

Review Article

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

Comment [KM1]: Responses

Suggestion; include area of study

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.

Comment [KM2]: This abstract is more of a literature review.

Suggestion; Touch a little on the background information, methods and then findings and conclusion of the study.

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-(*Hordeum 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)

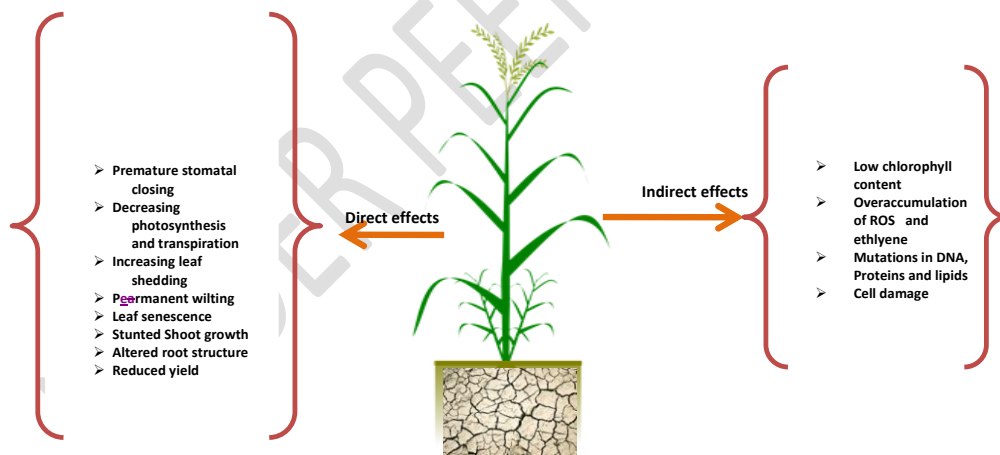


Fig 1 – Effects of barley to soil moisture stress

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).

Comment [KM3]: Are these results? It appears to be results and discussion but there is no such indication.

There is no Methods and materials section as well. This section would be a map for parameters you were looking at, study sites, study design, Barley variety and everything else

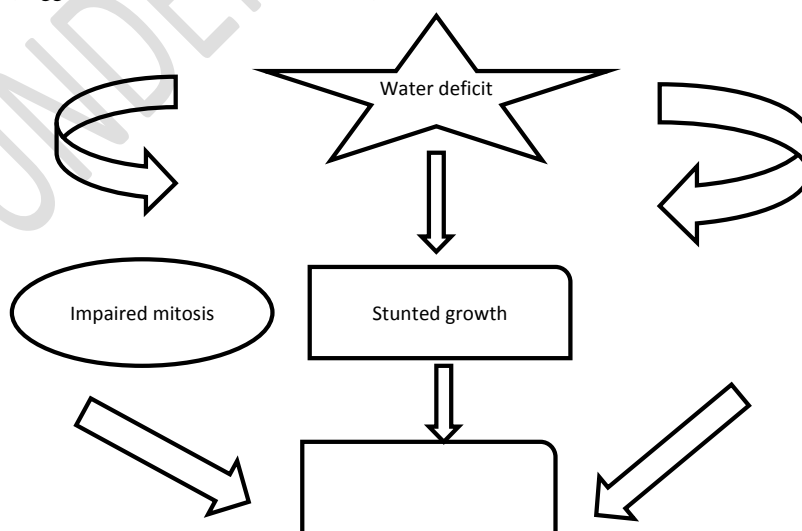


Fig2-General effects of water stress on plant growth

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

Comment [KM4]: I am missing cohesion between this starting paragraph and the previous one, does this mean the first effect was growth analysis or this subtitle is under growth analysis? Or is it independent?

Comment [KM5]: You have started bolding here, does it indicate the beginning of something new? If not, suggestion will be to write subtitles in the same manner

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 (Khoyerdil *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°C 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 CO₂ 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 CO₂ 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-deficit 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 ($O^{\cdot-}$), hydroxyl (OH^{\cdot}), hydrogen peroxide (H_2O_2) and singlet oxygen (O). 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 $O^{\cdot-}$ 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 oxidoreductase 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 droughttolerant 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).

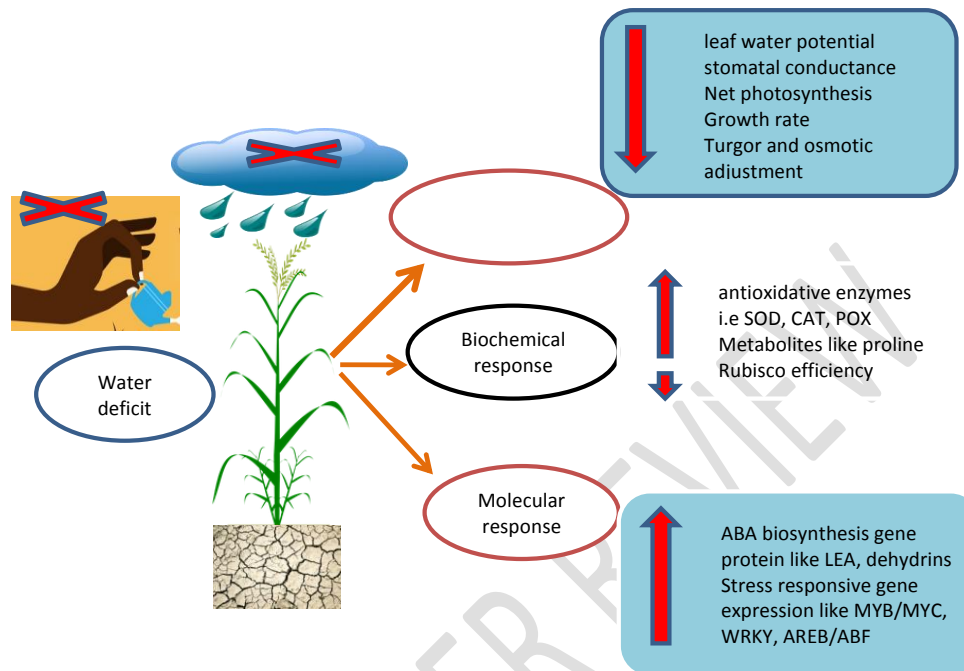


Figure 3: Physio-biochemical and transcriptional mechanism of barley under drought stress

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 (Behbahanzadeh 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 (acrosipire) 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.

References:

- 1 Abdoli, M. & Saeidi, M. (2013) Evaluation of water deficiency at the post anthesis and source limitation during grain filling on grain yield, yield formation, some morphological & phenological traits & gas exchange of bread wheat cultivar. Albanian Journal of Agricultural Sciences, 12(2), 255-265.
- 2 Aboughadareh, A.P., Ahmadi, J., Mehrabi, A.A., Etmnan, A., Moghaddam, M. & Siddiqui, K.H.M. (2017) Physiological responses to drought stress in wild relatives of wheat: implications for wheat improvement. Acta Physiologica Plantarum, 39,106-110
- 3 Acar, O., Tiirkan, I. & Ozdemir, F (2001) Superoxide dismutase & peroxidase activities in drought sensitive and resistant barley (*Hordeum vulgare* L.) varieties. Acta Physiologica Plantarum, 23, 351-356.
- 4 Ahmed, I.M., Cao, F., Han, Y., Nadira, U.A., Zhang, G. & Wu, F. (2013) Differential changes in grain ultrastructure, amylase, protein & amino acid profiles between Tibetan wild and cultivated barleys under drought and salinity alone & combined stress. Food Chemistry, 141, 2743- 2750
- 5 Alqudah, A.M. & Schnurbusch, T. (2015) Awn primordium to tipping is the most decisive developmental phase for spikelet survival in barley. Functional Plant Biology, 41, 424-436.

Comment [KM6]: They are so many subtitles that get introduced along the way without proper clarification as to what is the relevance, leaving the reader confused.

I suggest a re-write that has a detailed yet brief and to the point content. Let it be clear where the introduction, materials and methods, results and discussion sections end and start.

The study objectives should also clearly come out and be addressed in the conclusion based on findings.

There is really good potential here and the title is very much relevant.

Comment [KM7]: So then what is the conclusion about your plant of focus; Barley? what is its significance to climate change mitigation? is it drought tolerant in physiologically, biochemically or molecularly? Be clear on this.

- 6 Anjum, F., Yaseen, M., Rasul, E., Wahid, A. & Anjum, S. (2003) Water stress in barley (*Hordeum vulgare* L.) I: Effect on chemical composition and chlorophyll contents. *Pakistan Journal Agricultural Sciences*, 40, 45-49.
- 7 Arabzadeh, N. & Emadian, S.F. (2010) Effect of water (drought) stress on water relations of *Haloxylon aphyllum* and *H. persicum*. *Iranian Journal of Science & Technology*, 34, 3
- 8 Arasimowicz-Jelonek, M., Floryszak-Wieczorek, J. & Kubis J. (2009) Interaction between polyamine and nitric oxide signaling in adaptive responses to drought in cucumber. *Journal of Plant Growth Regulation*, 28, 177-186.
- 9 Asch, F., Dingkuhn, M., Sow, A. & Audebert A. (2005) Drought-induced changes in rooting patterns and assimilate partitioning between root and shoot in upland rice. *Field Crop Research*, 93, 223-236.
- 10 Assaha, Marius, D.V., Liu, L., Akihiro, U., Toshinori, N. & Hirofumi, S. (2016) Effects of drought stress on growth, solute accumulation and membrane stability of leafy vegetable, huckleberry (*Solanum scabrum* Mill.) *Journal of Environmental Biology*, 37(1), 107-114.
- 11 Azeem, I.K., Khan, I.A. & Sadaqat, H.A. (2008) Heat tolerance is variable in cotton (*Gossypium hirsutum* L.) and can be exploited for breeding of better yielding cultivars under high temperature regimes. *Pakistan Journal of Botany*, 40, 2053-2058.
- 12 Badr, K.M., Schafer-Preg, R., Rabey, E.H., Effgen, S., Ibrahim, H.H., Pozzi, C., Rohde, W. & Salamini, F. (2000) On the Origin and Domestication History of Barley (*Hordeum vulgare* L.). *Molecular Biology of Evolution*, 17(4), 499-510.
- 13 Bajji, M., Kinet, J.M. & Lutts, S. (2001) The use of the electrolyte leakage method for assessing cell membrane stability as a water stress tolerance test in durum wheat. *Plant Growth Regulation*, 00, 1-10.
- 14 Baldoni, E., Frugis, G., Martinelli, F., Benny, J., Paffetti, D., & Buti, M. (2021). A comparative transcriptomic meta-analysis revealed conserved key genes and regulatory networks involved in drought tolerance in cereal crops. *International Journal of Molecular Sciences*, 22(23), 13062.
- 15 Balla, K., Rakszegi, M., Li, Z., Bekes, F., Bencze, S. & Veisz, O. (2011) Quality of winter wheat in relation to heat and drought shock after anthesis. *Czech Journal of Food Science*, 29(2), 117- 128.
- 16 Balota, M., Payne, W.A., Evett, S.R. & Lazar, M.D. (2007) Canopy temperature depression sampling to assess grain yield and genotypic differentiation in winter wheat. *Crop Science*, 47, 1518- 1529.
- 17 Bandurska, H., Pietrowska-Borek, M. & Cieslak, M. (2012) Response of barley seedlings to water deficit and enhanced UV-B irradiation acting alone and in combination. *Acta Physiologiae Plantarum*, 34, 161-171.
- 18 Barutcular, C., Yildirim, M., Koc, M., Akinci, C., Toptas, I., Albayrak, O., Tanrikulu, A. & Sabagh, A.E. (2016) Evaluation of SPAD chlorophyll in spring wheat genotypes under different environments. *Fresenius Environmental Bulletin*, 25(4), 1258-1266
- 19 Behbahanzadeh, S.A., Akbari, G.A., Shahbazi, M., Alahdadi, I., Farahani, L., Tabatabaee, S. A. & Ganji, M. (2016) Qualitative and Physical Properties of Barley Grains under Terminal Drought Stress Conditions. *Journal of Agricultural Science & Technology*, 18, 1303-1317.
- 20 Bell, J.M., Shires, A. & Keith, M.O. (1983) Effect of hull & protein contents of barley on protein & energy digestibility & feeding value for pigs. *Canadian Journal of Animal Science*, 63, 201- 211.
- 21 Berdahl, J.D., Rasmusson, D.C. & Moss, D.N. (1972) Effects of leaf area on photosynthetic rate, light penetration and grain yield in barley. *Crop Science*, 12, 177-180.
- 22 Blum, A. (1988) *Plant Breeding for Stress Environments*. pp. 223. CRC Press, Boca Raton, Florida, USA.
- 23 Boughalleb, F. & Hajlaoui, H. (2011) Physiological and anatomical changes induced by drought in two olive cultivars (cv. Zalmati & Chemlali). *Acta Physiologiae Plantarum*, 33, 53-65.
- 24 Chaudhari, S.K., Muhammad, A. & Noshin, I. (2017) Physiological and biochemical responses of hexaploid wheat cultivars to drought stress. *Pure & Applied Biology*, 6(1), 60-71.
- 25 Chaves, M.M., Flexas, J. & Pinheiro C. (2009) Photosynthesis under drought and salt stress: regulation mechanisms from whole plant to cell. *Annals of Botany*, 103, 551-560

- 26 Clarke, J.M. & McCaig, T.N. (1982) Evaluation of techniques for screening for drought resistance in wheat. *Crop Science*, 22, 503-506
- 27 Daneshmand, F., Harvin, M.J. & Kalantari, K.M. (2010) Physiological responses to NaCl stress in three wild species of potato in vitro. *Acta Physiologiae Plantarum*, 32, 91-101.
- 28 de Carvalho, M.C. (2008) Drought stress & reactive oxygen species: production, scavenging and signaling. *Plant Signaling Behaviour*, 3, 156-165.
- 29 Farooq, J., Khaliq, I., Kashif, M., Ali, Q. & Mapara, S. (2011) Genetic analysis of relative cell injury percentage and some yield contributing traits in wheat under normal and heat stress conditions. *Chilean Journal of Agricultural Research*, 71(4), 511-520.
- 30 Farooq, M., Basra, S.M.A., Wahid, A., Ahmad, N. & Saleem, B.A. (2009a) Improving the drought tolerance in rice (*Oryza sativa* L.) by exogenous application of salicylic acid. *Journal of Agronomy & Crop Science*, 195, 237-246
- 31 Forster, B.P., Ellis, R.P., Thomas, W.T.B., Newton, A.C., Tuberosa, R., This, D., El-Enein, R.A., Bahri, M.H. & Salem, M.B. (2000) The development and application of molecular markers for abiotic stress tolerance in barley. *Journal of Experimental Botany*, 51, 19-27.
- 32 Forster, B., Ellis, R., Moir, J., Talame, V., Sanguineti, M., Tuberosa, R., Teulat, M., Ahmed, I., Mariy, S., Bahri, H., El-Ouahabi, M., Zoumarou-Wallis, N., El-Fellah, M. & Salem, M. (2004). Genotype and phenotype associations with drought tolerance in barley tested in North Africa. *Annals of Applied Biology*, 144, 157-168.
- 33 Foulkes, M.J., Scott, R.K. & Sylvester-Bradley, R. (2002) The ability of wheat cultivars to withstand drought in UK conditions: formation of grain yield. *Journal of Agricultural Sciences*, 138, 153-169.
- 34 Gao, H., Wang, Y., Xu, P., & Zhang, Z. (2018). Overexpression of a WRKY transcription factor TaWRKY2 enhances drought stress tolerance in transgenic wheat. *Frontiers in plant science*, 9, 997.
- 35 García del Moral L.F., Ramos J.M., García del Moral M.B. & Jimenez-Tejada M.O. (1991) Ontogenetic approach to grain production in spring barley based on path-coefficient analysis. *Crop Science*, 31(5), 1179-1185
- 36 Ghosh, L., Anisuzzaman, M., Alam, M.Z. & Islam, R. (2013) Effect of soil moisture on accumulation and distribution of dry matter in barley (*Hordeum vulgare* L.). *International Journal of Biosciences*, 3(5), 135-141.
- 37 Ghotbi-Ravandi, A.A., Sedighi, M., & Aghaei, K., & Mohtadi, A. (2021). Differential Changes in D1 Protein Content and Quantum Yield of Wild and Cultivated Barley Genotypes Caused by Moderate and Severe Drought Stress in Relation to Oxidative Stress, *Plant Molecular Biology Reporter*, 39: 501–507
- 38 Gill, S. & Tuteja, N. (2010) Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. *Journal of Plant Physiology Biochemistry*, 48, 909-930.
- 39 Gonzalez, A., Martin, I. & Ayerbe, L. (2008) Yield and osmotic adjustment capacity of barley under terminal water deficit conditions. *Journal of Agronomy & Crop Science*, 194, 81-91.
- 40 Guoth, A., Benyo, D., Csiszar, J., Galle, A., Horvath, F., Cseuz, L., Erdei, L. & Tari, I. (2010) Relationship between osmotic stress-induced abscisic acid accumulation, biomass production and plant growth in drought-tolerant & sensitive wheat cultivars. *Acta Physiologiae Plantarum*, 32, 719-727.
- 41 Gupta, N.K., Gupta, S. & Kumar, A. (2001) Effect of water stress on physiological attributes and their relationship with growth and yield of Wheat cultivars at different stages. *Journal of Agronomy & Crop Science*, 186(1), 55-62.
- 42 Habibi, G. (2012) Exogenous salicylic acid alleviates oxidative damage of barley plants under drought stress. *Acta Biologica Szegediensis*, 56(1), 57-63.
- 43 Harb, A. & Samarah, N. (2015) Physiological and molecular responses to controlled severe drought in two barley (*Hordeum Vulgare* L.) genotypes. *Journal of Crop Improvement*, 29, 82-94.

- 44 Harb, A., Awad, D. & Samarah, N. (2015) Gene expression and activity of antioxidant enzymes in barley (*Hordeum vulgare* L.) under controlled severe drought. *Journal of Plant Interactions*, 10(1), 109-116.
- 45 Harb, A., Simpson, C., Guo, W., Govindan, G., Kakani, V. G., & Sunkar, R. (2020). The effect of drought on transcriptome and hormonal profiles in barley genotypes with contrasting drought tolerance. *Frontiers in plant science*, 11, 618491.
- 46 Hasanuzzaman, M., Shabala, L., Brodrigg, T.J., Zhou, M. & Shabala, S. (2016) Assessing the suitability of various screening methods as a proxy for drought tolerance in barley. *Functional Plant Biology*, 44(2), 253-266.
- 47 Hayat, S., Hayat, Q., Alyemini, M.N., Wani, A.S., Pichel, J. & Ahmad, A. (2012) Role of proline under changing environments: A review. *Plant Signaling & Behavior*, 7(11), 1456-1466.
- 48 Ibrahim, A.M.H. & Quick, J.S. (2001) Heritability of heat tolerance in winter and spring wheat. *Crop Science*, 41, 1401-1405.
- 49 Izydorczyk, M.S., Chornick, T.L., Paulley, F.G., Edwards, N.M. & Dexter J.E. (2008) Effect of pin milling on the physiological properties of hull-less barley fibre-rich fractions and their potential as functional ingredients in two-layer flat bread. *Food Chemistry*, 108, 561-570
- 50 Janiak, A., Kwasniewski, M., Sowa, M., Kuczyńska, A., Mikołajczak, K., Ogrodowicz, P., & Szarejko, I. (2019). Insights into barley root transcriptome under mild drought stress with an emphasis on gene expression regulatory mechanisms. *International journal of molecular sciences*, 20(24), 6139.
- 51 Jiang, M.Y. & Jhang, J.H. (2004) Abscisic acid and antioxidant defense in plant cells. *Acta Botanica Sinica*, 46, 1-9.
- 52 Kalaji, H. M., Jajoo, A., Oukarroum, A., Brestic, M., Zivcak, M., Samborska, I.A., Cetner, M.G., Lukasik, I., Goltsev, V. & Ladle, R.J. (2016) Chlorophyll a fluorescence as a tool to monitor physiological status of plants under abiotic stress conditions. *Acta Physiologica Plantarum*, 38, 102.
- 53 Kannan, N.D. & Kul&aivelu, G. (2011) Drought induced changes in physiological, biochemical and phytochemical properties of *Withania somnifera* Dun. *Journal of Medicinal Plants Research*, 5, 3929-3935.
- 54 Kausar, R., Arshad, M., Shahzad, A. & Komatsu, S. (2012) Proteomics analysis of sensitive and tolerant barley genotypes under drought stress. *Amino Acids*, 44(2), 345-359.
- 55 Kennedy, S.P., Bingham I.J. & Spink, J.H. (2017) Determinants of spring barley yield in a high-yield potential environment. *Journal of Agricultural Science*, 155, 60-80.
- 56 Khateeb, W.A., Shalabi, A.A., Schroeder, D. & Musallam, I. (2017) Phenotypic and molecular variation in drought tolerance of Jordanian durum wheat (*Triticum durum* Desf.) landraces. *Physiology & Molecular Biology of Plants*, 23(2), 311-319.
- 57 Khoyerd, F.F., Shamshiri, M.H. & Estaji, A. (2016) Changes in some physiological and osmotic parameters of several pistachio genotypes under drought stress. *Scientia Horticulturae*, 198, 44-51.
- 58 Kumar, D., Narwal, S., Verma, R.P.S., Kumar, V., Kharub, A.S. & Sharma, I. (2014) Performance of barley varieties for malting quality parameters in north western plains of India. *Journal of Wheat Research*, 6(2), 132-137.
- 59 Lazaridou, A., & Biliaderis, C.G. (2007) Molecular aspects of Cereal β -glucan functionality: Physical properties, technological applications and physiological effects. *Journal of Cereal Science*, 46, 101-118.
- 60 Legg, B.J., Day, W., Lawlor, W. & Parkinson K.J. (1979) The effects of drought on barley growth: models and measurements showing the relative importance of leaf area and photosynthetic rate. *Journal of Agricultural Science*, 92, 703-716.
- 61 Lepout, L., Turner, N.C., French, R.J., Barr, M.D., Duda, R. & Davies, S.L. (2006) Physiological responses of chickpea genotypes to terminal drought in a Mediterranean-type environment. *European Journal of Agronomy*, 11, 279-291

- 62 Levitt, J. (1972) Responses of plants to environmental stresses. New York, NY: Academic Press, pp. 1-698.
- 63 Li, W. X., Oono, Y., Zhu, J., He, X. J., Wu, J. M., Iida, K., ... & Zhu, J. K. (2008). The Arabidopsis NFYA5 transcription factor is regulated transcriptionally and posttranscriptionally to promote drought resistance. *The Plant Cell*, 20(8), 2238-2251.
- 64 Li, Y., Johnson, D.A., Yongzhong, S.U., Jianyuan, C.U.I. & Zhang, T. (2005) Specific leaf area and leaf dry matter content of plants growing in sand dunes. *Botanical Bulletin Academia Sinica Taipei* 46, 127-134.
- 65 Li, Y., Schwarz, P.B., Barr, J.M., & Horsley, R.D. (2008) Factors predicting malt extract within a single barley cultivar. *Journal of Cereal Science*, 48, 531-538.
- 66 Lopes, M.S. & Reynolds, M.P. (2010) Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. *Functional Plant Biology*, 37, 147-156.
- 67 Marconi, E., Graziano, M. & Cubadda R. (2000) Composition and utilization of barley pearling byproducts for making functional pastas rich in dietary fiber and β -glucans. *Cereal Chemistry*, 77 (2), 133-139.
- 68 Maxwell, K. & Jhonson, G. N. (2000) Chlorophyll fluorescence—A practical guide. *Journal of experimental botany*, 51(345), 658-668
- 69 Mitra, J. 2001. Genetics and genetic improvement of drought resistance in crop plants. *Current Science-Bangalore* 80:758–63
- 70 Mittler, R. (2002) Oxidative stress, antioxidants and stress tolerance. *Trends in Plant Science*, 7(9), 405-410
- 71 Mohd, I., Shamsul, H., Qaiser, H., Shaheena, A. & Aqil, A. (2010) Physiological and biochemical changes in plants under waterlogging. *Protoplasma*, 241, 3-17.
- 72 Munns, R., James, R.A., Sirault, X.R.R., Furbank, R.T. & Jones, H.G. (2010) New phenotyping methods for screening wheat and barley for beneficial responses to water deficit. *Journal of Experimental Botany*, 61(13), 3499-3507
- 73 Nayyar, H., Kaur, S., Smita, K., *et al.* (2005) Water stress-induced injury to reproductive phase in chickpea : Evaluation of stress sensitivity in wild and cultivated species in relation to abscisic acid and polyamines. *Journal of Agronomy & Crop Science*, 191, 450-457.
- 74 Nilan, R.A. & Ullrich, S.E. (1993) Barley: taxonomy, origin, distribution, production, genetics & breeding. *Barley: Chemistry and Technology* (eds W. MacGregor and R.S. Bhatt). American Association of Cereal Chemists, Inc, USA, pp. 1-330.
- 75 Noctor, G., Mhamdi, A. & Foyer, C. (2014) Roles of reactive oxygen metabolism in drought: not so cut and dried. *Plant Physiology*, 164,1636-1648.
- 76 Okuyama, L.A., Federizzi, L.C. & Neto, J.F.B. (2004) Correlation and path analysis of yield and its components and plant traits in wheat. *Ciência Rural*, 34, 1701-1708.
- 77 Ozturk, A. & Aydin, F. (2004) Effect of water stress of various growth stages on some quality characteristics of winter wheat. *Journal of Agronomy & Crop Science*, 190, 93-99.
- 78 Painter, B.H. & Young, K.J. (2004) Grain & malting quality in two-row spring barley are influenced by grain filling moisture. *Crop & Pasture Science*, 55(5), 539-550.
- 79 Paramjit., Singh, V.P. & Kaur, A. (2001) Effect of different levels of nitrogen on growth and yield of malt barley variety Alfa-93. *Crop Research*, 21, 261-64
- 80 Pinto, S.R., Reynolds, M.P., Mathews, K.L., McIntyre, C.L., Olivares-Villegas, J.J. & Chapman, S.C. (2010) Heat and drought adaptive QTL in a simultaneously. wheat population designed to minimize confounding agronomic effects. *Theoretical & Applied Genetics*, 121, 1001-1021.

- 81 Rajbala, A., Hakala, K., Makela, P., & Peltonen-Sainio, P. (2011) Drought effect on grain number and grain weight at spike and spikelet level in six-row spring barley. *Journal of Agronomy & Crop Science*, 197(2), 103-112
- 82 Ramya, P., Singh, G.P., Jain, N., Singh, P.K., P&ey, M.K., Sharma, K., *et al.* (2017) Effect of Recurrent Selection on Drought Tolerance & Related Morpho- Physiological Traits in Bread Wheat. *PLoS ONE*, 11(6), 168-179
- 83 Ranjeet, Kumar, R., Sharma, S.K., Kritika, Gadpayle, A., Singh, K., Sivaranjani R., Goswami, S. & Rai R.D. (2012) Mechanism of action of hydrogen peroxide in wheat thermotolerance - interaction between antioxidant isoenzymes, proline & cell membrane. *African Journal of Biotechnology*, 11(78), 14368-14379.
- 84 Rehman, S.U., Bilal, M., Rana. R.M., Tahir, M.N., Shah, M.K.N., Ayalew, H. & Yan, G. (2016) Cell membrane stability and chlorophyll content variation in wheat (*Triticum aestivum* L.) genotypes under conditions of heat and drought. *Crop & Pasture Science*, 67, 712-718
- 85 Reynolds, M.P. (2002) Physiological approaches to wheat breeding in: "Bread Wheat: Improvement and Production", (Ed.); Report: Food & Agricultural Organization (FAO) of the United Nations, Rome, Italy, pp. 256
- 86 Richards, R., G. Rebetzke, A. Condon, and A. Van Herwaarden. 2002. Breeding opportunities for increasing the efficiency of water use and crop yield in temperate cereals. *Crop Science* 42 (1):111–21.
- 87 Roohi, E., Tahmasebi-Sarvestani, Z., Modarres-Sanavy, S.A.M. & Siosemardeh, A. (2013) Comparative study on the effect of soil water stress on photosynthetic function of triticale, bread wheat, and barley. *Journal of Agriculture Science & Technology*, 15, 215-228.
- 88 Roohi, E., Tahmasebi-Sarvestani, Z., Sanavy, S.A.M.M. & Siosemardeh, A. (2015) Association of some photosynthetic characteristics with canopy temperature in three cereal species under soil water deficit condition. *Journal of Agriculture Science & Technology*, 17, 1233-1244.
- 89 Saed-Moucheshi, A. 2018. Evaluation of morphological, physiological, and molecular characteristics of triticale genotypes under drought stress condition, 380. Shiraz: Crop Production and Plant Breeding, Shiraz University
- 90 Saleem, A., Ashraf, M. & Akram, N.A. (2011) Salt (NaCl)-induced modulation in some key physiobiochemical attributes in okra (*Abelmoschus esculentus* L.). *Journal of Agronomy & Crop Science*, 197, 202-213.
- 91 Salekjalali, M., Haddad, R. & Jafari, B. (2012) Effects of soil water shortages on the activity of antioxidant enzymes & the contents of chlorophylls and proteins in barley. *AmericanEurasian Journal of Agricultural & Environmental Science*, 12(1), 57
- 92 Samarah N.H., Alqudah A.M., Amayreh J.A. & Mc&rews G.M. (2009) The effect of late-terminal drought stress on yield components of four barley cultivars. *Journal of Agronomy & Crop Science*, 195(6), 427-441.
- 93 Samarah, N.H. (2005) Effects of drought stress on growth and yield of barley. *Agronomy for Sustainable Development*, 25(1), 145-149
- 94 Sanchez, D., Garcia, J. & Antolin, M. (2002) Effects of soil drought & atmospheric humidity on yield, gas exchange, and stable carbon isotope composition of barley. *Photosynthetica*, 40, 415-421.
- 95 Schwarz, P. & Li, Y. (2010) Malting and brewing uses of barley. *Barley production, improvement, and use* (eds. S.E. Ullrich), pp. 478-521. Wiley-Blackwell, Oxford, UK.
- 96 Seki, M., Umezawa, T., Urano, K. & Shinozaki, K. (2007) Regulatory metabolic network in drought stress responses. *Current Opinion in Plant Biology*, 10, 296-302
- 97 Sharafi, S., Golezani, K., Mohammadi, S., Lak, S., & Sorkhy, B. (2014) Evaluation of barley genotypes by drought tolerance indices & multivariate analysis. *International Journal of Bioscience*, 4(7), 117-129.

- 98 Sharma, K.D. & Kumar, A. (2014) Identification of physiological and yield related traits of wheat (*Triticum aestivum* L.) under varying soil moisture stress. *Journal of Agrometeorology*, 16(1), 78-84
- 99 Sharma, K.D., Kumar, A. & Verma, S.R. (2016) Variations in physiological traits as screening tool for drought tolerance in barley (*Hordeum vulgare* L.). *Indian Journal of Plant Physiology*, 21(1), 93-100.
- 100 Siebke, K., von Caemmerer, S., Badger, M. & Furbank, R.T. (1997) Expressing an RbcS antisense gene in transgenic *Flaveria bidentis* leads to an increased quantum requirement for CO₂ fixed in photosystems I and II. *Plant Physiology*, 105, 1163-1174
- 101 Sieling, K., Böttcher, U. & Kage, H. (2016) Dry matter partitioning and canopy traits in wheat & barley under varying N supply. *European Journal of Agronomy*, 74, 1-8
- 102 Singh, D., & Laxmi, A. (2015). Transcriptional regulation of drought response: a tortuous network of transcriptional factors. *Frontiers in plant science*, 6, 895.
- 103 Tavakoli, A., Ahmadi, A., Saeidi, M. & Madah H.S. (2011) Study of water relation and gas exchange in drought tolerant and susceptible wheat (*Triticum aestivum* L.) cultivars under post-anthesis drought stress condition. 2nd Iranian Conference on Plant Physiology, Yazd, pp. 124
- 104 Teulat, B., Zoumarou-Wallis, N., Rotter, B., Salem, M.B., Bahri, H. & This, D. (2003) QTL for relative water content in field-grown barley and their stability across Mediterranean environments. *Theoretical & Applied Genetics*, 108,181-188
- 105 Tiryakioğlu, M., Karanlık, S. & Arsalan, M. (2015) Response of bread-wheat seedlings to waterlogging stress. *Turkey Journal of Agricultural Forestry*, 9, 1-10.
- 106 Turkan, I., Bor, M., Ozdemir, F. & Koca, H. (2005) Differential responses of lipid peroxidation and antioxidants in the leaves of drought tolerant *P. acutifolius* Gray and drought-sensitive *P. vulgaris* L. subjected to polyethylene glycol mediated water stress. *Plant Sciences*, 168, 223- 231.
- 107 Turner, N.C. & Begg, J.E. (1981) Plant water relations and adaptation to stress. *Plant Science*, 58, 97-131.
- 108 Vaezi, B., Bavei, V. & Shiran, B. (2010) Screening of barley genotypes for drought tolerance by agrophysiological traits in field condition. *African Journal of Agricultural Research*, 5(9), 881- 892.
- 109 Vahamidis, P., Stefopoulou, A., Kotoulas, V., Lyra, D., Dercas, N. & Economou G. (2017) Yield, grain size, protein content and water use efficiency of null-LOX malt barley in a semiarid Mediterranean agroecosystem. *Field Crops Research*, 206, 115-127.
- 110 Vartapetian, B.B. & Jackson, M.B. (1997) Plant adaptation to an aerobic stress. *Annals of Botany*, 79, 3-20
- 111 Vendruscolo, E.C.G., Schuster, I., Pileggi, M., Scapim, C.A., Molinari, H.B.C., Marur, C.J. & Vieira, L.G.E. (2007) Stress-induced synthesis of proline confers tolerance to water deficit in transgenic wheat. *Journal of Plant Physiology*, 164, 1367-1376.
- 112 Verma, R.P.S., Kumar, V., Sarkar, B., Kharub, A.S., Kumar, D., Selakumar, R., *et al.*, (2012) Barley cultivars released in India: name, parentages, origins & adaptations. Directorate of Wheat Research, Karnal, Haryana, Research Bulletin, 29, 26
- 113 Vitrakoti, D., Aryal, S., Rasaily, S., Ojha, B.R., Kharel R. & Sapkota, M. (2016) Study on genotypic response and correlation analysis of the yield and yield attributing traits of different barley (*Hordeum vulgare* L.) Genotypes. *International Journal of Applied Science & Biotechnology*, 4 (4), 529-536.
- 114 Wahid, A. & Close, T.J. (2007) Expression of dehydrins under heat stress and their relationship with water relations of sugarcane leaves. *Biology of Plants*, 51, 104-109.
- 115 Wani, A.S., Faraz, A., Faizan, M., Ahmad, A., Hayat, S. & Tahir, I. (2017) Foliar spray of proline enhanced the photosynthetic efficiency and antioxidant system in *Brassica juncea*. *Notulae Botanicae Horticulturae Agrobotanicae*, 45(1), 112-119.
- 116 Wehner, G.G., Balko, C.C., Enders, M.M., Humbeck, K.K. & Ordon, F.F. (2015) Identification of genomic regions involved in tolerance to drought stress and drought stress induced leaf senescence in juvenile barley. *BioMedical Central Plant Biology*, 15, 125.

- 117 Wood, P.J., Weisz, J., Beer, M.U., Newman, C.W. & Newman, R.K. (2003) Structure of (1 → 3) (1 → 4)-β-D-glucan in waxy and nonwaxy barley. *Cereal Chemistry*, 80 (3), 329-332.
- 118 Yazdanseta, S., Haravan E.M., Sorkhi, B. & Mohammadi, A. (2014) Assessment of yield, yield related traits and drought tolerance of barley (*Hordeum vulgare* L.) genotypes. *International Journal of Biosciences*, 4(12), 62-72.
- 119 Yildirim, M., Kilic, H., Kendal, E. & Karahan, T. (2011) Applicability of chlorophyll meter readings as yield predictor in durum wheat. *Journal of Plant Nutrition*, 34(2), 151-164.
- 120 Zandkarimi, H., Ebadi, A., Salami, S. A., Alizade, H., & Baisakh, N. (2015). Analyzing the expression profile of AREB/ABF and DREB/CBF genes under drought and salinity stresses in grape (*Vitis vinifera* L.). *PloS one*, 10(7), e0134288.
- 121 Zhang, Y., Yao, Q., Li, J., Wang, Y., Liu, X., Hu, Y., *et al.* (2015) Contributions of an arbuscular mycorrhizal fungus to growth and physiology of loquat (*Eriobotrya Japonica*) plants subjected to drought stress. *Mycological Progress*, 14, 84.
- 122 Zhang, Y.L., Hu, Y.Y., Luo, H.H., Chow, W.S. & Zhang, W.F. (2011) Two distinct strategies of cotton and soybean differing in leaf movement to perform photosynthesis under drought in the field. *Functional Plant Biology*, 38, 567-575.
- 123 Zlatev, Z. & Lidon, F.C. (2012) An overview on drought induced changes in plant growth, water relations & photosynthesis. *Emirates Journal Food & Agriculture*, 24, 57-72.