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MORPHOLOGICAL, PHYSIOLOGICAL AND BIOCHEMICAL ADAPTATION OF WHEAT (*Triticum aestivum* L)TO DROUGHT STRESS

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ABSTRACT

Agriculture and crop productivity have been seriously threatened by water scarcity. Given how damaging the stress is and how long it lasts, losses from drought are likely greater than losses from all other causes. Wheat has experienced the consequences of drought stress on its morphological, physiological, and biochemical characteristics as well as effects on growth, water relations, and photosynthesis. Wheat responds to prevailing water stress in a range of morphological, physiological, and biochemical ways at the cellular and molecular levels, making it a complicated phenomenon. Stress from drought has an impact on root growth, stem lengthening, and leaf size, as well as on the relationship between plants and water and the efficiency of water usage.Numerous physiological studies are being conducted to learn more about the alterations that drought stress causes in wheat plants. There are two techniques to examine morphological changes: changes in the root system and changes in the shoot system, such as effects on height, leaf senescence, flowering, and so on. Alterations in chlorophyll content, perturbations in photosynthetic processes, and plant-water relationships are examples of physiological alterations. In various chemicals, biomolecules, and enzymes, biochemical changes take place. This review summarizes the adaptation of wheat to drought stress on growth and productivity. This review could be useful for wheat researchers and growers for making the right decision on the breeding effort intending to create a drought tolerant variety under water limited regions and selection of wheat genotype that can endure water scarcity.

Keywords: Wheat, drought, Morphological, Physiological, Biochemical Changes

INTRODUCTION

One of the most extensively farmed grains is wheat (*Triticum aestivum*), which is particularly popular in the Mediterranean region and other semi-arid regions from temperate to subtropical portions of the world (Ahmed et al., 2019). Wheat is mostly grown in arid and semiarid parts of the world. Wheat's ability to thrive under a variety of climatic circumstances is largely determined by its ability to adapt. According to Bayoumi (2009), the bulk of developing countries' first cereal crop is wheat, which is used as a staple crop by around one-third of the world's population. Because it includes energy, dietary proteins, calcium, zinc, fiber, carbohydrates, and lipids, it acts as a vital food supply. Nevertheless, there is a great chance of raising the average yield in many nations where the feasible yield hasn't been reached.

Most wheat is grown in rainfed conditions, where variations in the pattern of precipitation have led to water scarcity acting as a determining factor for declining crop yield, particularly when water deficit stress happens during the flowering and grain filling period stages (Bassi et al., 2017). Due to the effects of climate change and the decreasing availability of subsurface water resources for agriculture, there is a strong likelihood that there will be drought stress in the upcoming days. Numerous studies have shown that abiotic stressors have a significant impact on wheat productivity.According to a study, there is a 4.1% to 6% yield loss for every degree centigrade as the temperature rises (Liu et al., 2016). According to Mujeeb-Kazi et al. (2019), salinity causes a decrease in wheat yield. On the other hand, drought is currently receiving a lot of attention because it is thought to be a serious threat to wheat yield.

Unpredictable rainfall, which frequently reduces average output by more than 50%, is the main issue restricting wheat production in many places. Although wheat can be grown in a wide range of agro-climatic conditions, the majority of these conditions are severely hampered by drought stress, which also reduces output. The frequency of droughts will rise due to anticipated global warming and climatic changes, which will result in losses in wheat yield. Global agricultural productions have been influenced, resulting in restrictions on crop yield potential due to the rise in annual average temperature, variations in rainfall patterns, and emerging drought threats in many locations.It is anticipated that the availability of subsurface water will continue to decline as temperatures will rise (IPCC, 2013). In the tropics and subtropics, decreased wheat yield is mostly caused by drought stress and high temperatures during the reproductive stage (the wheat crop's final growth phase).

WHEAT PRODUCTION IN NIGERIA

Wheat is the second most important grain in the world in terms of overall production volume and the most significant grain in terms of grain acreage (Shahbandeh, 2021). There were over 772 million metric tons of wheat produced worldwide. Comparing the current marketing year to the previous one, there was an increase of about ten million tons (Shahbandeh, 2021). Due to high temperatures that are unfavorable to the crop, low productivity, and other factors, wheat growing has been the most challenging aspect of Nigerian agriculture during the past few decades (Haruna et al., 2017).The nation imports a lot of food, and agriculture does not contribute significantly to the nation's foreign exchange earnings (Oirere, 2019). Nigeria relies on imported wheat to meet the needs of its enormous increasing population. However, since the oil shock in the last quarter of 2014 through 2016, wheat farming has drawn the attention of policymakers who believe Nigeria has the capacity to produce enough wheat on its own (KMPG, 2016).

PRODUCTION ISSUES

Wheat farming in Nigeria is carried out mostly by small scale farmers who have traditional skills and have limited access to finance and modern technology. Those farmers are using family member or other means of manual labour as the only means for cultivation (Falola et al., 2017). Inadequate funding for research, mechanized farming, modern laboratory facilities and lack of high-quality inputs continue to reduce local production (Proshare, 2018). Low wheat production is one of the major challenges facing Nigeria for decades. Oirere (2019) lamented that, local wheat production remained inadequate. Though, the production remains low at 60,000MT in 2016 (KPMG, 2016; Proshare, 2018). The production is still unchanged (60,000MT) in 2018 (USDA, 2019). According to (Knoema, 2021) reported that, in 2017 the country produced 67,000MT of wheat and still in 2019, wheat production for Nigeria was recorded at 60,000MT. These revealed that, the wheat production of Nigeria increased from 6,000MT in 1970 to 60,000MT in 2020, which reflects an average annual growing rate of 12.34%. However, the adoption of the newly introduced technology that involves use of machine that ridges and plants at the same time. The new technology is expected to yield positive result, the techniques had the capability to increase wheat yield per hectare as against what was obtainable using the previous techniques (Ibrahim, 2020).

DROUGHT STRESS

According to Ashraf and Fooled (2007), up to 50% of agricultural land is vulnerable to regular drought, making it the main environmental stressor reducing the production of cereal crops worldwide. According to predictions made by Yu et al. (2017), a growing issue with global warming would increase the frequency and severity of droughts in the near future. Lack of water resources may result, which affects the morphological, biochemical, physiological, and molecular characteristics of the plants. These modifications all slow down plant development and crop yield. Crops' physiological and morphological properties are negatively changed by drought stress. Due to unpredictable environmental elements and the interaction between biotic and abiotic factors, crop response to water scarcity is as complicated as the drought itself (Nevo and Chen, 2010). According to Farooq et al. (2019) and Hussain et al. (2016), such stress causes wheat to significantly reduce its photosynthetic efficiency, stomatal conductance, leaf area, and water-use efficiency.

Drought is a clear and present danger to the world's food security due to inadequate water resources. It was sparked by the devastating famines of the past. Future food demand for demands from a rapidly growing population is projected to exacerbate the effects of water stress because the water supply is already limited globally. According to Wery et al. (1994), the amount and quality of precipitation, evaporative demands, and soil moisture contents all influence how severe a drought will be. The drop in wheat cultivation is caused by a number of different stressors, with drought stress playing a key influence in lowering wheat production. Approximately 50% of the arable land in emerging nations is rainfed (Paulsen, 2002).According to Sallam et al. (2019), drought stress is the result of a lack of water that causes slow-moving morphological, biochemical, physiological, and molecular alterations. Drought stress causes plants to transpire less, and in order to do so, wheat plant stomata close to limit water loss. Furthermore, if the stomata close for an extended period of time, the plant's leaves sustain oxidative damage, which influences the physiological and biochemical activity of the wheat plant in several ways.The most frequent environmental stressors that have an impact on plant growth and development are droughts. For plant breeders and agricultural researchers, drought remains a significant concern. By 2025, it is predicted that 1.8 billion people would experience a complete water shortage, and 65% of people will live in water-stressed regions (Nezhadahmadi et al., 2013b).Drought lowers plant nutrient uptake efficiency, with nitrogen being a major contributing element. Because of poor membrane permeability, reduced active transport, and lower transpiration rate, roots have less potential to absorb nutrients (Ahmad et al., 2018). According to several types of studies, plant height, biomass, and yield are more vulnerable to drought stress than the quantity of spikes and grain weight (Nouri-Ganbalani et al., 2009).Knowing the plant's mechanisms for coping with drought stress is essential for the development of stress-tolerant plants. Numerous scholars have been examining the impact of drought and the variety of issues it causes since they are aware of how important it is in reducing wheat yield. They are always working to create novel genotypes that can thrive in stressful environments and are tolerant to drought.

The productivity of crops can be significantly impacted by drought. When the amount of water lost by transpiration through the leaves exceeds the amount of water taken in by the plant through roots, the plant experiences drought stress (Jamali et al., 2020). Reduced water content, reduced leaf water potential, loss of turgidity, stomatal closure, and slowed cell development are the principal symptoms of drought stress in plants. Plant physiology and biochemistry are significantly altered by drought (Almeselmani et al., 2011).The plant undergoes a variety of morphological changes in response to water stress, however under severe stress conditions, functional impairment and plant component loss occur (Sangtarash, 2010). Jointing and tillering. According to Farooq et al. (2009), drought stress has an impact on plant growth, respiration, photosynthesis, phenology, and assimilate partitioning.

One of the most important environmental stresses is drought (also known as "water stress"), which can happen due to a variety of factors, such as unpredictable rainfall, salt, changing temperatures, and intense lighting. Physiological, morphological, biochemical, and molecular characteristics of plants are altered as a result of this multimodal stress. Landscape restoration in arid and semiarid settings is severely hampered by extended drought.There are many different types of drought, including meteorological (caused by a protracted lack of rainfall), hydrological (caused by a shortage in river flow), pedological (attributed to a lack of water in the soil structure), agronomic (caused by a lack of water available to plants to balance the physiological needs of evapotranspiration), and sociological (caused by competing consumption to meet human and social needs). Agronomic droughts, which have a detrimental impact on seedling establishment and crop stand establishment, are particularly capable of having a significant impact on landscape restoration.Crop productivity is negatively impacted by three main processes caused by a lack of soil water: decreased canopy absorption of photosynthetically active sunlight, decreased radiation use efficiency, and decreased harvest index (Earl and Davis, 2003).

According to Chen et al. (2012), abiotic stresses such as drought have a significant impact on 99 million hectares of land in low-income least developed nations and at least 60% of wheat output in high-income countries. According to Nouri-Ganbalani et al. (2009), a water shortage might result in a reduction of 17 to 70% in wheat grain output. 20.6% output losses in 40% less water were observed by Daryanto et al. (2016). Due to the negative impact on the number of spikelets and eventually the number of kernels per spike, the double ridge to anthesis stage is the growth stage in which wheat production is most vulnerable to water deficiency.A lack of water affects the anthesis and grain filling stage, lowering grain output. It is generally known that plant height, biomass, and yield are more susceptible to water stress than the quantity of spikes and grain weight. According to Nouri-Ganbalani et al. (2009) and Aminzadeh (2010), wheat tolerance to drought depends on the number of tillers per plant, the number of kernels per plant, the 1000 grain weight, the awn length, and the length of the peduncle. According to Chen et al. (2012), drought stress can reduce leaf water potential, which can then impair turgor, stomatal conductance, and photosynthesis. As a result, wheat growth and yield may be reduced.

Wheat has evolved more resilient defenses against drought stress, although each of these defenses is unique and depends on the cultivars and crop variations. In light of the shifting climatic conditions, it is crucial to improve wheat crops' drought tolerance. The promotion of agricultural yield in drought-stressed regions lacks effective, practicable technological solutions as of now.However, developing crop plants that are more resilient to drought stress may be a promising strategy that aids in preserving food security. The creation of crops for greater drought tolerance requires a thorough understanding of the physiological and genetic mechanisms underlying the features that contribute at various plant developmental stages. Wheat crops' endurance to drought has been the subject of pertinent research. Ingram and Bartels provided an excellent evaluation of those commendable efforts more than ten years ago (Ingram and Bartels, 1996). Reviews dealing with various elements of plant drought tolerance have been conducted in a similar manner (Penna, 2003; Reddy et al., 2004; Agarwal et al., 2006).

EFFECTS OF DROUGHT ON WHEAT

Morphological Changes

Plant Height

It has been demonstrated that drought severely reduces seed germination and seedling stand. These circumstances, which are impacted by water shortage, determine the quality and quantity of crop stand.

Because turgor pressure decreases during a drought, cell development becomes a crucial physiological activity that is susceptible to the condition (Rijal et al., 2021). When there is a severe water scarcity, wheat cell elongation can be changed by cutting off water passage from the xylem to the nearby elongating cells (Rijal et al., 2021). The growth of wheat plants is impacted by drought. Wheat is a plant that reacts dramatically to water stress conditions and exhibits dramatic changes in plant growth when exposed to these kinds of conditions.

The impact of drought stress is further influenced by the length of the drought, its severity, and the stage at which the wheat plant is growing. Numerous studies on wheat plants at various developmental phases, including stem elongation, booting, and grain filling, have been conducted. The findings indicate that the plant under drought stress suffered more than other plants at this time than at any other. According to Caverzan et al. (2016a), plant height was lowered by 35% during the stem elongation stage and 23% during the booting stage, but only by 7% during the grain filling stage.Many other researchers (Azooz and Youssef, 2010; Farooq et al., 2013) have also observed that wheat grows less slowly when exposed to drought circumstances. So, one of the main causes of the overall decline in the growth of wheat plants is drought.The decrease in turgor pressure caused by water stress prevents wheat cells from lengthening. The amount of water in tissues decreases when water absorption declines. As a result, turgor is gone. The metabolites necessary for cell division are similarly decreased under drought stress. As a result, there is a reduction in growth due to decreased mitosis, cell elongation, and expansion.

Root System

The roots of plants draw water and nutrients from the soil, and they are also crucial when there is a drought. Plant roots penetrate the soil deeply when water supplies are scarce in order to absorb water from the ground. Numerous studies have revealed a connection between a plant's root's volume, weight, length, and density, as well as its resistance to water scarcity. The design of the root system is thought to be crucial for a plant's ability to survive in drought-stressed conditions as well as improve grain output (Dodd et al., 2011). A good root system architecture for wheat allows it to extract the most soil water possible while under drought stress.In order to combat drought stress, wheat exhibits a variety of adaptive mechanisms, including osmotic root adjustment, greater root penetration into the soil, increased root density, and increased root to shoot ratio (Ali et al., 2020).Roots continue to expand in drought-stressed conditions in search of water, but the development of the airy organs is constrained. The diverse ways that shoots and roots grow in response to dryness are adaptations to arid circumstances. Under drought conditions, the ratio of roots to shoots increases (Nicholas, 1998), which is related to the amount of abscisic acid in the roots and shoots (Rane and Maheswari, 2001). Under moderate and severe drought circumstances, wheat roots grew at a slower rate (Noctor and Foyer, 1998). In wheat, dryness had little effect on root growth (Rao et al., 1993).

When water is scarce, root growth takes precedence over shoot growth. If the water potential decreases, the gradient of the water potential is re-established for water intake and osmotic adjustment in the root helps to maintain the degree of turgidity to some extent. In order to increase the surface area for water absorption, the development of lateral roots also rises during drought stress. Similar to this, the diameter of the cross section increases, aiding in sustaining water retention in wheat vascular bundles.Additionally, under conditions of drought stress, sclerenchyma cell width increases and the production of aerenchyma cells decreases (Henry et al., 2012). Because they can better utilize the deep underground water to survive under drought stress, genotypes with superior root systems are employed in breeding programs to increase output.

Root–leaf relations

According to Nezhadahmadi et al. (2013), several leaf characteristics including form, area, expansion, size, waxiness, pubescence, senescence, and cuticle tolerance are affected by water deficiency in wheat as well as root characteristics like length, density, fresh weight, and dry weight. The estimation of leaf water potential is a practical and accurate method for gauging how plants react to water shortage. According to Zivcak et al. (2013), wheat leaves with non-photochemical quenching are able to quench more quickly under water-limiting conditions, which ultimately results in a reduction in the relative moisture content of the leaves.Wheat's leaf water potential drops during a drought because of the buildup of solutes, yet genotypic diversity may exist in how the plant responds to water potential in both well-watered and dry environments (Nawaz et al. 2014). Different gas exchange properties including stomatal conductance, net photosynthetic rate, and transpiration rate, among others, are also influenced by the leaf water potential. In spring wheat, stomatal conductance and transpiration rate fall as leaf water potential falls (Liang et al. 2002). Longer-lasting drought protection may come from leaf waxiness and trichome density (Bowne et al. 2012).When there is a lack of water, roots continue to expand in size as they look for it, but the growth of the plant's above-ground components, such as its leaves and shoots, is constrained. When there is a drought, wheat could thrive by developing deep roots, a high water absorption capacity, and a good grain production. Root growth and water absorption might be affected by uneven fertilizer application (Jin et al. 2015). Bread wheat roots spread as a result of quantitative trait loci (QTL) connected to decreased canopy temperatures. When there is a water shortage, roots grow deeper while growing closer to the surface when there is a plenty of water (Pinto and Reynolds 2015).

With the application of 32 ppm of silica to the leaves, root development and root length density were increased in conditions of water scarcity (Ratnakumar et al. 2016). To create wheat types that can withstand drought, it is essential to comprehend root-shoot communication. In plants maintained in water shortage conditions with constant shoot moisture content, decreased stomatal conductance may be observed. It is a dry-weather maintenance method without hydraulics. Non-hydraulic signals from the roots let plants identify water shortage in the roots, and they manifest as a change in growth or stomatal conductance in leaves.Wheat yield and drought tolerance could be improved by choosing cultivars for an earlier onset of the non-hydraulic root-sourced signal. Under osmotic stress, the root-shoot ratio increased to improve water absorption, which is related to the content of abscisic acid (ABA) in the roots and shoots (Mahdid et al. 2011; Nezhadahmadi et al. 2013). In semi-dwarf and tall genotypes growing in restrictive soil, Gibberellin A3 (GA3) administration to the roots restored leaf elongation; the longest leaves were obtained when Gibberellin A3 was administered to afflicted roots of tall genotypes (Filho et al. 2013).Abscisic acid regulates plant growth by changing leaf elongation and expansion and root development during water deficits (Reddy et al. 2014; Farooq et al. 2014). Wheat's ability to absorb water and minerals when there is a water shortage can be improved genetically by improving the root-shoot structure.Abscisic acid regulates plant growth by changing leaf elongation and expansion and root development during water deficits (Reddy et al. 2014; Farooq et al. 2014). Wheat's ability to absorb water and minerals when there is a water shortage can be improved genetically by improving the root-shoot structure.

Root-shoot structure is significantly impacted by the tillering inhibition gene in wheat. With early stem elongation, this gene improves root-shoot ratio and root biomass. It also increases root depth at maturity in wheat near isogenic lines (NILs). By reducing canopy temperatures, raising stomatal conductance, and maintaining green color during grain filling in these close to isogenic lines, it also reduces the amount of water that is taken up by the soil. These modifications may boost the harvest index and ultimately the yield (Hendriks et al. 2016).Low light increases the number of leaves to enhance photosynthesis, and low moisture encourages root development into deeper soil layers for water absorption to maintain high yield during drought (Nagel et al. 2015). Low light and low soil moisture both significantly improve responses of roots and shoots in wheat under water deficit.

Senescence of Leaf

According to a study, drought stress increases the rate of senescence if it happens during the reproductive period, which significantly lowers grain output (Nawaz et al., 2013). When a leaf's function declines, the chlorophyll membrane breaks down and the water content increases, causing a change in the color of the leaf. One of the striking symptoms of leaf senescence is chlorosis, which causes a decrease in photosynthesis (Ali et al., 2020).However, it also promotes the mobilization of stored carbohydrates during parenthesis from the stem and leaves to developing grains and helps in compensating the yield loss caused by senescence during drought stress (Farooq et al., 2014). Senescence during drought stress can cause senescence to the entire plant in wheat grown in extreme drought conditions. The beginning and stages of wheat senescence were identified using the total protein content, glutamine synthetase, and rubisco (ribulose biphosphate carboxylase). Senescence often starts in older leaves first, followed by younger leaves, in most circumstances.However, in some delicate cultivars, senescence is disrupted by dehydration and first appears in flag leaves before moving on to elder leaves. The amount of glutamine synthetase isoenzyme significantly decreased in younger leaves, and the sequence of senescence was slightly disrupted, compared to plants growing in conditions with sufficient water (Nagy et al., 2013).

Physiological Changes

In response to drought stress, a variety of physiological reactions have been identified. Numerous physiological characteristics help wheat crops cope with drought stress and lessen its impact. The efficiency of several physiological processes carried out by plants directly correlates with the availability of water. These physiological systems are affected and plants are unable to produce enough dry matter when water availability is reduced.According to studies (Barbeta et al., 2015; Ashraf and Harris, 2013), plant nutrient intake, growth rate, and height, as well as photosynthetic activities, are all reduced when there is a drought. According to Sallam et al. (2019), a lack of water also causes membrane stability, a drop in water content, and a decrease in chlorophyll levels.In order to reduce the effects of drought stress, there are various physiological adjustments that must be made in the plant (Vinocur and Altman, 2005). In order to adapt to drought conditions and survive them, plants have developed a variety of tolerant genotypes that support the maintenance of soluble sugars, proline content, amino acids, chlorophyll content, and enzymatic and nonenzymatic antioxidant activities as well (Abid et al., 2016).

Cell Growth Pattern

Wheat is extremely sensitive to water stress conditions and exhibits a significant change in plant growth when exposed to these kinds of conditions. However, the length, timing, severity, and stage of the wheat crop all affect how drought stress manifests itself. Different experiments have been conducted on wheat plants at various developmental stages, including stem elongation, booting, and grain filling, and the results show that the plants suffering from drought stress beginning at stem elongation stage suffered more than others.At the stages of stem elongation and booting, respectively, plant height was lowered by 35% and 23%, however at the stage of grain filling, it was only reduced by 7% (Caverzan et al., 2016a). Many other researches (Azooz and Youssef, 2010; Farooq et al., 2013) have also noted a decrease in wheat's root and shoot growth when subjected to dry circumstances. Drought is thus one of the main causes of the general decline in wheat plant development.

Additionally, the length, kind, and severity of the drought as well as the stage of plant development control any potential modifications. On the growth stage and tolerance level of wheat cultivars under drought stress, there is a wealth of information accessible. The length and kind of a drought can also have an impact on plant development. Three wheat cultivars and three distinct stages of wheat growth were used in a two-factor experiment by Shamsi and Kobraee (Shamsi and Kobraee, 2011). At the stages of stem elongation, booting, and grain filling, drought stress was applied. It persisted all the way up to harvest.

According to the findings, compared to the other two plant growth phases, stem elongation stage plants suffered more when under water stress. Plant height was decreased by 35%, 23%, and 7%, respectively, in plants subjected to dryness at the stem elongation and booting stages, but only by 7% in plants exposed to dehydration at the grain filling stages. Nearly the same results were given by those responsible for the drought at The length, kind, and severity of the drought as well as the stage of plant development also control potential modifications (Akram, 2011).Researchers conducted a two-factor experiment with three wheat cultivars and three different stages of wheat growth (Shamsi and Kobraee, 2011). Drought stress was imposed at stem elongation, booting, and grain filling stages and continued up to harvest. Results showed that plants were tolerant to drought stress to a greater extent than they were to other stresses.

Plant height was decreased by 35%, 23%, and 7%, respectively, in plants subjected to dryness at the stem elongation and booting stages, but only by 7% in plants exposed to dehydration at the grain filling stages. Additionally, the length, kind, and severity of the drought as well as the stage of plant growth significantly control the potential alterations (Akram, 2011). Almost identical results were reported by who commenced the drought at.The development stage and level of drought tolerance of wheat cultivars are well-documented in the literature. The length and kind of drought also affect plant growth differently. With three different wheat cultivars and three distinct growth stages, some researchers ran a two-factor experiment (Shamsi and Kobraee, 2011). Up to harvest, grain filling, stem elongation, and booting all experienced drought stress.The findings demonstrated that, in comparison to the other two plant growth stages, plants experiencing water stress during the stem elongation stage suffered more. Plant height was decreased by 35%, 23%, and only 7%, respectively, in plants exposed to dryness at the grain filling stage as opposed to those exposed to drought at the stem elongation stage and booting stage. Who initiated the drought as opposed to the drought led to almost identical findings being reported (Akram, 2011). Additionally, the length, kind, and severity of the drought and the stag.

Chlorophyll Content and Photosynthetic Rate

Plants constrict their stomata in response to a decrease in the amount of accessible water (perhaps via ABA signaling), which lowers the input of CO2. More electrons are sent to generate reactive O2 species as a result of reduced CO2, which also indirectly reduces carboxylation. In severe drought conditions, the activities of ribulose-1, 5-bisphosphate carboxylase/oxygenase (Rubisco), phosphoenol pyruvate carboxylase (PEPCase), NADP-malic enzyme (NADP-ME), fructose-1, 6-bisphosphatase (FBPase), and pyruvate orthophosphate dikinase (PPDK) are reduced.The effectiveness of Rubisco binding inhibitors is also increased by lower tissue water concentrations. The photosynthetic process is carried out by the green pigment chlorophyll. In wheat, chlorophyll a and chlorophyll b make up the majority of the chlorophyll. The ratio of chlorophylls a to b is typically 3:1, depending on cultivars, plant growth, and numerous environmental conditions (Ahmad et al., 2018). The amount of leaf chlorophyll decreases noticeably whenever wheat plants experience drought stress, according to numerous experts and scientists (Fotovat et al., 2007).

When compared to chlorophyll a, chlorophyll b is more affected by this stress and has had a greater decline in number. This is justified by the possibility that some of the decline in chlorophyll a was caused by its conversion to chlorophyll b (Fang et al., 1998). Scientists have discovered that when a wheat plant is exposed to light, an enzyme activation reaction of chlorophyll synthesis takes place, increasing the chlorophyll content in young leaves, while decreasing it by 13–15% in older leaves due to the activation of chlorophyllase and the inactivation of the enzyme under drought conditions (Nikolaeva et al., 2010).There is a change in the photosynthetic mechanism that inhibits photosynthesis as a result of the drought stress damaging the chlorophyll components. Numerous studies have demonstrated that cereal crops' photosynthesis is reduced as a result of drought stress. Drought stress also affects the electron transport chain, which leads to the formation of ROS that are detrimental to plant cells and organelles such mitochondria, chloroplasts, and perioxisomes (Farooqi et al., 2020).

The loss of chlorophyll in the leaves is another effect of reactive oxygen species. Minerals, chlorophyll concentration, mitochondria, and mitochondrial inner structure are all altered by this. The inability of chlorophyll biosynthesis to occur due to chlorophyll photo-oxidation, loss of chlorophyll substrate, and an increase in chlorophyllase activity are all consequences of an imbalance between the light capture and its utilization (Kabiri et al., 2014; Kingston-Smith and Foyer, 2000).Reduced activity of various photosynthetic enzymes, decreased levels of biochemical elements necessary for the formation of triose-phosphate, and most importantly, a decrease in the photochemical efficiency of photosystem II are some of the main factors limiting the rate of photosynthetic activity (Pandey and Shukla, 2015). Under drought conditions, RuBisCO (ribulose-1, 5-bisphosphate carboxylase/oxygenase) enzyme activity is inhibited, which prevents the production of ATP (Dulai et al., 2005).

Relative Water Content

The relationship between plants and water is influenced by several key factors, including relative water content, leaf water potential, stomatal tolerance, transpiration rate, and leaf temperature. In wheat leaves, relative water content increased initially during leaf development and decreased as the leaf matured (Siddique et al., 2001). Undoubtedly, wheat crops that had experienced drought stress had reduced relative water content than unaffected ones. These crops' responses to drought stress resulted in a notable decrease in leaf water potential, relative water content, and transpiration rate as well as a large increase in leaf temperature (Siddique et al., 2001).When there is a water shortage, the relative water content of leaves is thought to be the most crucial metric among the several types of water potential. The relative water content of wheat during its developmental phases is significantly reduced as a result of the drought stress. According to Nawaz et al. (2014), the impact of drought on wheat is greater at a later stage (after 6 weeks of emergence) and has an impact on water relations, nutrient uptake, growth, and yield. This is in contrast to the early stage (after 3 weeks of seedling emergence).According to Mehraban and Miri (2017), drought stress causes a decrease in water status during crop growth, soil water potential, and plant osmotic potential for water and nutrient uptake. This decrease in leaf turgor pressure then disturbs plant metabolic activities. Excised leaf water retention (ELWR) is facilitated by drought stress, which indicates the water retention mechanism in the leaf under stress that may result in leaf rolling or a reduction in exposed leaf surface area. Many researchers have discovered that under drought stress, there is constant change in the relative water content because it is regulated by numerous genes with additive effect.

Drought-tolerant genotypes maintain high turgor potential and relative water content in contrast to sensitive genotypes, which show a strong positive correlation between water content and photosynthetic rate (Moayedi et al., 2010). This indicates that water had little effect on the protoplasmic structures of drought-tolerant genotypes. Reduced water status and osmotic potential in plants are the final effects of decreasing relative water content. Maintaining leaf turgor pressure is an essential adaptation mechanism that plays a significant role in stomatal control and photosynthetic activities when there is a water deficit.Osmoregulation is crucial for the maintenance of turgor pressure as it aids in plant metabolism for survival and aids in the absorption of soil water (Mehraban and Miri, 2017). Relative water content is positively correlated with total grain yield per plant, biological yield per plant, and harvest index of wheat (Abdul et al., 2010). Thus, relative water content can be used to select wheat genotypes that are drought tolerant (Hasheminasab et al., 2012).

Biochemical Changes

According to Chen et al. (2012), wheat crops have an internal defense system containing antioxidant enzymes such superoxide dismutase (SOD), catalase (CAT), and peroxidase (POX) for scavenging ROS under stressful circumstances. Thus, as will be seen below, water stress had a part in the significant modifications in the biochemical characteristics of the wheat plants.

Proline Content

One of the key amino acids involved in the production of proteins is proline, according to one definition. Understanding the processes of drought resistance can be aided by looking at how wheat reacts to water stress by accumulating proline. Drought stress has a significant impact on wheat's ability to accumulate certain organic compatible solutes that regulate the intercellular osmotic potential. Organic compatible solutes build up over time, increasing the plant's solute potential and preventing water loss.More than any other osmoregulators, wheat plants acquire proline content as a result of the shortage of water (Maralian et al., 2010). The proline content of wheat plants is said to rise when they have experienced drought stress (Vendruscolo et al., 2007). According to research by Maralian et al. (2010), when wheat is experiencing water stress, the maximum amount of proline increases during the heading stage of the crop.It varies for different wheat genotypes because different genotypes have variable water stress thresholds, however the genotypes of wheat that accumulate more proline under drought have the potential to withstand drought stress. As a result, estimating the proline content of wheat can be a valuable characteristic when choosing a genotype of wheat that is drought resistant.

Antioxidant Properties

Reactive oxygen species (ROS) build up in the cells as a result of the drought stress. ROS can seriously oxidize plants, which stunts their growth and reduces their ability to produce grains of wheat. Redox homeostasis (Caverzan et al., 2016a) is the state of equilibrium between the generation and scavenging of reactive oxygen species. However, if the creation of reactive oxygen species outpaces the capacity of the cell to scavenge them, the redox homeostasis becomes out of balance, leading to a fast and temporary excess of reactive oxygen species that is known as oxidative stress (Sharma et al., 2012).Therefore, plants contain antioxidant defense systems that scavenge extra reactive oxygen species and stop cell deterioration. Reactive oxygen species generation and detoxification must remain in balance, which is maintained by enzyme- and non-enzyme-based antioxidants (Mittler, 2002). Numerous research on wheat have demonstrated that the antioxidant defense mechanism of the plant changes in activity in response to environmental stresses, such as drought, which cause oxidative stress.

Both enzymatic and non-enzymatic systems are activated in order to detoxify the hazardous levels of reactive oxygen species that are created as a result of drought stress and are damaging to plants (Caverzan et al., 2016b). Numerous studies have demonstrated how these enzymatic and non-enzymatic systems respond differently depending on the genotype, even when the identical conditions are present. Genotypes that are often more tolerable have stronger antioxidant capacities, which reduces plant oxidative damage.This response also depends on a number of other variables, such as the tissue type, duration, and intensity of the stress as well as the developmental stage (Caverzan et al., 2016a), demonstrating the complexity of the mechanisms governing the production and detoxification of reactive oxygen species as well as the impact of these species on the antioxidant system. Therefore, knowing how wheat responds to drought stress in terms of antioxidants aids in the development of new, improved genotypes with greater antioxidant capacity.

CONCLUSION

Stress from drought slows down the growth and development of crops, which results in modifications to their morphological, physiological, and biochemical characteristics. Drought is one of the main issues with getting the potential yield because the bulk of the world's wheat production land is in arid and semi-arid countries. With considerable obstacles to food production, the effects of water shortages around the world will only get worse.Drought causes substantial output losses in wheat and lowers wheat quality, among other production challenges for wheat such high temperatures and poor soil fertility. Wheat undergoes biochemical, structural, and morphological changes as a result of these stressors, which reduce yield. It hinders the natural growth and development of plants, preventing fruiting and grain filling, which ultimately results in smaller and fewer grains of wheat. Understanding how wheat responds morphologically, physiologically, and biochemically in this environment enables researchers to pinpoint the mechanisms behind drought tolerance and create wheat types that are resistant to drought. The application of technologies for climate-smart agriculture that will lessen the negative consequences of the stressors must be the main focus of future research.

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