress on the yields. Major stress signal formed during drought is abscisic acid which leads to the decrement in cytokinin contents in plant. Drought-induced stomata closure is regulated by abscisic acid which leads to suppression of xylem transport, decrease in turgor pressure and finally result in root growth inhibition [10]. Drought stress had a significant impact on wheat grain composition, including starch protein, gliadins, glutein and fibers. Cysteine is expressed in wheat leaf organs and during drought, its contribution to proteolysis activity rises (Figure 1).

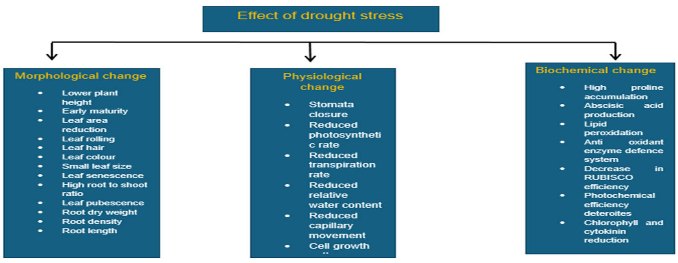

Figure 1. Effect on wheat morphology, physiology and biochemistry.

Drought resistance mechanism

Drought resistance refers to the ability of a crop to produce its economic product with minimum loss in a water-deficit environment relative to the water constraint free management. Drought resistance in plants involves mainly 4 mechanisms-drought avoidance, drought tolerance, drought escape and drought recovery [11].

Drought escape: The process of shortening the life cycle or growing season of plant in order to avoid the dry environmental conditions is known as drought escape. Early flowering time and a shorter vegetative stage in wheat can be very significant for wheat seedling at drought because this can minimize exposure to dehydration during the sensitive flowering and post-flowering, grain filling periods. A short vegetative phase can result in reduced plant biomass due to the reduction in time available for photosynthetic production and seed nutrient accumulation.

Drought avoidance: Drought avoidance is the ability of plants to maintain relatively high tissue water potential to continue physiological processes although there is a shortage of soil moisture. It is the mechanism of slow plant growth associated with closing of stomata, reduced photosynthesis, transpiration, root system development and alternation in many other physiological process. Leaf rolling is a versatile protection from water deficiency. Drought tolerant adaptive characters of plant roots includes long roots, high density and intense root system. Denser root system also absorbs larger quantity of water than thinner roots because of higher number of roots may contact with more water vapors present in the soil [12].

Drought tolerance: Drought tolerance is the ability of plant to resist dehydration through various physiological activities such as osmoprotectant synthesis, through morphological activities likes deep spread of roots, waxiness as well as through biochemical activities like accumulation of proline, soluble sugars. Tolerance efficiency of wheat can be known by evaluating stress tolerance indices of wheat. In drought condition NL1327 genotype had maximum mean yield of 2.0 ton/ha.

Morphological drought tolerance: Increased root penetration into the soil, increased root density and increased root to shoot ratio are the tolerant mechanisms that wheat uses to combat drought stress by prioritizing root development over shoot development. Cuticular wax is developed in crop grown in drought condition as adaptive mechanism to reduce the leaf water potential decrease, which is essential for high photosynthesis rate and relative high yield under drought stress.

Physiological drought tolerance: Physiological drought tolerance is maintained throught change in leaf water potential, abscisic acid, osmotic adjustment, cell wall elastic adjustment, dehydrin, transpiration efficiency. Plants can manage leaf water potential by adjusting the stomatal hole as transient response to water limitation and through difference in underground root development plan as a part of longer term water pressure. The genotypes that maintain a higher rate of photosynthesis, leaf water potential was found most at the tillering stage abscisic acid is one of the root signaling hormones produced during water deficient condition and played a major role in stomata conductance for transpiration reduction as well as involved in nHRS promotion. The way through which plant cell actively accumulate a total solute concentration higher than that of the external soil solution, which promote water from soil into the cell in water stress condition is known as osmotic adjustment. Such solutes protect cellular structure, promote their activities, facilitate water absorption and delay dehydration injuries by maintaining cell turgor pressure. Cell wall elastic adjustment property raises during water stress condition which prevent decline in water potential through reduction in cell size, shrinkage. Dehydrin is one of hydrophilic protein formed as drought tolerance tool characterized by a greater maintenance of shoot dry matter production in wheat crops by enhancing the water retention capacity, elevating chlorophyll content, maintaining photosynthesis and promoting the accumulation of compatible solutes. The transpiration rate decreased more efficiently than leaf net CO_2 assimilation rate at moisture stress condition.

Biochemical drought tolerance: Dissolvable sugars, cysteine, proline content, glycine betaine, mannitol, jasmonic acid ethylene, cytokinin, amino acids, chlorophyll content, enzymatic and non-enzymatic anti-oxidant activities, are developed within plant as tolerance mechanism under drought condition. Concentrations of water soluble carbohydrates like glucose, galactose, rhamnose and xylose content in the leaf and roots were higher in drought-tolerant genotypes than in sensitive ones. Cysteine is naturally occurring antioxidant in wheat crop which protect against the oxidative damage induced by water stress condition through the production of glutathione. Proline works as an antioxidant and scavenges reactive oxygen species, protects denaturation of macromolecules, regulates cytosolic activity. Glycine betaine have a protective role against drought stress by maintaining osmotic balance and protecting quaternary structures of proteins. Mannitol is sugar-alcohol which serves in osmoregulation as a coenzyme regulator and scavenging of reactive oxygen species acting as compatible osmolytes to maintain cell turgor and favorable plant water status, thereby sustaining biological processes and soil water uptake. Jasmonic Acid (JA) increase the activity of antioxidants, cytokinin prevents leaves senescence and ethylene induces stomatal closure along with expression of *SodERF3* gene, hence responsible for inducing tolerance to drought stress [13].

One of the inevitable consequences of drought stress is an increase in reactive oxygen species, classified as singlet oxygen, hydrogen peroxide, superoxide and hydroxyl radicals, however, kept controlled by antioxidant system in plant. Enzymatic antioxidant activities of Catalase (CAT) and Ascorbate Peroxidase (APX) coverts reactive oxygen species like H_2O_2 into O_2 and H_2O. Non enzymatic antioxidant activities take place through Glutathione (GSH) and carotenoids. GSH preserve chloroplast from H_2O_2 damage by increasing the ratio of reduced to oxidized glutathione and carotenoid protects the photosynthetic system by converting excess excitation energy into heat energy (Figure 2).

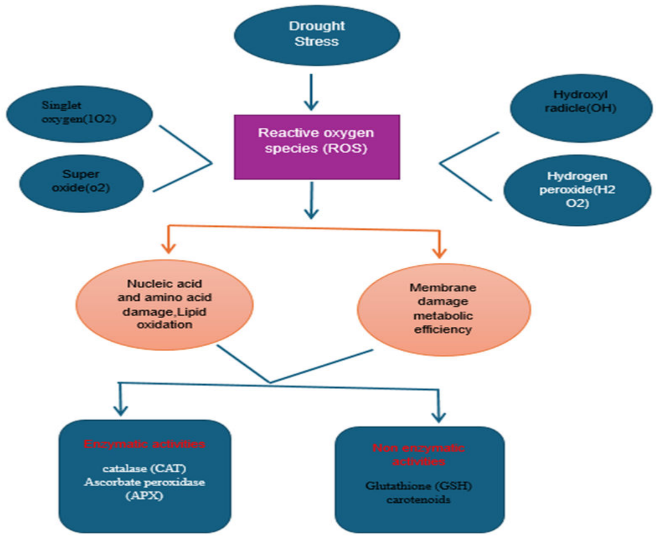

Figure 2. Biochemical drought tolerance in wheat.

Molecular defense mechanism: Secondary messengers like Ca^{2+}, ROS, ABA, perform important roles in signal transmitting pathways. MAPK phosphorylation pathway lead to activation of transcription factors resulting in formation of drought tolerance protein that reduces moisture stress in wheat crops. Several transcription factors genes such as basic Leucine Zipper (*bZIP*), Dehydration Responsive Element Binding (*DREB*), DNA-Binding with One Finger (DOF), Heat Shock Factor (*HSF*), Myeloblastoma (*MYB*), NAC and WRKY for the drought tolerance protein formation. Two types of genes were present in the plants in response to drought stress, ABA-dependent (*bZIP, HSF, MYB*) and *WRKY*) and ABA-independent (*HSF, WRKY, ERF, NAC*) based on their dependence on ABA [14]. The expression products of drought-responsive genes are mainly the proteins involved in the signalling pathway and transcriptional regulation (such as protein kinase, protein phosphatase and transcription factors), functional proteins that protect the cellular membranes and other proteins such as late embryogenesis abundant proteins, antioxidants, osmotin, proteins associated with the uptake and transport of water and ions such as aquaporins and sugar transporters. Plants regulate the genes that encode various antioxidant enzymes such as Superoxide Dismutase (SOD), Catalase (CAT) and peroxidases responsible to neutralize ROS leading to a reduction in oxidative damage.

Concentrations of abscisic acid in the roots increses in response to drought and promote different stress-responsive genes involving accumulation of compatible osmolytes, synthesis of Late Embryogenesis Abundant (LEA) proteins, dehydrins, chitinases, glucanases, as well as other protective proteins heat shock protein resulting osmotic adjustment which help to maintain higher leaf relative water content at low leaf water potential under drought (Figure 3) [15].

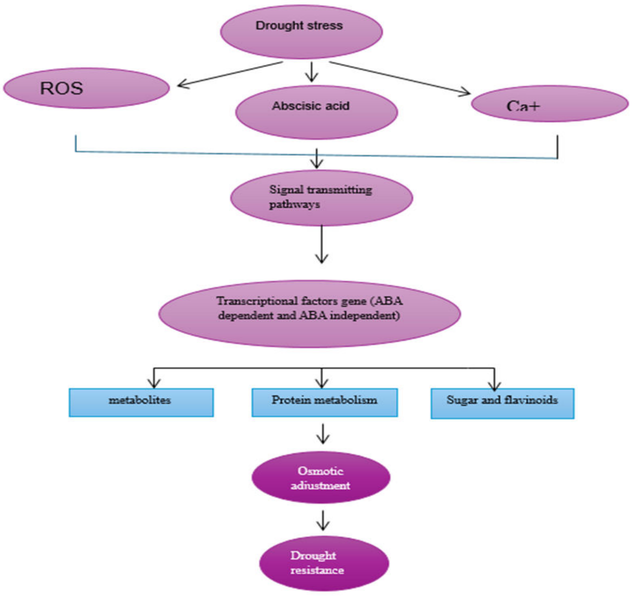

Figure 3. ABA involved in molecular drought tolerance.

Drought recovery: Drought recovery is the ability of plant to restart growth after the exposure to extreme drought stress. Recovering capacity is crucial for the development and introduction of more drought-tolerant genotypes of crop species. Leaf respiration of three wheat genotypes was observed by exposing them to drought stress and rapid recovery observed in katya genotype by rewatering which is considered as most drought tolerant. Post-drought recovery is possible through proline accumulation in such condition (Figure 4) [16].

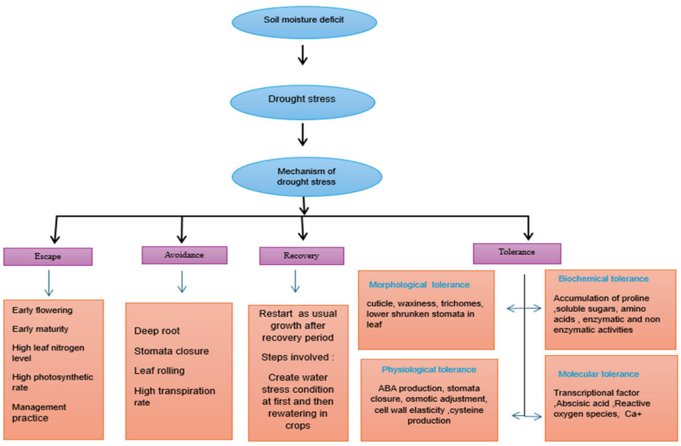

Figure 4. Mechanism of drought resistance in wheat.

Discussion

Management practices for drought stress in wheat

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

Genetic management: Farmers should reduce area under crop cultivation and only plant drought-tolerant plants under drought stress. Drought-tolerant wheat cultivars are being developed using modern technology such as physiological trait-based breeding, quantitative trait loci, transgenic approach and application of exogenous substances such as nitric oxide, glycine, proline, antioxidants, use of microorganisms like fungi, bacteria, genome editing, genetic marker-assisted backcrossing.

CRISPR-Cas9 is considered better than other conventional genome editing because of its two key benefits, first is sgRNAs can work with the same Cas9 protein at various loci and second, the specificity for the target DNA can be rapidly modified by programming the sgRNA sequence [17]. Qualitative traits loci can be effectively moved by CriSpr-Cas9 innovation to create transgenic wheat with a capacity of drought stress tolerance for physiological traits such as net photosynthesis, relative water content, cell membrane stability.

Transgenic approaches identify the candidate genes, microRNAs and transcription factors for the induction of desired characteristic into transgenic plants. Transcriptional factors genes like *bZIP, bHLH, ERF, NAC, HD-ZIP* and *WRKY* are used as drought tolerance tools in wheat [18]. MicroRNAs (miRNA) are a class of single-stand RNA molecules that are 21-24 nucleotides in length involved in specific gene expression during the plant defense response against biotic and abiotic stresses. Genetic marker is a fragment of DNA that is associated with a certain location within the genome and used for the screening of stress resistance traits. Different PCR and non PCR based markers like Restriction Fragment Length Polymorphisms (RFLPs), Amplified Fragment Length Polymorphisms (AFLPs), Simple Sequence Repeat (SSR) and Single Nucleotide Polymorphism (SNP) are used to screen stress resistance traits. Molecular crosstalk, epigenetic memories, Reactive Oxygen Species (ROS) signalling, accumulation of plant hormones such as salicylic acid, ethylene, jasmonic acid and abscisic acid, change in redox status, inorganic ion, R-gene resistance and Systemic Acquired Resistance (SAR) are the changes adopted by plants to defense themselves from the abiotic stress. Genetic engineering is focused on Water Use Efficiency (WUE) which can be achieved by inserting genes for compatible osmolites such as sugar, amino acids as well as overexpression of embryonic proteins aiming to dehydration tolerance [19].

Agronomic practices: Seed treatment, priming, foliar spraying, organic matter application, intercropping, provision of silage, establishment of rain water harvesting structures, micro irrigation technique are some practices to manage drought stress. Seed ethephon application preserve leaf water during tillering by increasing root volume and dry weight at drought condition. Efforts should be made for adjusting flowering time, breeding strategies for short or long duration crops, screening of tolerant germplasm. Mulches hinder weed development by restricting light entrance into the dirt, subsequently further developing water accessibility to trim plants in dry season conditions. Crop diversification, water conservation and harvesting and watershed development practices must be prioritized for better production result. Among the plant growth substances, salicylic acid, cytokinin and abscisic acid application increase the water potential and the chlorophyll content to alleviate water stress in wheat, however it can be also managed by exogenous application of silicon [20]. Ridge and furrows method as well as raised bed sowing found to save 20%-30% irrigation water, increase water use efficiency. Application of nitrogenous and potassium fertilizer at grain filling stage helps in increasing the rate of photosynthesis which will increase dry matter translocation to vein and increase grain weight by recovering drought condition.

Conclusion

Plants suffer from drought stress at any phase of lifecycle. Drought stress shows morphological effects on germination, number of tillers, flag leaf, root length. Similarly, physiological processes such as relative water content, photosynthetic rate, chlorophyll content varies with water availability in soil. Biochemical constituent like proline content, anti-oxidant enzymes defence system, osmotic adjustment, abscisic acid production, lipid peroxidation are also affected by water scarcity in soil. Basic physiological, morphological and biochemical process need to be studied well to clarify defence mechanism of wheat crop. Mainly four defense mechanisms like escape, avoidance, recovery, tolerance is shown by plant. Leaf respiration can be continued well by frequent watering after passing through drought soil condition. Knowledge of these all basic concept help researcher to find out new drought tolerant wheat cultivars using modern technology like molecular marker, genome editing, transcriptase factors.

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