Society for Advancement of Wheat and Barley Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Wheat and Barley Research
10(3): 151-165
Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Review Article

Management strategies for abiotic stresses in barley

Sonia Rani[a], Ankur Chaudhary[b] and Kanta Rani[c]
[a]*ICAR-Indian Institute of Wheat and Barley Research, Karnal, India*
[b]*CCS Haryana Agricultural University, Hisar, RRS Uchani Karnal, Haryana, India*
[c]*Goswami Ganesh Dutt Sanatan Dharam College, Palwal, Haryana, India*

Article history
Received: 01 Nov., 2018
Revised : 19 Dec., 2018
Accepted: 27 Dec., 2018

Citation
Rani S, A Chaudhary and K Rani. 2018. Management strategies for abiotic stresses in barley. *Wheat and Barley Research* **10**(3): 151-165. doi.org*/10.25174/2249-4065/2018-85229*

****Corresponding author***
Email: *ankurchaudhary292@gmail.com*

Abstract

Globally, abiotic stresses are major limiting factor in achieving optimum production and productivity of various crops. These stresses cause about 50% reduction in yields of various crops. Although, barley (*Hordeum vulgare* L.) is a comparatively abiotic stress tolerant crop but still abiotic stresses (drought, salinity, sodicity, acidity, water logging, heat, nutrient toxicities/ deficiencies etc.) affect the barley production and productivity. The duration of the stress and the plant's growth stage at which stress occurs affects the yield. For the sustainable barley production there is need that various abiotic stresses be effectively addressed through adoption of management practices like tillage and planting options, residue management, sowing time, stress tolerant cultivars, irrigation scheduling and integrated nutrient management. Barley potential to cope up against abiotic stress can be further accelerated by synchronizing breeding and agronomic, climatic driven and location specific researches.

Keywords: Abiotic stresses, temperature, heavy metals, water logging, lodging, nutrient management

1. Introduction

Barley (*Hordeum vulgare* L.) is one of the fourth most important cereal small grain crop and commonly used in malting and brewing industry for animal feed and human consumption cultivated in both high-yielding high-input agricultural systems as well as in marginal low-input agricultural environments. Global climate change and the increasing occurrences of droughts (water and heat stresses) of varying severity, duration and scale in various parts of the world can have adverse effects on crop growth, and grain productivity (Ashraf, 2010). They are recurring features of nearly all the world's climatic regions since various critical environmental threats with global implications have linkages to water crises (Gleick, 2000). According to a worldwide approximation, abiotic stresses causes yield losses in various agricultural crops by an average 50% of which high temperature, salinity, drought and low temperature constitutes about 20%, 10%, 9% and 7% (Thilert, 2006; Oerke *et al.*, 1994). Abiotic stresses resulting from excessive salinity or water deficit led to reduction in photosynthesis, transpiration and other biochemical processes associated with plant growth, development and crop productivity (Shannon, 1997 and Tiwari *et al.*, 2010). However, during more severe and persistent stress conditions an uncontrolled accumulation of reactive oxygen species (ROS) may occur, which causes several damages including membrane and protein modifications in cells, enhanced level of lipid and protein peroxidation and activation of antioxidant apparatus. Plants are equipped with both non-enzymatic antioxidants and enzymatic ROS scavengers to protect cells from oxidative damage (Breusegem *et al.*, 2001). Due to their signal molecule function, these plays crucial role in the signalization of adverse conditions for cells and in the activation of defense responses. Much of the injury on plants under abiotic stress is linked to oxidative damage at the cellular level leading to cell death (Mittler, 2002; Hameed *et al.*, 2011). Plants containing high activities of antioxidant enzymes have shown considerable resistance to oxidative damage caused by ROS (Gapinska *et al.*, 2008). Abiotic stress leads to oxidative stress in the plant cell resulting in a higher leakage of electrons towards O_2 during photosynthetic and respiratory processes (Asada, 2006). So there is need to fine tune the agronomic and breeding strategies to cope various abiotic stresses (heat and cold stress, drought, waterlogging, salt stress) in barley to make its resilient cultivation against climatic anomaly.

Temperature stress in barley: Temperature stress has a strong effect on the growth and development of barley. Temperature stress can be divided into two categories one is low temperature which includes cold and freezing and high-temperature range, which is associated with heat stress.The negative impact of climate change on crop yield has been established, with a projected increase in global temperature on the order of 4°C by the late twenty-first century (IPCC 2014). Heat stress associated with high ambient temperatures considered as one of the major abiotic stresses that limit crop growth and productivity (Shao *et al.*, 2015). High temperature more than optimal cardinal adversely affects crop growth and reduce yield due to loss of moisture through early evaporation that results in poor crop establishment, shrink the optimum duration for vegetative growth i.e., tillering and jointing that results in poor source development, also high temperature during reproductive stage results in premature flowering, accelerate grain filling period, reduced grain number and size ultimately reduce crop yield (Wahid *et al.*, 2007; Wallwork *et al.*, 1998). High temperature (heat stress) affects the duration of the growing season, geographic distribution (Dawson *et al.*, 2015) and malting quality of barley (Savin *et al.*, 1996). The effects of heat stress depend on several factors, such as stress intensity (temperature in degrees), duration and rate of temperature increase (Wahid *et al.*, 2007). Symptoms of heat stress in barley include the reduction of yield and yield components, such as number of tillers per plant, spike length, thousand grain weight and a lower final starch concentration possibly caused by irreversible inactivation of sucrose synthase (Abou-Elwafa and Amein, 2016; Wahid *et al.*, 2007; Hogy *et al.*, 2013; Wallwork *et al.*, 1998). Barley, like other cereal crops, is particularly sensitive to heat stress during panicle development and meiosis, with high temperatures (over several days) causing abnormal pollen development and complete sterility (Sakata *et al.* 2000). However, yield loses varies and associated with stage and duration at which plant encountered with abnormal temperature, inherent genetic tolerance, mechanism involved in ameliorating the stress and also availability of soil moisture due to its role in evaporative cooling of the canopy. Regarding photosynthetic machinery, it impairs rubisco activase in the Calvin cycle, photosystem I and II, drastic inhibition of carbon-dioxide fixation photophosphorylation capability, inhibition of the electron flow from QA to QB (Cao and Govindjee, 1990; Berry and Bjorkman, 1980; Wahid *et al.*, 2007). Oshino *et al.*, (2007) studied the effect of high-temperature injury on anthers development in barley and observed a premature progression of early developmental stages and fate e.g., progression to meiosis of pollen-mother cells. Gene expression and differentiation of anthers were studied under normal (20^0C day/15^0C night) and heat stress (30^0C day/25^0C night) conditions, revealing that genes that are active in the anthers under normal temperature conditions, such as H3, H4, and glycine-rich RNA-binding protein genes, were transcriptionally inhibited under heat stress (Abiko *et al.*, 2005). After anthesis, a field trial in Iran showed a 17% reduction in grain yield in barley under heat stress and significantly affected parameters, including the translocation of photosynthates to the grain, starch synthesis and deposition in the developing grain (Modhej *et al.*, 2015). Field trials have shown grain yield reduction caused by heat stress causing a higher penalty when temperature increased during stem elongation (Ugarte *et al.*, 2007). In another field experiment using a panel of 138 spring barley genotypes, Ingvordsen *et al.*, (2015) corroborated the decrease in grain yield upto 55.8%) caused by heat stress. High temperature stress coupled with drought decreased the days to visible awns, days to heading and days to maturity and resulting in a lower plant population m^{-2}, tillers $plant^{-1}$, plant height and dry matter production m^{-2} (Hossain *et al.*, 2012).

Freezing stress: Low-temperature stress includes cold (also known as chilling, above freezing point temperature) and freezing (below freezing point temperature), has a severe effect on small-grain crop plants in temperate climates (Kosova *et al.*, 2011). In regions, such as southern Australia, where winter temperatures are not low enough to cause freezing damage at the vegetative stage, radiation frost constitutes a problem at the reproductive stage. Radiation frost occurs during clear nights when the plant canopy is receiving less heat than what is radiated away, causing temperatures to drop below zero. Yield is severely affected by frost as a result of floret and spike abortion as well as damage to developing grains (Reinheimer *et al.*, 2004 and Zheng *et al.*, 2015). Freezing tolerance in barley is a polygenic trait with complex interactions between loci, genotype and environment (Busconi *et al.*, 2001; Ceccarelli *et al.*, 2010). This tolerance associated with freezing invariably affects metabolic processes such as redox reactions, photosynthesis, carbohydrate metabolism, transcription and protein expression. Various types of proteins are involved in development of defense mechanism such as late embryogenesis abundant and heat shock proteins, photosynthetic electron transport chain components, chaperons and reactive oxygen species- destroyer enzymes (Janmohammadi *et al.*, 2015; Gharechahi *et al.*, 2014). Proteomic study showed that higher activity of Rubisco activase, greater abundance of Rubisco (large and small subunits), oxygen-evolving enhancer proteins viz., Ferredoxin-NADP reductase and Cytochrome P450-dependent fatty acid hydroxylase were associated with greater freezing tolerance level in barley. Moreover, lower relative level of hypothetical ATP synthase beta subunit, mitochondrial protein AtMg00810, small subunit methyltransferase G of ribosomal RNA are more important for imparting freezing tolerance and H_2O_2 acts as a signalling molecule involved in the commencement of cold-induced acclimation in barley (Gołębiowska-Pikania *et al.*, 2017). These types of study further amplified with strategic screening with double haploids (DH) lines that not only produce totally homozygous lines but also uncovered the inherent genetic diversity as a whole (Gołębiowska-Pikania *et al.*, 2017).

Salt stress: Increased salinization is a severe threat for sustainable agriculture and it is projected that by the year 2050 more than 50% of cultivable soil will be affected (Vinocur and Altman, 2005). Over the world, about 800 mha of lands are affected with various salt and constitute more than 6% of total land area of the world (FAO, 2010). The largest such area, of 189 Mha, is located in the Middle East (Wicke *et al.*, 2011). These numbers are expected to increase due to future climate change and poor irrigation practices (Hayes *et al.*, 2015). Alkaline (Sodic) soils have the pH values greater than 8.5 with insoluble salts of sodium, carbonate and bicarbonates that results in lower infiltrability with more dispersion of soil aggregates (Chhabra, 1996). While, under saline condition that is mostly found under arid and semi-arid regions, soluble salt of chlorides and sulfates of calcium, magnesium and sodium hamper the crop growth and water uptake (Physiological drought) from the soil. Salt stress in plants induced through development of soil salinity results in water stress, nutritional and hormonal imbalance, specific ion toxicity, disturbance in homeostasis of Na^+ and Cl^- ions, induces reactive/active oxygen species (ROS/AOS) production in chloroplasts that oxidizing biological molecules, such as DNA, proteins and lipids (Fadzilla *et al.*, 1997; Liang *et al.*, 2003; Meneguzzo *et al.*, 1999; Steduto *et al.*, 2000; Gunes *et al.*, 2007; Daneshmand *et al.*, 2010). That inhibit rate of photosynthesis, protein building and lipid metabolism in plant that subsequently leads to death of plant cell (Paul and Lade, 2014). Barley is regarded as salt tolerant among crop plants, however, under severe stress scenario, its growth and development are also severely affected by ionic and osmotic stresses (Mahmood, 2011). Barley varieties grown in these marginal areas have to be tolerant to soil salinity. Salt tolerance in cereals is known to be associated with the control of shoot Na^+ content as tolerant lines have more efficient systems to exclude sodium from their cells (Dubcovsky *et al.*, 1996). Barley is notable in that it can maintain growth whilst accumulating high concentrations of Na^+ in its leaves The high tissue tolerance of barley is likely to involve sequestration of Na^+ into intracellular vacuoles and the synthesis of compatible solutes that accumulate in the cytoplasm to balance the osmotic potential of the vacuolar Na^+ (Munns *et al.*, 1988). Wakeel *et al.*, (2011) suggested that the Na^+ toxicity affects plant growth, increased Na^+/K^+ ratio and thus displacement of K^+ by Na^+ in the plant cell affects the activity of plasma membrane and H^+-ATPase activity. Plants respond in many ways to salinity and at a number of levels subsequently, result in a wide range of metabolic responses (Munns and Tester, 2008; Zuther *et al.*, 2007). Under salt stress condition, there is decreased in plasma membrane H^+-ATPase activity, plasma membrane fluidity in the leaves and glutathione content while, the ratio of phospholipids to proteins in plasma membrane vesicles increased (Liang *et al.*, 2006). Both superoxide dismutase (SOD) and catalase (CAT) activities decline in plants (Singha and Choudhuri, 1990) while malondialdehyde (MDA) accumulates rapidly (Fadzilla *et al.,* 1997) that results in plasma membrane permeability. Both enzymatic (superoxide dismutase, catalase, ascorbate peroxidase, peroxidase) and non-enzymatic (glutathione, ascorbic acid and carotenoids) systems scavenging AOS in plants (Breusegem *et al.*, 2001). In leaves, under salt induced water deficit conditions, shoot growth is reduced, considerable alteration in soluble carbohydrate, proline, total phenolic compounds, antioxidant activity, Na^+ content and K^+ homeostasis or Na^+/K^+ ratio, leaf photosynthetic pigments, leaf soluble protein content as provoked by oxidative stress. General metabolic adaptation which enables plants to cope with water or osmotic stress, involves an increased synthesis of osmoprotectants, such as proline and soluble sugar that not only contribute to osmoregulation but also protect the structure of different biomolecules and membranes (Yancey *et al.*, 1982; Hare *et al.*, 1998) or act as free-radical scavengers that protect DNA from damaging effects of ROS (Ashraf and Foolad, 2007). Proline accumulation has been reported to counter balance the deleterious effects of water deficit, salinity and act as an organic nitrogen reserve that recover the system quickly (Sairam and Tyagi, 2004).

Heavy metal toxicity: As compared to rice and wheat, barley is more sensitive to aluminium (Al) toxicity although genetic variation within species also exists (Kochian, 1995). Toxic aluminium (Al) cations solubilized by the acidity causes rapid inhibition of root elongation androot growth subsequently, reduces uptake of water and nutrients. Prominent pathways for detoxification includes chelation or exclusion of Al at the apoplast via rhizosphere alkalinization (Degenhardt *et al.*, 1998), release of organic acids (Ma *et al.*, 1997) and phenolic compounds (Kidd *et al.*, 2001). Citrate secreted from the root apices excluding Al and thereby detoxifying Al. Positive correlation found in response to Al stress between citrate secretion and Al resistance while, negative correlation between citrate secretion and Al content of root apices (Zhao *et al.*, 2003). *ALMT1* gene encoded a malate transporter that is associated with malate efflux and Al tolerance and demonstrate its ability to confer effective tolerance to acid soils through a transgenic approach in crop species (Delhaize *et al.*, 2004). Al stress significantly increased the Ca^{+2} efflux, inhibited the K^+ efflux and ATPase activities, especially in the Al-sensitive genotypes. While, higher Al and low-pH tolerant genotypes XZ16 (Tibetan wild barley) showed higher ability of H^+ uptake, rhizospheric alkalization, lower Al-induced Ca^{2+} efflux and ATPase inhibition (Liu *et al.*, 2018). Both copper (Cu) and Manganese (Mn) in excess inhibit respiration, negatively affect nitrogen and protein metabolism, causes reduction of chlorophyll contents and inhibit photosynthetic functions in leaves (Foy *et al.*, 1978). Cu in excess blocks the photosynthetic electron transport, inhibits photophosphorylation and decreases membrane integrity (Maksymiec *et al.*, 1994). Alteration of the source–sink relationship with consequently diminished requirement for products of photosynthesis and down-regulation of the Calvin cycle enzymes (Maksymiec, 1997). Mn toxicity is observed in strongly acidic soils, reduced soil potential conditions created by organic matter accumulation, compaction or flooding, in some soils after unequilibrated fertilization (e.g. with high rates of superphosphate or nitrate), and in soils deficient in Calcium, Iron, Magnesium or Phosphorus. Cu or Mn toxicity was most probably the consequence of depletion in low-molecular antioxidants as a result of their involvement in detoxification processes and disbalance in antioxidative enzymes. Cu excess affected mainly the non-protein SH groups, while Mn influenced the ascorbate content. Ascorbate peroxidase activity was diminished under Mn toxicity and was not changed under Cu excess, protein carbonylation, a lower superoxide dismutase activity, elevated catalase and guaiacol peroxidase activities (Demirevska-Kepova *et al.*, 2004). Although barley is sensitive to Mn toxicity, a large genetic variation in Mn tolerance exists among cultivated genotypes (Hebbern *et al.*, 2005). Cadmium (Cd) interferes with many cellular functions mainly by complex formation with side groups of organic compounds such as proteins resulting in inhibition of essential activities that results in poor antioxidant defense systems causes oxidative damage, lipid peroxidation, and membrane leakage in plants.

Drought stress: Drought is becoming more common worldwide, causing devastating effects on crop production (Ludlow and Muchow, 1990). It represents a permanent constraint to agricultural production in many developing countries, although, drought also causes great yield losses in developed agricultures. Drought events are often associated to high temperatures which imposed an additional level of stress to plants. Samarah and Alqudah (2011) reported that late-terminal drought stress during grain filling has recently become more common in the semi-arid Mediterranean region, where barley (*Hordeum vulgare* L.) is grown as an important winter cereal crop. Drought stress reduced grain yield of barley. Grain yield was correlated positively with leaf gross photosynthetic rate and negatively with leaf osmotic potential. Several reports have suggested that drought stress during seed development of barley reduced leaf photosynthetic rate (Samarah, 2004; Masoud *et al.*, 2005), decreased grain filling duration (Sanchez *et al.*, 2002; Samarah 2004) enhanced plant maturity, resulting in severe reduction in grain yield and yield components (Forster, 2004; Samarah, 2004). In addition to its effects on the physiological processes in plants, drought stress during seed development can reduce seed germination and vigor. In barley, the unsuitable weather conditions in three out of seven years studies resulted in production of low seed vigor (ranged from 61–86%) as compared with the high seed vigor (exceeded 94%) of the seeds produced in the remaining four years (Chloupek *et al.*, 2003). Samarah and Alqudah (2011) reported that drought not only reduced the germination in the small seed size category, which consisted of shriveled, misshapen, and hard seeds, but also reduced the vigor

Waterlogging: Optimum soil gas exchange is severely hampered under water logging condition that result in alteration of soil redox potential subsequently, availability of plant nutrients. Prolong submerged conditions results in depletion of soil free oxygen while, accumulation of greater amount of CO_2 and ethylene associated with higher root and microbial respiration (Bailey-Serres and Voesenek, 2008). Prolong duration of waterlogging, inhibits the gaseous trade-off between roots and atmosphere (Setter and Waters, 2003) in barley rhizosphere subsequently, leads to nitrogen losses through leaching and denitrification besides, formation of toxic substances. Furthermore, this hypoxia stress with reduced redox potential limits ATP synthesis production in plants (Barrett-Lennard, 2003). In addition to this, some minerals due to more solubility on reduction (Mn^{4+} to Mn^{2+},, Fe^{3+} to Fe^{2+}, SO_4^{2-} to H_2S) becomes reaches to toxic levels accompanied with other organic compounds formed by anaerobic respiration of plant roots and microbes. However, losses are varies with sensitivity or cultivar nature, duration of water-logging, and the development stage of crop that encountered with waterlogging. Physiologically, plant respond at various level and in variable intensity with reduced stomatal conductance, diminishing leaf water potential, altered membrane transport, accelerated root senescence, stubby root and shoot, ultimately, death of plant under sever waterlogging conditions (Barrett-Lennard, 2003; Zeng *et al.*, 2013). Moreover, waterlogging not come solely as the phenomenon largely in the proximity of salinity where, intensive irrigation, sea water intrusion especially in coastal environments, and rise of saline water multiply its effect on plants (Barrett-Lennard, 2003) and thus reduced crop yield. Under combined scenario (salt and waterlogging), there was about two fold escalation of Na^+ while, 40% reduction of K^+ in leaves of barley and also the effect was more pronounced in sandy loam as compared to vermiculite. Just for two weeks of above scenario significantly reduced plant biomass, maximal quantum efficiency (PSII), relative water and chlorophyll content of barley varieties (Zeng *et al.*, 2013). Another study advocates positive correlation between Mn^{2+} toxicity to impart waterlogging stress tolerance in barley. The study revealed that under high Mn^{2+} level, most waterlogging genotypes showed chlorophyll content above 60%, while sensitive possessed less than 35% and suggested that traits conferring tolerance to Mn^{2+} toxicity also imparts tolerance to waterlogging and thus accelerate breeding for waterlogging tolerance in barley (Huang *et al.*, 2015).Cultivated barley shows a genetic diversity in water logging tolerance, and this tolerance varies according to life stage, with barley being more susceptible to water logging at pre-emergence, seedling growth, and reproductive stages (Setter and Waters 2003). Masoni *et al.*, 2016 reported genotypic difference in barley regarding tolerance to waterlogging and it reduced grain yield, root dry weight, number of spikelets per spike and kernels per spike by 20-24 % in sensitive cultivar (Amorosa).

2. Lodging

The process by which shoots of cereals are displaced from their vertical orientation is named as lodging. In cereals such as wheat and barley, lodging is most likely to occur usually after ear or panicle emergence. Lodging can be caused by the buckling of stems (stem lodging) or displacement of roots within the soil (root lodging) (Tams *et al.* 2004). In stem lodging, roots are held firm in a strong soil where the wind force buckles one of the lower internodes of the shoot. Root lodging becomes more likely when the anchorage strength is reduced by weak soil or poorly developed anchorage roots. The effect is a reduction in crop yield with further losses in grain quality, greater drying costs, and an increase in the time taken for harvesting. Lodging losses are more due to higher application of nitrogen based fertilizers along with early sowing especially under coarse textured soils in barley. So there is need to optimize sowing time along with nutrient dose to cope with this stress which can be largely regulate with best agronomic management practices. Also the use of growth regulators like Chlormequat chloride (CCC) or Ethephon can be used to reduce the plant height and ultimately the lodging. With the use of these growth regulators the higher fertilizer doses can be used and yield can be improved significantly as the barley is sensitive to lodging under high fertility levels.

Light Stress: Plants grown under high light intensity showed reduction in quantum yield of photosystem II, photosynthetic electron transport capacity, photochemical quenching. Photosystem I found more stable against photo-inhibition associated with the cyclic electron flow (Kalaji *et al.*, 2012; Kennedy *et al.*, 2018). Both high and low light stresses reduced activity of photosystem II in barley seedlings, while, response varies with stress type, its duration and genotype. Moreover, chlorophyll a fluorescence performance index parameter quite sensitivity under low and high stress and can be recommend for early detection of light stresses. A study was conducted to understand source sink dynamics in spring barley with objectives to quantify grain abortion, post-anthesis assimilation in response to reduction in post-anthesis incident radiation and grain weight heterogeneity in relation to post-anthesis assimilation per unit grain number. Two treatments were superimposed at post anthesis in barley as shaded (59% of incident radiation on crop) and unshaded, under former one barley mean grain weight reduced by 12–16%, grain yield by 19–20% consequently harvest index by 5–6% with shading from 14 days after anthesis until harvest maturity. Moreover, shading reduced grain filling rate about (23–27%) but more filling in central spikelets than at distal or basal locations on the ear while, the situation failed to produce any significant effect on grain number and duration of grain filling (Kennedy *et al.*, 2018).

3. Nutrient Stress: Nutrient stress and toxicity

Crop nutrition is a key determinant of yield potential. An adequate supply of essential macro and micronutrients is required for crops to achieve sufficient vegetative growth to ensure better grain yield. Fertilizer is a major input cost for farmers but is nevertheless often applied in excess of a crop's requirements. They may be leached from the soil or lost to volatilization (Sylvester-Bradley and Kindred, 2009). Insufficient availability of N and phosphorus (P) has the greatest impact on yield potential of crop plants. One of the important aspects for P uptake is the plants interaction with mycorrhizae. Selecting varieties of barley and mycorrhizae that maximize P uptake in an agricultural environment is a possible strategy to improve phosphorus use efficiency (Grace *et al.*, 2009). Phosphorus (P) as energy source of plants and under deficient condition, it results in poor root and shoot growth. Most of applied P fixed reversibly or irreversibly on reaction with aluminum and iron oxides especially under acidic soils, transformed by microbes as energy source for their growth (Jez *et al.*, 2016) and remaining through drainage and runoff leads to serious environmental concerns such as water eutrophication (Andersson *et al.*, 2013). However, plants show various mechanisms such secretion of organic acids *viz*, malate and citrate into rhizosphere to solubilize and enhance its uptake via ligand exchange (Ding *et al.*, 2016). Even then phosphorus use efficiency in plants generally about 30%. Hence, there is need to intensify breeding strategy and develop varieties or screening traits with high phosphorus acquisition and use efficiency in barley, especially for marginal arid and semiarid areas.

Response of barley under various stresses in relation to climate change: Future climatic variability sets harsh environmental conditions for plants manifest by elevated salinity in soils and elevated CO_2 concentrations in atmosphere (Pérez-López *et al.*, 2010). In future, salt content in soils will rise due to intensive global warming and higher drought incidence, which can hamper the congenial crop growth. Soil salinization inhibits plant growth due to osmotic effect, specific ion toxicity, hinder CO_2 gas exchange, and alter nutritional balance. Osmotic effect associated with lower water potential reduces water availability which is coping up through energy driven process either by reducing dehydration or accumulation of compatible solutes and ions (Munns, 2002). This energy driven stress ameliorating process limits plant growth as process happened at the cost of salt tolerance. Future CO_2 enriched environment offer greater advantage and make resilient crop under salt stress (Munns *et al.*, 1999) associated with higher carbon or energy supply compared to ambient CO_2 and that may also facilitate greater accumulation of ions/compatible solutes or more osmotic adjustment (Johnson *et al.*, 2002). Under stress condition at ambient, there is decrease in volumetric elasticity modulus of cell and poor osmotic adjustment, while reverse in case of elevated condition (Pérez-López *et al.*, 2010). Moreover, ^{13}C isotopic composition ($\delta^{13}C$) significantly decreased in all the plant organs under elevated CO_2. While, the ratio of $\delta^{13}C$ between the leaf and root was decreased, marked that higher allocation to the below-ground parts of barley and that helps in partially mitigation of salt stress under elevated CO_2 (Pérez-López *et al.*, 2014). Hence, under elevated CO_2 and salt stress barley perform sound by decreasing passive dehydration through stomatal closure, reducing hydraulic conductance, maintenance of greater leaf turgidity, higher relative water content, greater osmotic adjustment consequently, water use efficiency associated with elevated photosynthetic rate, with grater supply of carbon as energy source under wide range of salt stress (Pérez-López *et al.*, 2009; Pérez-López *et al.*, 2010; Robredo *et al.*, 2007). In future, duration, intensity and frequency of heat waves will be rise associated with elevated CO_2 and that utterly threaten the crop production. A study based on 22 barley accessions shown that even with 10 days heat waves [33 (day) /28 (night)^{0}C] under future elevated CO_2 (700ppm) and temperature scenario during flowering resulted in 42% grain yield reduction as compared to without heat waves (control), while, yield reduction was 52% compared to ambient conditions [temperature (19/12^{0}C) with CO_2 (400 ppm)]. While, under ambient conditions without heat waves yield gain was of about 37%, as compared to same scenario but with heat waves. Furthermore, heatwave superimposed under both scenario i.e., ambient and future failed to produced significant difference between the relative grain yield and study suggested that there is need to develop heat resilient cultivars to tolerate short term fluctuations in temperature/heat (Ingvordsen *et al.*, 2018).

Recent advances in stress management in barley:

Breeding perspective: Heat resilient canopies are attributed by open canopy with glaucousness (light, bluish-gray waxy bloom on plant parts), low carbon isotope discrimination (CID) that regulate stomatal conductance and maintain balance with photosynthetic capacity (Johnson *et al.*, 1983; Condon *et al.*, 2004). Rolled or erect upper leaves that help in deflecting and insulating direct solar radiation from the photosynthetic surfaces consequently results in cooler and longer viability of green canopy under warm dry conditions. Moreover, in this canopy system greater amount of water soluble carbohydrates (WSC) are present in the stems compared to closed canopies (van Herwaarden *et al.*, 1998a) and that later remobilized to the grain during grain filling period and helps in modulating the adverse effect of heat stress in plants (van Herwaarden *et al.*, 1998b). However, the adverse effect of heat stress can be minimized by avoiding it either through adjusting sowing time or by early maturing genotypes at the most sensitive stages such as reproductive or grain-filling periods (Hossain *et al.*, 2012a; Prasad *et al.*, 2008). Even breeding for early cultivars to incorporate escape mechanism against heat stress during grain filling is not a viable option as it results in shorter phenophases and lower accumulation of biomass, consequently poor sink size. There is need to optimize flowering duration and time, which is more or less depends upon sowing time and prevailing environment condition but keeping flexibility in sowing time (Hunt *et al.*, 2018). Stay-green trait has been successfully explored for cereals such as wheat, sorghum to increase potential productivity through delayed leaf senescence, preventing breakdown or loss of chlorophyll, maintain higher photosynthetic efficiency and remarkable remobilization of nutrient especially nitrogen from source to sink during grain filling duration under drought scenario (Harris *et al.*, 2007; Cattivelli et al., 2008; Jordan *et al.*, 2012). In barley grain quality is mostly confined to its potential for malting and brewing, which is largely influenced by various environmental factors (Fox *et al.*, 2003). Cultivar without "stay-green" characteristic possessed greater proportions of long amylopectin and amylose branches at lower water stress, suggesting that water stress affects starch biosynthesis in grain, probably due to early termination of grain filling. While, grain from the "stay-green"-like cultivar (ND24260) did not show much variation in starch molecular structure under water stress and indicate "stay-green"-like traits has a greater potential to maintain starch biosynthesis and quality in grain during drought conditions and potentially useful in ensuring food security (Gous *et al.*, 2013). Root resistance and its rapid adaptation to stresses is a crucial trait of plants to allow their surviving in non-ideal conditions. Widodo *et al.*, 2009 reported that metabolite changes in response to the salt treatment also differed in the two cultivars. After 3 weeks of salt treatment, Clipper ceased growing whereas Sahara resumed growth similar to the control plants. Sahara, the better-adapted cultivar, displayed tolerance to high internal salt concentrations without apparent cell damage suggesting that this cultivar may have mechanisms either to maintain a higher K^+/Na^+ ratio in the cytoplasm through compartmentation of Na^+ into the vacuole or by increasing the metabolite levels to cope with the increased osmotic potential.

4. Agronomic approaches

Agronomic field based management strategies can be incorporated with resilient breeding material (genotypes) to ameliorate various abiotic stresses in barley. Conservation agriculture principles (no-till, residue retention and resilient diversified) cropping system can be explored to enhance the barley yield under marginal crop growth environment. Integration of multiple benefit technologies such as zero tillage with and without retention modulate the high temperature (heat load) on canopy and soil surface, prevent build up of surface salinity along with diminishing the unnecessary evaporation losses. These practices can be further fine tuned with the use of efficient irrigation system such as drip and sprinkler irrigation especially under moisture limiting environment. A study shown that greater water storage with prolong availability of moisture leads to 1.0, 1.7 and 6.3 times higher grain yield under no tillage than CT in three years of barley mono-cropping. Moreover, no-till results in higher N uptake, N grain content and yield based water use efficiency. The study strongly advocates integration of no-till along with pig slurry (agronomic rates) significantly improved grain yield, nutrient and water use efficiency of barley compared to conventional management (intensive tillage with mineral based N fertilization) under rainfed conditions (Plaza-Bonilla *et al.*, 2017). A five year study reported that no-till malt barley–pea (*Pisum sativum* L.) cropping system sustained barley malt yield and quality under temperate dryland scenario of short crop growing season owing to lower precipitation with cool climate. This resilience system prevents soil erosion, nitrogen leaching and escalate soil organic matter compared to no-till continuous malt barley, no-till malt barley–fallow and conventional till malt barley–fallow (Sainju *et al.*, 2013). Moreover, under compact soil as in case of intensive conventional tillage system barley root and shoot growth of barley is curtailed and concomitantly concentration of abscisic acid (ABA) elevate in xylem sap (Mulholland *et al.*, 1996). The adoption of no till system also reduces the impact of water logging as there is less water logging due to better infiltration. Paddy straw (6 t/ha) as a mulch provided congenial growth environment for barley crop through moderating soil temperature by raising minimum temperature 1.2°C during emergence, while decreased the maximum temperature during physiological maturity by 2.6°C in comparison to without residue (Kaur and Mahal, 2018). A long term study (14 years) also reported greater sustainability of no tillage in barley monocropping in rainfed agro-ecosystems of the Mediterranean region, where the water use efficiency and mean yield escalate upto 57 and 66% respectively, compared to conventional tillage (Morell *et al.*, 2011). This attributed of reduced undesirable intensive water use during the pre-anthesis and subsequent greater availability of same during sink development along with enhanced soil moisture usage under no tillage. Another important agronomic strategy is the adjustment of the sowing time as the timely sowing helps in preventing the terminal heat stress in barley.

Plant growth-promoting rhizobacteria (PGPR)

Under stress scenario, plant growth may be improved by using microbial based inoculation i.e., plant growth promoting rhizobacteria (PGPR) includes generally bacterial strains that have potential to synthesize growth promoting substances for plants viz., enzymes, phytohormones, siderophores, vitamins along with ethylene synthesis inhibitors, organic phosphate mineralizer, atmospheric nitrogen fixer and also resilience to various stresses (drought, metal toxicity and salinity etc.) (Vessey, 2003; Esitken *et al.*, 2006; Turan *et al.*, 2013). The mechanism of growth improvement by these microbes regulating hormonal and nutritional balance in plants, amplified production of plant growth regulators, enhance solubilization of nutrient for the ease in their uptake, hydration and impart resistance against pathogens (Boostani *et al.*, 2014; Qurashi and Sabri, 2012). Moreover, this sophisticated technology widely promoted due to its ecofriendly and sustainable validity. PGPRs are very operational in colonizing roots of the plant and grow into micro-colonies and subsequently, produce biofilm that protect the plants from external stresss (*Asari*, 2015).Various strains viz., Enterobacter, Arthrobacter, Azotobacter, Azospirillum, Flavobacterium, Erwinia, Rhizobium and Bacillus species are now promptly used in agriculture in one or more ways with multiple perspectives and ultimately increased crop productivity especially under stress scenario (Bharti *et al.*, 2013). Moreover, ACC-deaminase producing bacteria are most suitable as PGPRs due to higher ability to eradicate the ethylene precursorthat induces plant response to various abiotic stresses (Dimkpa *et al.*, 2009; Yang *et al.*, 2009). The best “PGP potential” (Ahmad *et al.*, 2008) and identification based on PGPRs performance in agriculture is a major hurdle as numerous climatic and biotic factors limits its potential in large-scale scenario (Nelson, 2004). Hence, there is need to discover/screen beneficial plant growth promoting microorganisms and genetic interventions to make PGPRs best tools under climatic variability. Barley grains coated with biofilm forming PGPR on bacterial inoculation (*Bacillusamylo liquifaciens*) was effective in alleviating the injurious effect of salinity on growth attributes such as seedling length, fresh and dry masses as well as relative water content (Kasim *et al.*, 2016). *Piriformospora indica*, root colonizing basidiomycete fungus induced resistance to fungal diseases and tolerance to salt stress in barley by systemically altered "defense readiness" due to activation of glutathione-ascorbate cycle that resulted in elevation of antioxidative capacity subsequently increased grain yield of barley (Waller *et al.*, 2005). Barley grown in *Glomus intraradices* (arbuscular mycorrhizal fungus) inoculated soil under drought and well watered conditions showed greater drought resistance associated with lower reduction in leaf elongation, turgor pressure, stomatal conductance and net photosynthetic rate as compared to control (without mycorrhiza). Water transferred to root compartment through hyphae under drought conditions was only of 4% while, higher hyphal density found in the root compartment compared to hyphal compartment suggested that greater amount of water uptake may occurs in former one (Khalvati *et al.*, 2005). Application of boron (6 kg ha^{-1}) along with PGPR species namely *Bacillus Megaterium, Bacillus subtilis, Azospirillum brasilense and Raoultella terrigena* improved activity of antioxidant enzyme and significantly ameliorate oxidative stress due to freezing (Turan *et al.*, 2013).

Exogenous application of stress ameliorating chemicals: Silicon under salt stress maintain the optimal membrane fluidity and enhanced enzymes activities of superoxide dismutase (SOD), peroxidase (POD), catalase (CAT) and glutathione reductase (GR) activities, which contributes to reducing oxidative damage to enzymes induced by active oxygen species and enhances plasma membrane H^+-ATPase activity (Liang *et al.*, 2003; Liang *et al.*, 2006). Exogenous GABA enhanced the activities and gene expression of phenylalanine ammonia lyase, ferulic acid 5-hydroxylase, 4-coumarate coenzyme A ligase, cinnamic acid 4-hydroxylase, p-coumaric acid 3-hdroxylase, caffeic acid o-methyl transferase which are involved in phenolics biosynthesis and mediate salt stress in barley (Ma *et al.*, 2019). Under combined salinity and drought stress, application of 50 µM SA or 10 mM KNO_3 ameliorated the oxidative stress in barley by maintain low MDA and Na^+/K^+ ratio in leaves of barley (Fayez and Bazaid 2014). Barley leaves treated with 50µM sodium nitroprusside, a nitric oxide donor, alleviated the damage of salt stress, reflected by decreased ion leakage, and malendialdehyde (MDA), carbonyl, and hydrogen peroxide content. The presence of the nitric oxide donor increased the activities of SOD, ascorbate peroxidases (APX), and CAT. Meantime, sodium nitroprusside addition increased accumulation of ferritin at the protein level, indicating that nitric oxide directly regulated ferritin accumulation. These results suggested that nitric oxide can effectively protect seedlings from salt stress damage by enhancing activities of antioxidant enzymes to quench the excessive reactive oxygen species caused by salt stress and inducing the increase of ferritin accumulation to chelate larger number of ferrous ion (Li *et al.*, 2008). Under cadmium toxicity, exogenous salicylic acid (SA) ameliorate stress by inhibited lipid peroxidation in roots with increased root, shoot length, dry weight and strongly suppressed the Cd induced up-regulation of the antioxidant enzyme activities (Metwally *et al.*, 2003). Furthermore, SA decreased the levels of the four dehydrin-like proteins with greater accumulation of H_2O_2 induced by SA, which causes more oxidative injury underwater stress (Sun *et al.*, 2006). Application of zinc (300 µmol L^{-1}) significantly reduced MDA contents upto 17.8% and 19.7% in shoots and roots, respectively. While, lower values observed with ascorbic acid (upto 7.4% and 4.5% in shoots and roots, respectively) in alleviating cadmium (Cd) toxicity. Moreover, ascorbic acid enhanced translation mechanism of Cd from root to shoot which would be undesirable (Wu and Zhang, 2002). Salicylic acid (SA) used an important tool to modulate crop response under various abiotic and biotic stresses by regulating biochemical and molecular mechanism. Exogenous SA modulates action and activity of important cellular antioxidants enzymes such as superoxide dismutase, catalase and peroxidise along with higher root density and chlorophyll content by improving photosynthesis and regulating osmotic potential that subsequently, enhance plant tolerance against various stresses (Anosheh *et al.*, 2012; Pakar *et al.*, 2016; Odat, 2018). A comparative study shown that Salicylic acid (SA) performed best with greater amelioration effect compared to cycocel and jasmonic acid under salinity conditions (Pakar *et al.*, 2016). Application of synthetic zeolite with 5% significantly ameliorate salinity stress and increased concentration of calcium (Ca^{2+}), iron (Fe^{2+}) and manganese (Mn^{2+}) by about 5%, 19% and 10%, respectively with improved nutrient balance and water holding capacity (Al-Busaidi *et al.*, 2008). Ethephon response varied by genotypes regarding shortening of plant height but significantly reduced grain yield in most of cases. So, restricted use can be done only under severe lodging scenario. Moreover, it should be use under congenial temperature and moisture scenario for plant growth not under stress environment (Thomason *et al.*, 2007).

Conclusions

This review discussed the effect and management strategies that can be adopted to cope with the effects of abiotic stress on barley. To meet the food demand for growing populations, there is a need to reduce the yield losses due to different abiotic stresses because of changing climatic conditions. Often defence is one of the way at the genetic level by the identification of tolerant genotypes against the abiotic stress such as temperature stress, moisture stress, problematic soil- acidity, salinity and sodicity, poor quality water, waterlogging, nutrient deficiency/ toxicity, crop lodging etc. Also by adjusting the agronomic practices like sowing time, method, irrigation scheduling and use of exogenous application of stress ameliorating chemicals can help in mitigating the adverse effect of abiotic stress.

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