Review Article

Response of barley (*Hordeum vulgare* L.) to water deficit – physiological, biochemical and molecular perspectives

Abstract:

Barley (*Hordeum vulgare* L.) is one of the earliest cultivated cereals and a foundational crop of ancient agriculture. After rice, maize, and wheat, barley is the fourth most widely cultivated cereal crop in the world. It is cultivated in numerous developed and developing nations, where it frequently faces severe drought stress. Every year, droughts afflict the entire planet, frequently with catastrophic effects on crop production. Many crop modification projects have as a primary target the enhancement of drought resistance. However, progress toward this objective has been modest due to the complexity of the trait, the variability and unpredictability of drought conditions in the field, and the variety of drought tolerance mechanisms developed by plants. Barley is regarded as the most drought-resistant grain crop. It functions as an uncomplicated genetic model for researching drought tolerance mechanisms and associated agronomic and physiological traits. Several morphological, physiological, biochemical, molecular and quality traits can be identified from various barley varieties that can improve the performance of barley under drought stress. The present report is a comprehensive review that intends to give insights into the modulation of drought stress responses in barley and to provide a thorough picture of the drought tolerance mechanisms in barley.

Key words: Barley, Drought, Growth, Physiology and Yield

Introduction

Barley is one of the world's oldest cultivated crops. Archaeological evidence from the Fertile Crescent indicates that the crop was domesticated from its wild relative some 10,000 years ago. (Hordeuum spontaneum C. Koch) (Badr *et al*., 2000). After rice, maize, and wheat, barley is the fourth most widely cultivated cereal crop in the world. It is cultivated in numerous developed and developing nations, where it frequently faces severe drought stress. Barley is cultivated in a wide range of photoperiods, thrives on a variety of soils, and is the preferred grain in marginal regions. Although barley may live and produce grain under a wide range of climatic circumstances, higher grain yields can be produced on well-drained, fertile loam soils with relatively cold temperatures (15-30°C) and moderate annual precipitation (500-1000 mm) (Nilan and Ullrich, 1993). Water scarcity is a significant environmental constraint on plant growth. Crop production losses attributable to drought are likely greater than those attributable to other factors, as both the severity and duration of the stress are crucial. Barley is the most drought-resistant of small grain cereals and an important crop in Mediterranean-rim nations (Forster et al., 2004). However, its yield potential and annual productivity are much lower than those of the previously mentioned grains (Saed-Moucheshi, 2018) due to water scarcity in places where it is cultivated. In the vast majority of these regions, barley is normally grown as dry-land or rainfed crops. In the barley gene pools of primitive landraces and similar wild species, there is a wide range of reactions to abiotic stressors (Forster et al., 2000). Achieving genetically higher yield under water-limited situations has been identified as a formidable obstacle for plant breeders, compared to the advancements in grain output in favorable environments (Richards et al. 2002). Therefore, many methodologies are proposed as a means of identifying the best genotypes that are more drought-tolerant. Consequently, drought stress indices based on yield loss under drought circumstances have been utilized to identify drought-tolerant genotypes (Mitra, 2001). Each of these indexes that are divided into direct and indirect effect evaluates a unique aspect of drought resilience (Fig. 1). Thus, genetic variation plays a crucial role in determining favorable adaptation to environmental challenges and promotes the dispersal of numerous barley genotypes to harsh climatic conditions (Verma et al., 2012)

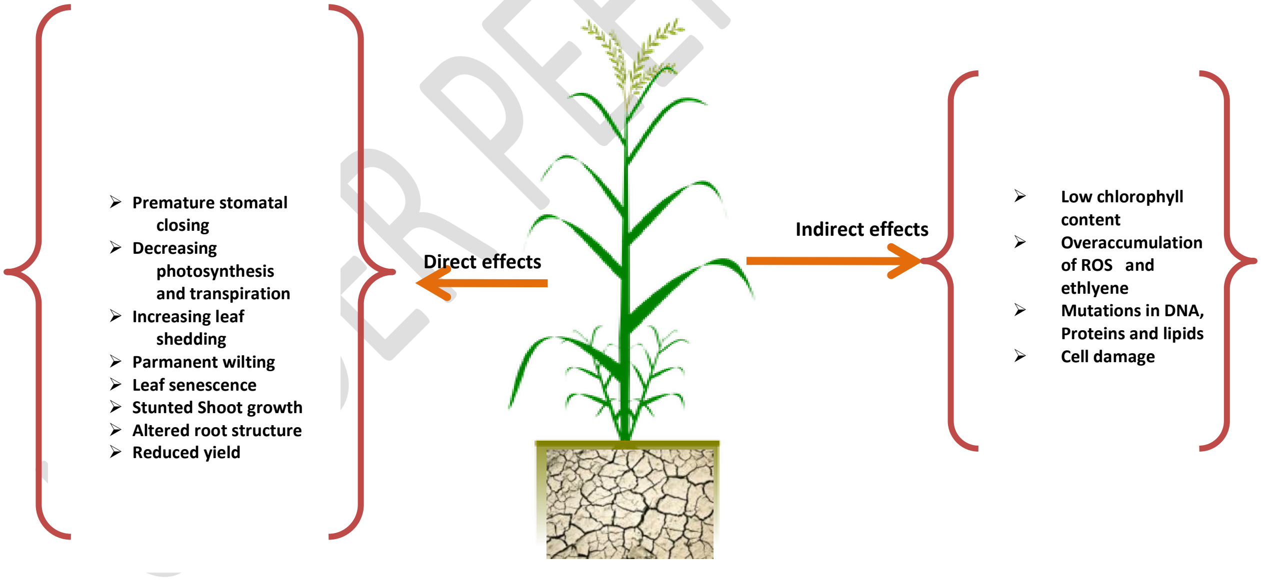

Fig 1 – Effects of barley to soil moisture stress

Effects of drought stress on Barley:

Growth Analysis: Plant height is directly linked to the productive potential of plant in terms of grain yield. Drought stress reduced plant height, number of spikelets per spike and grain weight. The effects of stress depended on the time, duration and intensity. Plant height of barley showed low positive correlation with yield, although it should have been higher in irrigated condition (Vitrakoti *et al*., 2016). Okuyama *et al*. (2004) reported that under non-irrigated condition, yield showed a positive moderate correlation with culm diameter and plant height. Leaf traits and leaf architecture are important for crop adaptation to environmental conditions. Leaf area is presumed to be a sign of crop growth, development, and plant health, and it has a strong link with leaf dry weight and grain development in barley (Sieling et al., 2016). During the growth and development stages, leaf area (LA) and related traits showed big differences between barley row types (Alqudah and Schnurbusch, 2015). Using the leaf area of a single leaf (flag or penultimate) has been suggested by many authors as a way to improve the yield of barley (Berdahl *et al*., 1972; Alqudah and Schnurbusch, 2015). It is important for seed development for assimilate to move to reproductive sinks. Seed set and grain filling can be limited by how much dry matter is available or how much it is used. This is called assimilate source limitation and sink limitation, respectively (Asch et al., 2005). Dry matter is often sent to the roots more when there is drought stress, which can help the plant in uptake of more water (Leport *et al*., 2006). Under water-limited conditions, grain yield is determined by how much water is taken out of the soil, how well this water is used to turn into dry matter, and how it is partitioned and relocated around (Foulkes et al., 2002). Ghosh et al. (2013) found that soil moisture has a big effect on photosynthesis and, in the end, had a big effect on the total dry weight of three cultivars of barley (IBON/47, BB-1, and KARAN-163) at most of their growth stages. The main cause of loss of total dry matter in rainfed barley was reduction in the number of leaves ,decrease leaf area and premature senescence (Legg *et al*., 1979; Wehner *et al*., 2015).

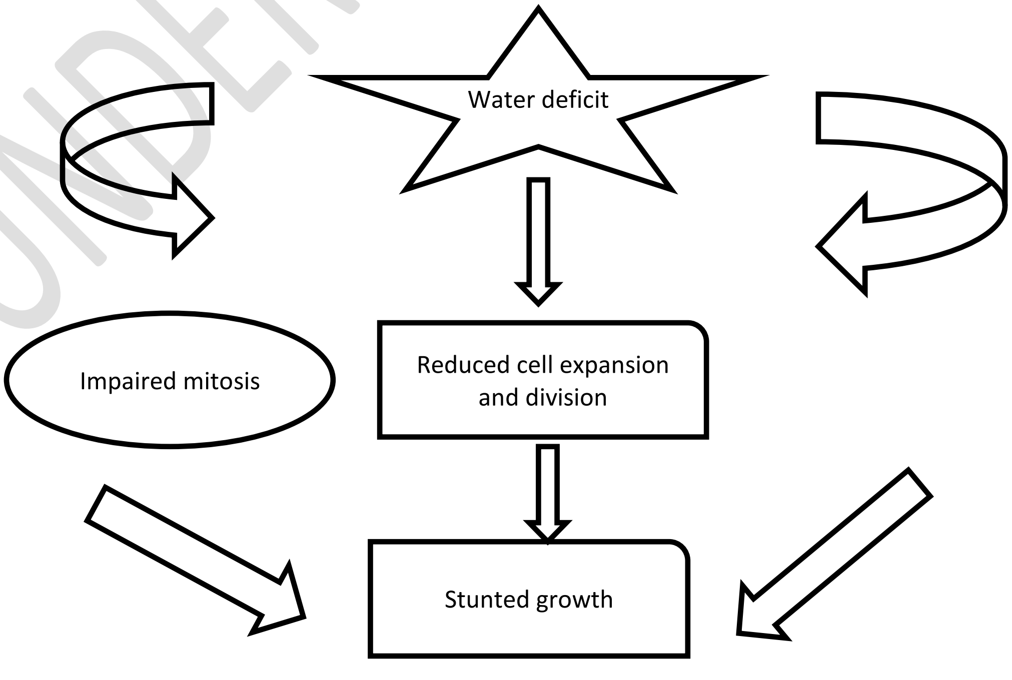

Fig 2-General effects of water stress on plant growth

Physiological responses

Through morphological and physiological approaches, many individuals have attempted to figure out how plants can effectively manage drought. Several physiological processes that respond to drought stress have been identified (Sharma and Kumar, 2014). Many plant species, including barley, have been found to have direct links between yield and morpho-physiological traits (Ahmed et al., 2013; Sharafi et al., 2014). Some of these physiological processes help plants avoid or deal with stress or dehydration and protect them from damage caused by drought. When plants are stressed by drought, the leaf water potential gradually decreases. This causes a decrease in turgor, relative water content, chlorophyll stability index, and membrane damage, which leads to less plant growth as well as less grain yield.

Plant water relations:

Leaf water potential: The water status of a crop plant is shown by its relative water content, its water potential, or a combination of these and other water-related factors. Different crops can be made more resistant to drought by choosing characteristics like leaf water potential (WP) and osmotic adjustment capacity (Nayyar *et al*., 2005). Guoth et al. (2010) found that the water potential of the tolerant barley cultivar didn't change much when it was under stress, but that the sensitive cultivar did change a lot. The leaf water potential interacts with stomatal conductance, and under water deficit conditions, a good correlation has been found between leaf water potential and stomatal conductance (Ahmed et al., 2013). Ghotbi-Ravandi et al. (2021) found that moisture stress had a significant effect on leaf water, osmotic, and turgor potentials of all barley accessions and that accessions differed a lot in all water relation components under control conditions and water stress.

Leaf osmotic potential: As a response to a decrease in the water potential, osmotic adjustment takes place which is the active accumulation of solutes in cells.This leads to cells retaining water and a consequent tendency to retain their turgor pressure under water deficit. Osmotic adjustment reduces the sensitivity of processes dependent on turgor, such as growth and stomatal activity, when the water potential falls (Daneshmand *et al*., 2010). According to Arabzadeh and Emadian, (2010) osmotic potential values of water stress treated roots of *H. aphyllum* and *H. persicum* were significantly higher than the osmotic potential values of similar tissues of the control seedlings. In barley water stress application reduced leaf water potential and leaf osmotic potential and thus enabled the plant to enhance its resistance to drought (Gupta *et al*., 2001; Zhang *et al*. (2015).

Relative water content: Relative water content is a measure of plant water status that reflects metabolic activity in tissues and is the most useful index for dehydration tolerance. Drought stress can be physiologically measured by measuring leaf relative water content (RWC), which controls the plant's reaction to water deficiency (Khoyerdi et al., 2016). Adapting the growth cycle to water availability becomes a priority as a result. Developing well-adapted crops, as seen in barley, could boost yields under such conditions (Gonzalez et al., 2008). The RWC in barley was noticed to be reduced under water stress conditions (Sharma et al., 2016). The RWC was shown to be a useful screening parameter for drought resistance in cereals, as well as a reliable indicator of plant water status (Teulat et al., 2003; Aboughadareh et al., 2017). In cereals, maintaining relative water content and high osmotic adjustment lead to higher yield and yield stability under drought (Clarke and McCiag, 1982). During water stress, all barley genotypes showed a substantial linear association between osmotic potential and relative water content (Vaezi *et al*., 2010).

Membrane stability: Plant cell membranes are initially targeted by biotic and abiotic stimuli, but drought-tolerant plants preserve their integrity and stability in drought stress (Levitt, 1972). Because drought stress causes water loss from plant tissues, which impairs membrane structure and function owing to electrolyte leakage, stability is necessary for plant growth and development (Bajjii et al., 2001). The integrity of cell membranes in the presence of pressures such as drought or high temperature may reflect the plant's ability to tolerate periods of stress. Cell membrane thermostability, also known as relative cell injury percentage, is an effective physiological criterion (Assaha et al., 2016) that has been widely used by many researchers for screening drought and heat-tolerant genotypes in crops such as wheat, barley (Ibrahim and Quick, 2001; Farooq et al., 2011), rice (Farooq et al., 2009a), and cotton (Azeem et al., 2008; Ali and Awan, 2009). Cell membrane stability showed a significant positive correlation with test weight under heat and drought conditions Rehman *et al*,. 2016).

Chlorophyll stability: Chlorophyll stability index is the ratio of chlorophyll concentration in a heated plant sample to that at ambient temperature. The stability index of chlorophyll is inversely related to stress conditions. CSI is suggestive of photosynthetic pigment maintenance in drought environments. Numerous studies have demonstrated the considerable inverse relationship between CSI and grain yield (Yildirim et al., 2011). Anjum et al. (2003) discovered that moisture shortages reduced barley genotypes' chlorophyll stability index of Chl-a and Chl-b and total chlorophyll from 6% to 23%. Ahmed et al. (2013) discovered that under stress, the chlorophyll content (Chl a and Chl b) of all barley genotypes (XZ16, XZ5, and CM72) was considerably lower compared to controls. The decrease in chlorophyll content during drought stress may be attributable to photo-oxidation caused by oxidative stress, which in turn lowers the photosynthetic process and yields (Barutçular *et al*., 2016).

Canopy temperature depression: Temperature influences plant evapotranspiration at the level of the entire canopy. As a result of transpiration, the canopy temperature decreased by up to 8^0C relative to the ambient temperature; this process is known as canopy temperature depression (CTD). Under water-limited conditions, the ability to absorb water from deep soil profiles has been identified as one of the most essential drought adaptation processes, as indicated by a substantial correlation with canopy temperature (Pinto et al., 2010). According to Blum et al. (1988), a study of canopy temperature depression relative to air temperature enables the detection of genotypic changes associated with the genetic improvement of cereals for water-restricted conditions. Balota et al. (2007) suggest low canopy temperature (CT) as a drought tolerance selection method. In contrast to leaf stomatal conductance, canopy temperature has a greater potential usefulness because it may be applied to the entire plant or canopy level (Munns et al., 2010). Reynolds, (2002) explained that high canopy temperature depression (CTD) or low canopy temperature (CT) may be indicative of high demand for photo-assimilation due to many rapidly filling 11 kernels (i.e. sink strength) in physiologically well-adapted lines, higher metabolic capacity, and good vascularity capable of meeting evaporation demand. Canopy temperature had a negative correlation with grain production and that genotypes of triticale, wheat, and barley with reduced CT produced greater grain yield, indicating that a cooler canopy results in improved tolerance to water stress (Roohi et al. 2015)). According to Lopes and Reynolds (2010) and Chaudhari et al. (2017), wheat lines with less CT at grain filling had higher grain yields.

Gaseous exchange parameters:

Among physiological processes, the efficiency of photosystem II (PSII) and photosynthesis plays a vital role under stress conditions (Saleem *et al*., 2011). The water deficiency of plants modulates the photosynthetic activity of leaves, which in turn modifies the chlorophyll fluorescence (Ghotbi-Ravandi et al., 2021). Under soil moisture stress, leaf gas exchange metrics indicated that net photosynthetic rate, stomatal conductance, and transpiration rate decreased in all barley genotypes studied. The relative mean decreases were 32.3%, 19%, and 15%, respectively (Tiryakioglu et al., 2015). Under water-deficit conditions, photosynthesis-related proteins in barley reduced significantly, suggesting that chloroplastic metabolism and energy-related proteins may play an important role in the adaptation process under drought stress (Kausar et al., 2012). While in another study, drought stress during the grain-filling period reduced the net photosynthetic rate of the barley flag leaf, but had no influence on the grain-filling rate at a severe vapour pressure deficit (Sanchez et al., 2002). Abdoli and Saeidi (2013) observed that the net photosynthetic rate decreased with chlorophyll content, which was accompanied by a decrease in stomatal conductance. The controlled severe drought imposed during the vegetative stage decreased photosynthesis and plant growth in both barley genotypes in a similar manner (Harb and Samarah, 2015). According to Tiryakioglu et al. (2015), under drought circumstances, stomatal opening and net transpiration rates are lowered. Stomata close in reaction to drought; consequently, the supply of CO2 is restricted, and the photosynthetic apparatus is predisposed to enhance energy dissipation and downregulate photosynthesis (Chaves et al., 2009). The decrease in stomatal conductance may result from a decrease in hydraulic conductivity between soil and plant or a deficiency in the root system's oxygen supply (Vartapetian and Jackson, 1997; Mohd et al., 2010). The link between photosynthesis and stomatal conductance, as revealed by Tavakoli et al. (2011), demonstrated that stomatal limitation was significantly more relevant than non-stomatal constraint. Roohi et al. (2013) and Aboughadareh et al. (2017) reported a steady decrease in stomatal conductance (47-71%) under water deficit. The average decrease in stomatal conductance was greater in barley (65%) than in wheat (61%) and triticale (55%). Increasing the vulnerability of stomatal conductivity to water stress results in a rise in apparent mesophyll resistance, which can be discriminated against amongst grain varieties (Tiryakioglu et al., 2015). Chlorophyll fluorescence has been used as a rapid technique to estimate the operating quantum efficiency of electron transport throughout PS II in leaves (Kalaji *et al*., 2016) and its relationship with CO_2 assimilation (Siebke *et al*., 1997). The dynamic changes in chlorophyll fluorescence are a direct reflection of photosynthesis in crops (Maxwell & Johnson, 2000). Fluorescence parameters are good reflection of photosynthesis and can be used to analyze the impact of stress on photosynthesis quickly, precisely, and non-destructively (Hasanuzzaman *et al*., 2016). Drought stress causes not only a substantial damage to photosynthetic pigments, but it also leads to deterioration of thylakoid membranes (Huseynova *et al*., 2007; Kannan and Kulandaivelu, 2011). Drought stress alters the Chl a fluorescence kinetics and hence damage the PSII reaction center (Zhang *et al*., 2011). Habibi, (2012) observed that the significant decrease in Fv/Fm under water stress conditions, which was possibly due to the reduction of stomatal conductance and restriction of CO_2 for photosynthesis and indicated photoinhibition (Boughalleb and Hajlaoui, 2011). The decrease in Fv /Fm values implies that photochemical conversion efficiency, indicate the possibility of photoinhibition.

Biochemical parameters:

It is known that free proline accumulation is one of the initial metabolic reactions of plants to water shortage (Hayat et al., 2012). To boost plant tolerance to abiotic stressors and maintain a high relative water content, plants may accumulate low-molecular-weight substances such as proline (Zlatev and Lidon, 2012), perhaps via buffering the cellular redox potential (Wahid and Close, 2007). Proline's function as an osmolyte or osmoprotectant in the leaves of drought-stressed plants is controversial (Seki et al., 2007; Wani et al., 2017). Indeed, it has been established that proline confers drought tolerance on plants by enhancing the antioxidant system rather than by enhancing osmotic adjustment (Vendruscolo et al., 2007). Drought stress increases the generation of reactive oxygen species (ROS), which can trigger harmful processes, including lipid peroxidation, as measured by MDA level, and cell membrane damage (Mittler, 2002). Malondialdehyde has been identified as the end product of membrane lipid peroxidation. Bandurska et al. (2012) discovered that limiting irrigation increased the amount of MDA in barley's leaves and roots. Similarly, the effect of a water-deficitdeficit environment on the leaves of beans, mulberry, and wheat led to an increase in lipid peroxidation (Turkan et al., 2005; Arasimowicz-Jelonek et al., 2009; Khateeb et al., 2017). Increased MDA accumulation is associated with decreased RWC and photosynthetic pigment concentration during extended drought (Jiang and Jhang, 2004).

Antioxidative defense system: In response to drought stress plants are challenged by oxidative stress (Noctor *et al*., 2014). Oxidative stress is resulted from the generation of reactive oxygen species (ROS) such as superoxide (O^{-}), hydroxyl (OH^{-}), hydrogen peroxide (H_2O_2) and singlet oxygen ($O^{\cdot}$). Although in plants, ROS are mainly produced in organelles involved in energy transformation (chloroplasts and mitochondria), they are also found to be generated in other sites in plant cells such as peroxisomes, cytosol, endoplasmic reticulum, and apoplast (Gill and Tuteja, 2010). Under normal growth conditions plants produce ROS, but they are kept in balance with the different antioxidants of the cell (Kar, 2011). In plants, there are enzymatic and non-enzymatic antioxidants (Gill and Tuteja, 2010). The first line of defense against the accumulation of ROS is superoxide dismutase (SOD), which dismutates the O^{-} radicals to H_2O_2 (de Carvalho, 2008). Catalase (CAT) and ascorbate peroxidase (APX) are two enzymes that scavenge H_2O_2 and prevent its accumulation to toxic levels. Peroxidase on other hand is an oxido-reductase that causes H_2O_2 breakdown (Jiang and Jhang, 2004). When plants were exposed to different soil water stress, the activities of antioxidant enzymes CAT, POX and SOD protecting the plant against deleterious effects of ROS were increased at flowering and milking stages. Moreover, Salekjalali *et al*. (2012) indicated that antioxidant protection in barley plants could be attributed mainly to POX and SOD. Acar *et al*. (2001) observed a gradual increase in SOD activity in the extracts of leaves of drought tolerant varieties of *H. vulgare* under drought stress. Harb *et al*. (2015) observed that in two barley cultivars (Yarmouk and Rum), the activity of APX was significantly higher in the drought treated plants compared with the well watered plants of Yarmouk genotype at the early stage of drought treatment. But in Rum genotype, drought treatment did not increase the activity of APX at the early and the late stages of drought treatment. The number of iso-enzymes of SOD and CAT were increased in response to the mechanism of action of hydrogen peroxide in cereal under drought stress (Ranjeet *et al*., 2012).

Transcriptional regulation of drought stress in Barley:

ABA plays an important part in plant adaptation during drought and other osmotic stress. Extensive study has focused on the effect of ABA on plant response to stress. Due to the activation of ABA biosynthesis genes, ABA accumulates in drought-stressed plants (Iuchi et al., 2001). ABA modulates the expression of several genes, resulting in crucial physiological and biochemical changes that aid plant stress resistance (Gao et al., 2018). Molecular and genomic investigations have indicated the existence of an ABA-independent signal transduction pathway during drought stress in addition to the ABA-dependent route. ABA regulates the expression of the majority of target genes via the transcription factors ABA-responsive element (ABRE) binding protein/ABRE binding factor (AREB/ABF) (Harb et al., 2020). The set of genes regulated by AREB/ABFs is known as the AREB/ABF regulon. In addition, genes responding to drought are also controlled by processes outside of ABA (Zandkarimi et al., 2015). Dehydration-responsive element binding protein (DREB), NAM, ATAF, and CUC regulons play a significant role in ABA-independent regulation by regulating several drought-responsive genes. In addition to these key regulons, the transcription factors MYB/MYC, WRKY, and nuclear factor-Y (NF-Y) are implicated in drought response and tolerance (Singh and Laxmi, 2015). DST (drought and salt tolerance), ZFP (zinc finger transcription factor), SERF (serum response factor), SNAC (stress responsive NAC transcription factor), SKIP (ski-interacting protein) these are some other important regulators under drought tolerance mechanism. Numerous studies have been conducted on the genes, transcription factors, and proteins that play a vital part in the defense process and are specifically activated by stress. The function of nuclear-localized transcriptional regulatory components in drought tolerance must be uncovered. These genetic resources are possible options for combating water stress in barley. This will facilitate the investigation of mechanisms of water stress tolerance and the introduction of resistant cultivars (Janiak et al., 2019). In cereals and other crop plants, a large number of candidate molecules involved in transcriptional, translational, and regulatory mechanisms with a potential role in water stress tolerance have been identified and characterized. Engineering new crop varieties with these candidates/molecular regulators may be an alternative for enhancing crop plants' drought resistance (Baldoni et al., 2021).

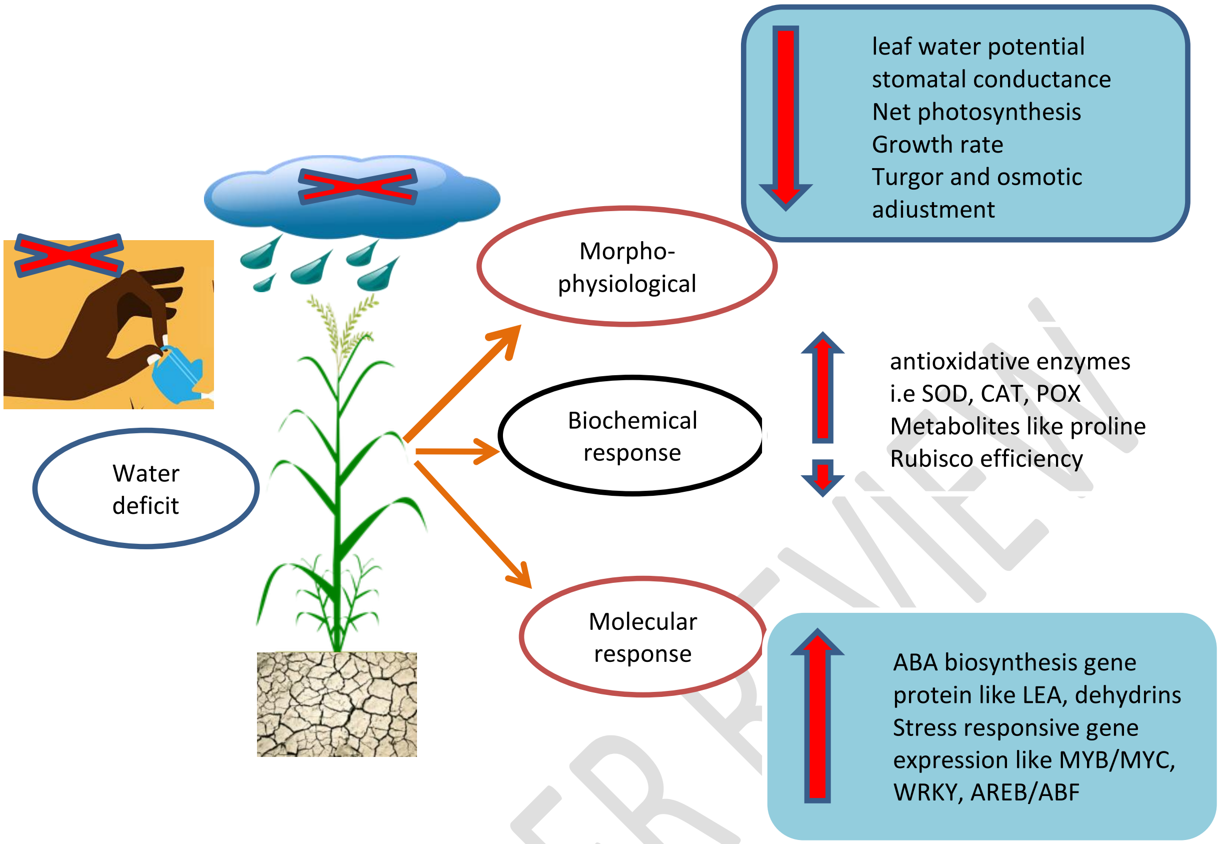

Figure 3: Physio-biochemical and transcriptional mechanism of barley under drought stress

Yield and its attributes:

Grain yield of barley is determined by the product of three components: the number of ears per meter square, the number of grains per ear and 1000 grain weight. Crop yield is also heavily influenced by the length of grain filling and the growth cycle (Garcia del Moral et al., 1991). Plant growth, yield, plant water relations, and photosynthetic activity are all affected by drought (Rajbala et al., 2011). The severity of drought stress may have an adverse influence on grain development, duration of grain filling, grain yield, and yield components of barley during the seed-filling period (Samarah, 2005). Individual grain weight (Samarah et al., 2009; Yazdanseta et al., 2014), grain quantity per spike (Samarah, 2005), spike number (Kennedy et al., 2017; Sanchez et al., 2002; Garcia del Moral et al., 1991) and the number of tillers per plant were all reduced under drought stress (Samarah, 2005). Over the four-year experiment, Sharma et al. (2016) discovered that biomass improved more than grain yield in both irrigated and rainfed conditions. They also found that under drought, yield-attributes, and yield reduced. Over all four growing seasons, the greatest loss in yield attributes was recorded in a number of grains spike^{-1} (25.8%), followed by many spikes m^{-1} (19.5%), and the lowest reduction in 1000-grain weight (4.9%).

Seed quality parameters

Protein content: Drought stress is extremely damaging to crop plants during the early reproductive stage, resulting in significant yield loss in cereal production and negative effects on grain quality (Balla et al., 2011). Morocco, a two-row barley cultivar, had less protein content than the other six-rowed genotypes. Grain starch content declined and protein content increased in all genotypes during anthesis, although drought-sensitive genotypes experienced a higher percentage increase in protein content (Behbahanizadeh et al., 2016). Ahmed et al. showed a similar increase in protein content in barley (2013). According to Ozturk and Aydin (2004), grain protein content increased by 18.1% and 8.3% under continuous water stress and late water stress treatments, respectively, when compared to fully irrigated under different water stress treatments (fully irrigated, rainfed, early water stress, late water stress, and continuous water stress). Kumar et al. (2014) discovered that BH-902 had the lowest mean protein content in barley genotypes (10.6%), followed by DWRUB-52 (11.0%). The content in RD-2668 (11.7%) and K-551 (12.2%) was higher. Grain protein concentration (GPC) of malted barley should be less than 11.5%, as higher protein content degrades malting output and ultimate beer quality.

β-glucan: Beta-glucans, a non-starch polysaccharide comprised of -(1-4) connected glucose units separated every two to three units by a single -(1-3) linked glucose and referred to as a mixed linkage -glucan, are a key functional element present in cereal grains such as barley or oats. These are the primary structural components of the cell walls of the barley grain, and they are plentiful in this cereal when compared to other cereals such as wheat and rice (Lazaridou et al., 2007). Husk barley contains 3 to 7% -glucan (Marconi et al., 2000), but husk-less barley contained up to 16% -glucan (Izydorczyk et al., 2007). Wood et al. (2003) discovered that waxy barley has a greater -glucan concentration (6.1%, with a high amylopectin level of 95 - 100% in starch) than normal barley (4.5%, with around 75% amylopectin content in starch).

Husk content: The husk (hull) of barley sticks to the pericarp and is thus retained after threshing. The barley husk shields the coleoptile (acrospire) during the germination process, aids in filtering, provides strong grain texture, and its amylase activity makes it the most recommended cereal for malt recovery. Malt can be used in brewing, distillation, infant meals, confectionaries, cocoa-malt drinks, and pharmaceutical syrups (Bornare et al., 2012). Because of its increased dietary fiber and reduced low-density lipoprotein (LDL) content, it is also regarded as a functional food and is used in many bread items and recipes. It is also high in tocopherols and tocotrienols (known to reduce serum LDL cholesterol through their antioxidant action). The most popular malting barley cultivars contain a flaw; to varying degrees, they are weakly hulled. Barley's crude protein (CP) concentration decreases as the percentage of hulls in the grain increases, owing to the low digestion of barley hulls (Bell et al., 1983). Kumar et al. (2014) reported the lowest mean value of husk content in barley genotypes RD-2668 (10.3%), DWRUB-52 (11.1%), and K-551 (12.4%), and BH-902 (12.2%).

Malt yield: The most essential quality criteria for malting barley are mean grain size, size distribution, and grain protein concentration (Vahamidis et al., 2017), and there is a positive association between kernel size/weight and malt extract production (Schwarz and Li, 2010). This is crucial since the amount of extract used influences how much beer may be produced (Li et al., 2008). According to Paramjit et al. (2001), the number of irrigations reduced malt yield substantially. According to Painter and Young (2004), a single 25 mm irrigation during the early linear stages of grain filling (20-40% complete as a percentage of final grain weight) increased the amount of maltable grain and malt extract while decreasing the quality of grain passing through a 2.5 mm slotted sieve and diastase. Irrigation at the later stages of grain filling (after more than 90% of grain filling was finished) had little or no effect on grain quality and malting quality.

Conclusion:

Climate change has a significant impact on agriculture owing to rainfall fluctuation and thus the availability of water to the crops and livestock. Water deficit disturbs normal turgor pressure and the loss of cell turgidity stops cell enlargement that causes reduced plant growth. The ability of high yielding cultivars offers an opportunity to boost the growth and yield of the crop under drought stress conditions. To address the changing climate scenario, a thorough investigation incorporating the identification of physiological and biochemical systems sensitive to drought stress tolerance in fodder crops is required.

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