



## Effect of abiotic stresses and mitigation strategy associated with their tolerance in wheat

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### Abstract

Global warming influences environmental factors which directly and indirectly affects agricultural crop production by exposing to several new biotic and abiotic stresses. The abiotic stresses like heat, drought, moisture, salinity and pre harvest sprouting stresses are most common whose effect became more severe due to climate change. Globally wheat is the most widely cultivated and used crops due to its economic and social values. Its production and productivity are highly vulnerable to these abiotic stresses. The development of wheat varieties tolerant to these abiotic stresses is a very challenging assignment for wheat researchers. The conventional breeding program is being practiced for such objectives but it will not be sufficient to achieve the target production and more advanced research is needed for better understanding the mechanism of these stresses and how plants became more tolerant. The progress made in the understanding of these abiotic stress tolerances is due to advances in three main research areas: physiology, genetic, and breeding research. Identifying morphological traits, physiological and biochemical traits for précised phenotyping and associated genes contributing to particular stress tolerance is very important under mitigation strategy. Previous studies showed that some abiotic stress tolerance is controlled by a polygene and its genetic constitution will help to analyze the gene network(s) controlling stress tolerance. Furthermore, stress mitigation options particularly through the application of plant hormones, several agronomic interventions, genetic and biotechnological management strategy are convenient for improving plant performances under various abiotic stresses are also essential to stabilize the wheat productivity.

**Key words:** Climate Change, Abiotic stress, Wheat, Morphological, Physiological, Biochemical, Genetic, Mitigation strategy.

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## 1. Introduction

Wheat is the second most important cereal crop of the world providing 21% of total food calories after rice and largest source of protein (21%) to feed the 4.5 billion population of developing countries (Braun *et al.*, 2015). It covers about 220 million hectares area (mha) with a production of 716 million tons of food grain with a productivity of 3.2 tons per hectare (Oshino *et al.*, 2011).

However, Asian countries occupies 45% of total wheat area with productivity 2.33 ton per hectare as much below the global average and contributed only 33 per cent in global wheat production (FAO, 2010-11) Its demand will increase in developing countries up to 60% more in 2050 over current production (Anonymous, 2011). In India wheat production and productivity was enhanced after



the green revolution of late 1960s followed by another green revolution during 1980s (Yadav *et al.*, 2019). These two green revolutions, contributed significantly for enhancement of wheat production and productivity which results in annual growth rate in wheat production globally was ~ 3%, but simultaneously, in recent years it has declined to < 0.9 % due to appearance of new biotic and abiotic stresses due to climate changes. Although currently, the global wheat production has been sufficient enough to meet the current demand and consumption, but we will have to enhance production for future need and achieve the targets of ~ 858 Mt up to 2050, as aligned with current global production of 763 Mt (Gupta *et al.*, 2020). It includes at least a 15% increase in global wheat production (1.5% annual increase) over the next three decades to feed the world's growing population, which is expected to feed 9.7 billion people in 2050 (<https://population.un.org/wpp/>). It's a difficult task to achieve this target production because of continuously shrinkage in cultivated land due to urbanization and the probable negative impact of global warming. Climate change leads to appearance of several biotic and abiotic stresses for wheat which results in lower down its quality and yield. In this connection there is need to improve its quality and productivity in order to feed a rising population on limited cultivated land. So, in the current scenario this topic is an emerging issue as in presence of all kind of stresses how could we stay with our stable production. Mitigation of abiotic stresses is the need for the hour as here we are making a war against the nature. In this review article we discussed in details about all kind of abiotic stresses we are facing day by day which effect on wheat production and at the same time describe its way out to sustain its production.

## **2. Abiotic stresses and its significance**

Global temperature may play significant role on agricultural productivity in according to the severity of the several exposed abiotic stresses like high temperature, drought, salinity, water logging, and mineral toxicity. Among these abiotic stresses the wheat crop is mainly affected by water stress during critical growth stages in vegetative periods and terminal heat stress in reproductive phase. These abiotic stresses disturb the biochemical and physiological activities of crop plants which results in to more than 50% yield reduction in various ways (Acquaah, 2007).

Drought stress can be simply defined as a scarcity of water which leads to dramatic changes in morphological, biochemical, physiological, and molecular features of the plants (Sallam *et al.*, 2019; Kumar *et al.*, 2020). All of these changes significantly hamper plant growth and crop production. Drought is most common abiotic stress that affects growth and development of crop plants. The yield losses in the present varieties of wheat due to moisture stress in central India can range from 11.6 to 43.6% if irrigation is provided throughout the crop season (Tiwari *et al.*, 2014). The impact of drought stress may appear at any growth stage but the level of its adverse effects depends on stage specific stresses and the local environment. Therefore, genotypes may be tested for their drought tolerance at different growth stages. Some genotypes may show tolerance to drought at the germination or seedling stage, but these may be very sensitive to drought at the flowering stage or vice versa. Therefore, genotypes may be tested for their drought tolerance at each critical growth stages. Furthermore, a decrease in precipitation and increased evaporation as a consequence of global warming may increase the frequency of drought and its severity will increase in the future. Therefore, understanding the drought induced damages in wheat plants and approaches how to improve drought tolerance is crucial to increase wheat productivity. Recently few microbiomes have been identified that can be useful against drought tolerance on wheat (Mahapatra *et al.*, 2020).

Heat stress induced by high temperature is expressed as increase in air temperature due to beyond a particular threshold level and period which results in irreversible damages of plant (Farooq *et al.*, 2011). The heat stress situation becomes more intense when soil temperature increases due to the increase in air temperature associated with the decline in soil moisture. During the period from 1880 to 2012, the Earth's system warmed by 0.85°C (IPCC, 2014). This warming period will be continuing and is predicted to rise between the range of 1.5–4.0°C in the future (Wheeler *et al.*, 2013). Likewise, CIMMYT-ICARDA predicted that global temperature will increase up to 2–3°C by 2050 which may results in 20–30% of wheat yield losses in developing countries (Anonymous, 2011). Similarly, Kavita *et al.* (2016) mentioned that that for every 1°C rise in temperature above the optimal growing temperature of 15–20 °C, the duration of grain-filling is reduced by 2.8 days.



Further, Singh *et al.* (2019) highlighted that continual heat stress is a problem in about 7 m ha area, while terminal heat stress is a problem in about 40% of the irrigated wheat growing areas of the world. High temperature affects crops yield by affecting in different ways including poor germination, plant establishment, reduced photosynthesis, leaf senescence, decreased pollen viability which leads to production of reduced number of effective tillers, number of seed per panicle with smaller grain size and consequently reduction in wheat productivity. Wheat is very sensitive to heat stress particularly in some physiological growth stages. It has been estimated that reduction in global wheat yield falls by 6% for each 1°C of further temperature rise while it has been estimated that the mean ambient temperature is predicted to increase by 1–6°C by the end of the twenty-first century (IPCC, 2014). The optimum temperature for proper growth and development of wheat crop is around 21° to 24 °C. However the range of optimum temperature is specific to agro climatic zones in which it is grown. Moreover, in most of the cultivated area where rice –wheat cropping system is followed, the cultivation of long duration rice varieties leads to late sowing of wheat crop. In such conditions, it experiences heat stress particularly in post flowering stages. In the central and peninsular parts wheat crop faces heat stress throughout the crop season while significant parts of north-western and north-eastern plains experience terminal heat. So the farmers in north-western, central India and north-eastern plains zone prefer early sowing of wheat to escape terminal stress (Misra and Varghese 2012). Wheat crop when exposed to high temperature i.e. above the optimum range in any critical growth stages results in yield reduction.

Globally, salinity affects over 20% of the world's cultivable land, and its region is growing by the day due to environmental change and anthropogenic activities. (Munns *et al.*, 2008). It has been assessed that overall 20% of all out developed and 33% of irrigated agricultural lands are influenced by high salinity. In India, it is predicted that ~4.5 mha area under wheat is salt affected (Jasrotia *et al.*, 2018). A saline soil is described as one in which the electrical conductivity (EC) of the saturation extract in the root zone exceeds 4 dS m<sup>-1</sup> (roughly 40 mM NaCl) at 25 °C and has a 15 percent exchangeable sodium. (Smruti Shree *et al.*, 2018). The yield of wheat begins to decay at 6–8 dS

m<sup>-1</sup> (Royo *et al.*, 2003). It has been estimated that total salt affected area in India is probably going to increment to 16.2 million ha by 2050.

Germination of wheat seed inside the grain ear head before harvest is called pre-harvest sprouting (PHS). It also known as premature germination occurs when grain is exposed to excessive precipitation and high humidity after it has matured but before it can be harvested. Kernel swelling, germ discoloration, seed-coat parting, and root and shoot emergence are all signs of PHS (Thomason *et al.*, 2019). Pre-Harvest Sprouting (PHS) in bread wheat is a setback that occurs to varying degrees all over the world. As the outcome of PHS, wheat qualities as well as yield are affected. It induces changes in sugar content; total protein and amino acid composition, along with enzymatic activities, are the reasons for the consistency and yield degradation. Pre-harvest sprouting is negatively associated with test weights, yield, seed viability, seedling vigour, flour yield, and baking consistency. Germinated seed products may be spongy, soggy, off-color, and of poor quality (Groos *et al.*, 2002). Farmers and food processors can suffer significant financial losses as a result of reduced grain quality and yields caused by PHS.

Water logging is characterized as a state of the soil in which water remains on the surface for an extended period of time or where the available water fraction in the soil surface layer is at least 20% higher than the field water potential. It adversely affects crop production in about 4.5 million hectares in irrigated soils of the Indo-Gangetic plains of northern India (CSSRI 1997). Estimated 20–25% yield loss can happen depending upon plant damage; it may exceed 50% due to severe water logging condition. Singh *et al.* (2020) have reported 50 per cent reduction in grain yield of bread wheat under waterlogging conditions. Water logging tolerance is defined as survival or the maintenance of high growth rates, biomass accumulation or grain yield under water logging relative to non water logged (usually drained soil) conditions (Setter and Waters, 2003). Water logging is one of the most dangerous natural phenomena, and it may also be referred to as flood, submergence, soil saturation, anoxia, and hypoxia, depending on the moisture or water level on the ground. Generally, two types of flooding are present in the field: (1) water logging, in which root and some portion of the shoot goes under water (Anoxia), and (2) complete submergence, where



the whole plant goes under water (Hypoxia). Almost a total of over 22 million hectares of lowland cultivable area worldwide are vulnerable to flash flooding, which damages almost 18% of the global wheat supply (Mohanty et al, 1985). Out of that 10 million hectares of land in India and Bangladesh are regularly affected by flood in monsoon season regularly (Huke and Huke, 1997). In case of wheat, water logging causes degradation of chlorophyll, protein, RNA, and also reduces the concentration of nutrients like nitrogen, phosphorus, metal ions, and minerals in shoot. After the onset of flood leaf chlorosis starts (Wang *et al.*, 1996), root and shoot growth was also affected which results in reduction of accumulation of dry matter and also finally in yield (Malik *et al.*, 2002) Researchers suggested that it is a combined effect of reduced kernel and tiller numbers which is responsible for reducing yield of wheat in water logging. It has been estimated that 20–40 % yield loss can happen depending upon plant damage (Collaku *et al.*, 2002) and it may be reach up to 50% due to severe water logging (Setter *et al.*, 2003).

### **3. Effect of different abiotic stresses on wheat production**

#### *3.1 Drought Stress*

Drought stress is very much sensitive to plant growth and development; it leads to leaf wilting, stunted plant growth. Under deficient soil moisture, seed unable to germinate or show impaired germination and on progress it shows poor crop stand establishment. Water stress in vegetative phase reduces the numbers of effective tillers, number of seed per panicle, number of days to heading, peduncle length, and shortens the anthesis period, while at post-anthesis stage; Post-anthesis period when exposed to drought stress causes detrimental effect on pollination, fertilization and seed development and shortens the duration of grain filling, seeds per panicle, fresh and dry biomass production, maturity period etc. which cumulatively results in reduced grain yield. Drought has a negative impact on many other abiotic stress related plant parameters, including relative water content, leaf area index, dry matter accumulation, and net assimilation rates. Drought stress has a negative impact on plant physiological processes at various stages of development, including germination, vegetative growth, reproductive, and maturity. Under such stress conditions plant limits the stomatal opening which restricts the photosynthesis, respiration, transpiration, uptake and

transportation of water and nutrient and translocation of assimilates.

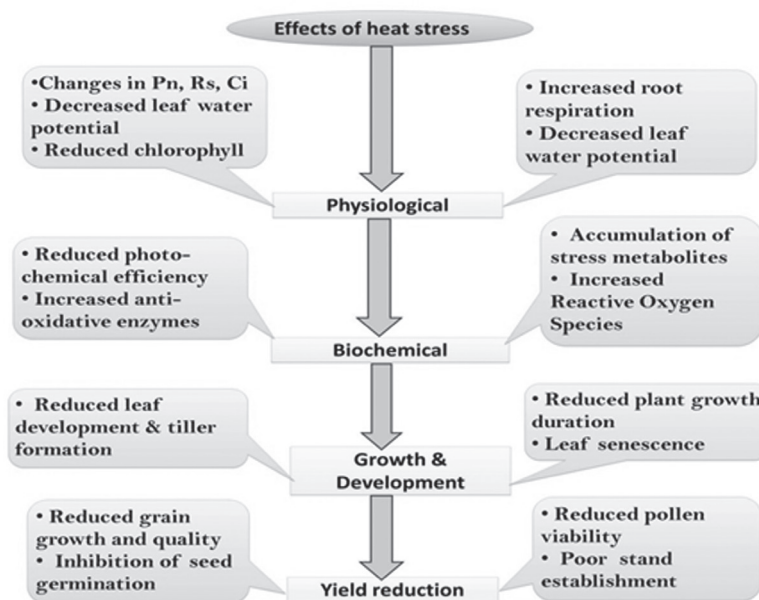
Drought stress damages the cell membrane structure, disorganization of ultra-structural cellular components and disruption of its properties, enzyme activities and anion and cationic imbalance are some of the major reasons for disturbing plant physiological processes. Drought stress causes the formation of reactive oxygen species (ROS). Hydrogen peroxide ( $H_2O_2$ ), superoxide ( $O_2^-$ ), singlet oxygen ( $^1O_2$ ) and hydroxyl radicals (OH $\cdot$ ) are the most common species which are generated due to iron-catalyzed Fenton reaction due to the activities of lipoxygenases, peroxidases (POX), NADPH oxidase, and xanthine oxidase. The ROS in any form causes substantial damage to cell components and can cause cell death (Hasanuzzaman *et al.*, 2013).

#### *3.2 Heat Stress*

The effects of heat stress on plants are very complex; it affects crops in different ways including germination, plant growth and development, physiological, biochemical and cumulatively its effect in yield reduction (Fig. 1). It affects as poor germination, degree of such effect varies depending on the crops, cultivars, phenological stages, sowing dates and management practices. Heat stress is a serious threat, particularly during reproductive and grain-filling phases, that results into yield loss (Pandey *et al.*, 2019). It has been observed that the grain yield of wheat per spike was reduced by 3–4% per 1°C increase in temperature above 15 °C. (Wardlaw *et al.*, 1989). The effect of high temperatures (>30 °C) for short periods is thought to be equivalent to 2–3 °C warming in the seasonal mean temperature (Wheeler *et al.*, 1996). Global warming due to Climate change continuously increases the environmental mean temperature.

Heat stress hampers the wheat seed germination arise due to surrounding high soil temperatures and seeds experience delay in germination due to altered metabolic activity. On further growth progression it has the potential to disrupt plant establishment, reduced photosynthesis, leaf senescence, decreased pollen viability, pollen development when exposed prior to anthesis and negatively impact grain number and grain filling duration, reduced seed size on exposure during reproductive phase which results in reduced grain yield.



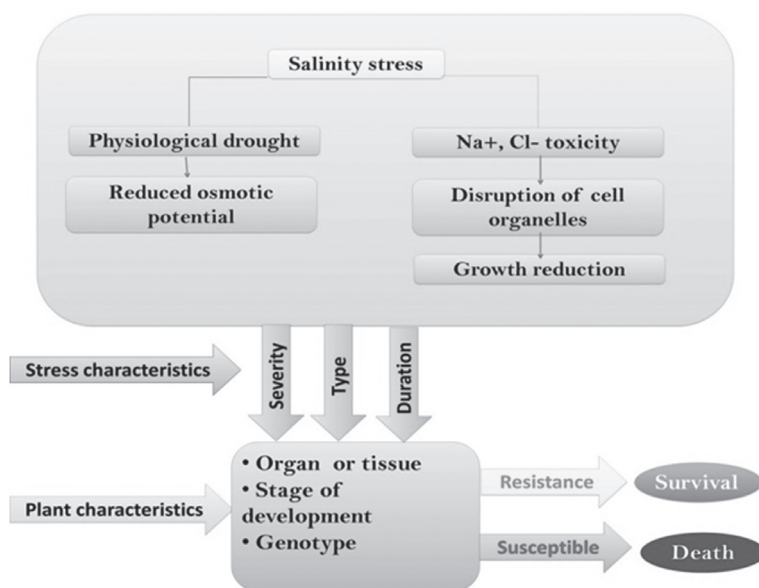


**Fig. 1** Major effects of heat stress on plants growth and development. Pn, Rs, and Ci indicate photosynthesis, stomatal conductance, and intercellular CO<sub>2</sub> concentration respectively (Akhter *et al.*, 2017)

### 3.3 Salinity

High salts concentration in the soil affects plant growth from germination to harvesting. Salinity is one of the most damaging abiotic stresses, affecting plant morphological, physiological, and biochemical characteristics such as germination, growth, water uptake, photosynthesis, nutrient uptake, enzymatic activities, and yield. Higher salinity causes lower germination rate, photosynthesis,

transpiration, and higher accumulation of Na<sup>+</sup> and Cl<sup>-</sup> ions which disturb the normal metabolic processes of wheat plants (Fig 2). It may affect the plants in two ways, either by decreasing the rate of water entry into plants results in osmotic stress immediately, reduces cell expansion in root tips, young leaves, and causes stomatal closure (Munns and Tester, 2008) or by promoting the entry of toxic ions. The osmotic ability of the root-zone soil solution is usually related to crop growth reduction due to salinity.



**Fig. 2:** Effect of salt stress responses on plants adaptation (Hasanuzzaman *et al.*, 2017)



A failure in Na<sup>+</sup> exclusion manifests its toxic effect after days or weeks, depending on the species, and causes premature death of older leaves (James *et al.*, 2011).

### *3.4 Water logging*

Water logging is a serious problem in low-laying rainfed areas. Water logging condition cause lack of oxygen supply for the plant which hampers nutrient and water uptake, as a result the plant shows wilting. In oxygen-deprived condition plants shift its metabolism to anaerobic from aerobic mode. To cope with the oxidative stress, plants that can withstand it have mechanisms such as increased availability of soluble sugar, aerenchyma formation, increased activity of glycolytic pathway and fermentation enzymes, and involvement of antioxidant defence mechanisms (Ahmad *et al.*, 2013). When water recedes and O<sub>2</sub> re-enters the soil and root tissues, the formation of reactive oxygen species (ROS, e.g., superoxide, hydroxyl radicals, singlet oxygen and hydrogen peroxide) might especially damage cell membranes. ROS production is a consequence of a low energy charge, high level of reducing equivalents and saturation of the mitochondrial electron transport chain, favoring electron leakage to O<sub>2</sub> upon re-aeration (Blokina *et al.*, 2003). ROS can be detoxified by defense mechanisms including enzymes (e.g., superoxide dismutase) and antioxidants (e.g., ascorbate, glutathione). Water logging causes degradation of chlorophyll, protein, and RNA and also reduces the concentration of nutrients like nitrogen, phosphorus, metal ions, and minerals in shoot. After the onset of flood leaf chlorosis starts further root and shoot growth were also affected by, resulting in a decrease in dry matter accumulation and eventually in yield (Malik *et al.*, 2002).

Wheat crop when grown in salt affected with waterlogged soil, the yield reduces significantly by reduction in grain weight, length of spike and spikelet number. The traits mostly to be affected on exposed to water logging stress is mainly determined by the stressed crop growth stages. Water logging at early vegetative stages reduces tillering and hence spikes per plant, water logging at anthesis stage can reduce numbers of florets and hence grains per spike, and water logging during grain filling can reduce weight of individual grains (de San Celedonio *et al.*, 2014; Marti *et al.*, 2015).

### *3.5 Pre-Harvest Sprouting (PHS)*

Pre-harvest sprouting in bread wheat is a setback that occurs to varying degrees all over the world. The problem arises when standing full-grown wheat crops are subjected to excessive precipitation and high humidity prior to harvest, and seeds in the spike sprout. Sprouted seeds have a higher  $\alpha$ -amylase activity, which causes starch degradation, sugar content changes, total protein by modifying amino acids, enzymatic activities, and lower bread consistency.

## **4. Physiological, biochemical and developmental responses of abiotic stresses in wheat plants**

### *4.1 Early Vigour*

A more prominent biomass/early ground cover by plant canopy during early development stages gives more productive water usage by soil mulching and subsequently diminishing in evapo transpiration from the soil. In this way, remaining soil moisture will be used by the plants for a longer period under extreme stress condition to survive. By implication, early vigour also leads to a deeper root system. This trait might be utilized as an appropriate selection criterion under a range of moisture stress conditions. It very well may be measure rapidly and effectively through a visual score or utilizing NDVI and can likewise be utilized for quick assessment of large populations (Tiwari *et al.*, 2017).

### *4.2 Osmotic Adjustment (OA):*

Osmotic adjustment (OA) maintains cell water content by increasing the osmotic power that cells can exert on their surroundings, resulting in increased water uptake. It involves the net accumulation of organic or inorganic solutes/osmolytes, total soluble sugars, total free amino acids, proline, glycine betaine, sodium chloride, and potassium in cells because of a decrease in the water potential, As an outcome of this net accumulation, the cell osmotic potential is brought down, and turgor pressure tends to be maintained along with more water in leaf cells with more OA bringing about higher turgor as compared with leaves having less OA. Osmoregulation and turgor support permit continuous development of roots and take-up of moisture from the soil (Sharp and Davies, 1979). Free amino acids and proline accumulation contributed essentially for osmotic change in wheat flag leaves under



salinity stress adding to higher grain yield (Bandeh-high *et al.*, 2008).

#### 4.3 Canopy Temperature

The high surface area of leaves makes plants most vulnerable to heat stress. A significant amount of energy is spent by all plant to maintain the cellular temperature. The leaf and its canopy temperature in plant system depend on transpiration, respiration and carbon dioxide level in leaf tissues. Direct relations with several physiological processes of plants make canopy temperature one of the best parameters for heat tolerance screening.

#### 4.4 Stomatal conductance

Under field condition, when the plants are gradually exposed to heat or drought stress, the early response is the closure of stomata. Stomatal closure is likely to be mediated by chemical signals traveling from dehydrating root to shoots. One of the chemical signals involved in stomatal functioning has been identified as abscisic acid (ABA) (Daveis and Zang, 1991). Stomatal activity directly regulates the water supply through xylem (Nardini *et al.*, 2001). Under field conditions, stomatal regulation of water loss has been established as an early event in plant response to water deficit, limiting carbon absorption by the leaves. (Chavas, 1991; Cornic and Massacci, 1996). This stomatal response has been linked more closely to the soil moisture content (Tardieu *et al.*, 1991; Stoll *et al.*, 2000). The first response of virtually all the plants to acute water deficit under heat and drought stress is the closure of their stomata to prevent the transpiration water loss (Mansfield *et al.*, 1990).

#### 4.5 Relative Water Content (RWC)

Assessment of water loss from excised leaves has been indicated as a good criterion for characterizing drought resistance. Leaf water status is intimately related to several leaf physiological variables, such as leaf turgor, growth, stomatal conductance, transpiration, photosynthesis and respiration. Water content and water potential have been widely used to quantify the heat stress in leaf tissues. Leaf water content expresses the relative amount of water in plant tissues. However water potential measures the energetic status of water inside the leaf cells (Slatyer and Taylor, 1960). When water uptake by roots is equal to transpiration, then RWC is about 85% - 95%. Critical RWC (below which tissue death occurs) varies amongst

species and tissue types, it may be 50% or less. Reducing level of RWC represents the severity level of dehydration of plant tissues when it expose to water losses due to heat or other abiotic stresses (Morgan *et al.*, 1997). Various studies revealed that increasing duration and severity of stress decreased the RWC of plants. RWC is related with grain yield under irrigation and dry land conditions. Drought-tolerant genotypes have higher RWC, and this trait can be used for screening and identification of genotypes.

#### 4.6 Photosynthesis

Photosynthetic CO<sub>2</sub> assimilation is known to be sensitive to environmental stresses (Dubey, 1997). Under high heat stress conditions, drought and salinity often are occurring simultaneously particularly in arid and semi-arid areas leading to significant yield losses. Dehydration under drought stress affects the leaf CO<sub>2</sub> assimilation and declines net photosynthesis due to stomata closure (Cornic *et al.*, 1992) and RUBISCO activity (Bota *et al.*, 2004).

#### 4.7 Transpiration

Under heat stress or drought, a reduction in dry matter output is normally linearly related to a decrease in cumulative transpiration (Jones, 1992). Leaf expression and transpiration for various crop show sensitivity to declining plant available soil water. However, in general these processes decrease when about a third of the transpirable soil water remains in the soil (Turner, 2001)

#### 4.8 Membrane Leakage

Cell membrane alteration, which results in irregular function or complete dysfunction, is a significant effect of plant environmental stress. The basic structural and functional changes caused by pressure are yet to be fully resolved. However, the cellular membrane dysfunction due to stress is well expressed through increased permeability and leakage of ions, which can be readily measured by the efflux of electrolytes. Thus, the assessment of membrane dysfunction under stress by estimating cell electrolyte spillage from influenced leaf tissue into a fluid medium is discovering developing use as a proportion of cell film security (CMS) and as a screen for stress tolerance. The CMS is positively related and explains above 70% of drought tolerance when contrasted with other physiological characteristics.



#### **4.9 Chlorophyll Content Index**

Under any environmental stress, plant shows loss of chlorophyll content and the variation in total chlorophyll/ carotenoids ratio may be a good indicator of level of stress in plants. High chlorophyll content under stress is a desirable trait as it indicates a low degree of photo inhibition of the photosynthetic apparatus. Water stress condition drastically reduces the chlorophyll content. Hence, the estimation of flag leaf chlorophyll content and its stability over time can indicate resilience of the plant's photosynthetic activity and canopy temperature. The cooling efficiency of the plants through transpiration is measured by its canopy temperature. The relationship between canopy temperature, air temperature and transpiration is complex, and it involves atmospheric conditions (vapour pressure deficit, air temperature and wind velocity), soil moisture and plants canopy size, canopy architecture and leaf adjustments to water deficit.

#### **4.10 Chlorophyll Fluorescence**

Estimations of the moderate and the quick chlorophyll fluorescence energy have been seen to be sensitive to drought stress. The chlorophyll fluorescence has likewise displayed positive relationship with grain yield under terminal heat stress condition (Pandey *et al.*, 2015).

#### **4.11 Stem Reserve Mobilization**

Stem reserves are sugars, for example, fructans, sucrose, glucose and fructose which get gathered in the stem as stores. Water soluble carbohydrates (WSC) collect up to anthesis time and partitioned to the stem from where they are later accessible as a supply for remobilization to the creating grains. These reserves are a significant source of carbon for grain filling as request regularly surpasses current assimilation, possibly contributing 20 to 40% weight of the grain in non-stressed condition (Vignjevic *et al.*, 2015) and this can be up to 70% under stressed conditions during grain filling (Rebetzke *et al.*, 2008). Genetic variability for stem reserve mobilization exists in wheat, and it tends to be investigated for the development of efficiency under high temperature and water stress situations Nagarajan and Rane, 2002.

### **5. Selection of stress-tolerant genotypes**

Presently stress tolerant good genotypes are chosen based on high yield performance under concerned stress condition regardless of thinking about other related

attributes. Be that as it may, yield assessment under stress conditions isn't generally the most appropriate selection quality. There is a methodology dependent on an assessment of some physiological attributes and natural qualities associated with stress tolerant would be a superior alternative. Normally, when plants are exposed to abiotic stress, plants attempt to limit their adverse impact by a few methods viz. stress avoidance, stress escape and stress tolerance. These mechanisms are constrained by many related segment attributes in the avoidance mechanism, the plant evades the stress through such qualities like decrease in leaf region, expanded pubescence, leaf rolling and leaf reflectance with epicuticular wax collection. In the escape mechanism, plants sense the future event of stress and accordingly alter the phenology to complete their life cycle early with the goal that the impact of stress is not appear in the genotypes. While, in the tolerance mechanism, the plant experiences stress but it can withstand the stress condition through various adaptive features. Deep root system, coleoptile length, leaf (phyllotaxy, direction and edge), pubescence, wax, stem length, peduncle length gathering osmolytes, maintaining film trustworthiness, overhang temperature and relative water content, stomatal thickness on leaf surface, stomatal conductance and other morphological, anatomical, physiological, and biochemical attributes in stress tolerance. It is realized that each genotype has different adaptive mechanisms with various related characteristics. Despite new improvements in phenotyping procedures, the identification of a single trait will represent all the variations present in the population for tolerance to abiotic stress has not been possible yet. Subsequently, there is a need to build up a protocol that can identify various traits related to abiotic stresses. Mudi *et al.* (2016) reported disease stress tolerance index on barley for suitable selection criteria of disease tolerance among different genotypes. Among these, few significant traits have been recognized indicating high and positive correlation with stress resilience e.g. root engineering, happening proficiency/ carbon isotope segregation, stomatal conductance, canopy temperature, osmotic alteration, stay green etc. Phenotyping for assessing the effect of specific stress conditions in wheat is normally done by correlating them with the controlled condition.



### 5.1 Characterization and selection for Drought Tolerance

To screen drought stress genotypes of wheat, morphological, physiological, and biochemical boundaries such as root system, early vigourness, leaf pubescence, plant waxiness, stomatal density, osmotic adjustment, relative water content, membrane leakage, canopy temperature, chlorophyll content index, chlorophyll fluorescence, stomatal conductance, photosynthetic rate, and transpiration rate have been identified. None of these boundaries could turn out practically feasible for selecting individual plants from the breeding materials. Henceforth, determination of individual segregants depends on survival under natural dry conditions in which impact might bring about progress in grain yield. The segregating material can be exposed to artificial moisture stress under controlled conditions to choose drought stress tolerant and susceptible plants depending on seedling survival. The carbon isotope discrimination (CID) technique has recently been used to successfully identify drought-tolerant genotypes. (Rebetzke *et al.*, 2002).

Deep root system, early vigour, rapid ground covering plant and waxiness etc. have been proposed as important morphological traits for screening for early drought tolerance. slower rate of leaf senescence, high osmotic adjustment, high chlorophyll content, photosynthetic rate, transpiration efficiency/carbon isotope discrimination, stomatal conductance, low canopy temperature, prolonged stay green habit etc. have an advantage in overcoming water stress. The deep root system enables plants to explore higher soil volumes and thus remain hydrated under heat and drought and permit cooling of the canopy under such stress. So that it can be a good selection index in identifying genotypes for drought and heat tolerance.

### 5.2 Characterisation and selection for Heat Tolerance

For selection of heat tolerant genotype, we have to identify the traits associated with heat tolerance in wheat through experiments conducted both in the field and under controlled environmental facilities. Selection and screening of heat tolerant genotypes is based on component traits associated with better yields under heat stress. The traits used as selection criteria for heat tolerance should be: (1) strongly correlated with grain yield under heat stress condition (2) rapid, stable, and easy to measure; and (3) highly heritable

(Edmeades *et al.*, 2001). Potential traits for screening heat tolerance in wheat are photosynthesis rate, Leaf chlorophyll content, flag-leaf stomatal conductance, membrane stability (Reynolds *et al.* 1994), Canopy temperature depression etc. Genotype screening based on electrolyte leakage, an index of membrane stability, from leaves subjected to extreme temperatures, is one of the rapid screening methods (Shanahan *et al.*, 1990). Electrolytes are collected from stressed tissue soaked in deionized water and quantified by measuring electrical conductivity. Good correlation between membrane stability and grain yield under heat stress has been found (Blum *et al.*, 2001). Reduction of tetrazolium triphenyl chloride in mitochondria may also be used as an indicator of heat tolerance. The relative degree of tetrazolium triphenyl chloride reduction to formazan, which is detected by a spectrophotometer, is used to quantify cell viability (Towill and Mazur, 1974). A visual rating of stay-green is quick and easy way for the plant breeders to screen on mass scale (Xu *et al.*, 2000). Nonetheless, this trait may be a disadvantage as it is associated with the tendency to retain the stem reserves (Blum, 1998). ). It is established that many physiological traits/parameters, such as grain-filling time (GFD) and canopy temperature (CT), have been shown to have a close relationship with terminal heat tolerance (THT). Reduced GFD is thought to protect the plant from damage caused by terminal heat stress, while a low CT helps the plant to withstand terminal heat stress Sharma *et al.*, 2015.

### 5.3 Characterization and selection for Salt stress

Salt stress influence the wheat crop at all phases of plant development. Hence it is basic to comprehend wheat's reaction to salt stress at each period of development which can be useful in identifying salt tolerant genotypes. The morphological characters of different plant parts such as leaf (shape, size, zone, senescence, cuticle tolerance and waxiness), root (length, root hairs, root region, new and dry weight, thickness) and others vegetative plant parts (plant height, diameter and fresh and dry biomass) are influenced. Under salinity stress conditions, the creation of ramified root framework has a significant contribution to above ground biomass. A developed root system can contribute to keep up plant development during early development



stages and extract water and micro-nutrients from the soil. As observed in previous investigations salt stress reduces the plant leaf area which diminishes the rate of photosynthesis resulting in low biomass production (Kingsbury *et al.*, 1984). The physiological activity of wheat is additionally hindered by saltiness at both cell and entire plant levels through ionic and osmotic pressure. These physiological processes include modification for plant development, mineral dissemination and membrane variability coming about because of calcium separation by sodium and membrane permeability (Mehta *et al.*, 2010). High salt concentration in soil diminishes leaf water potential, loss of turgor pressure due to osmotic imbalance, results in stomatal closure, decrease in CO<sub>2</sub> conductivity through stomata, photosynthetic rate, chlorophyll content, carotenoids, membrane variability alteration in cell wall integrity, increase in oxidative stress due to more reactive oxygen species (ROS) production and increased development of toxic metabolites. This may lead to damaging effects on the macromolecules such as DNA, RNA, proteins and lipid; it may also lead to the impairment of plant function and ultimately lead to death of the plant.

Generally reactive oxygen species (ROS) are produced in thylakoid, mitochondria and peroxisome during photosynthetic process, Electron transport chain and glyoxylate cycle respectively. Salinity tolerant genotypes have many enzymatic mechanisms under anti-oxidant defense system for scavenging of salinity induced ROS. The enzymes which are overproduced comprises of glutathione reductase (GR), glutathione synthetase, superoxide dismutase (SOD) and ascorbate peroxidase (APX). Many solutes are needed in the plant cell, including proline, glycine betaine, abscisic acid, and polyol, to maintain the osmotic potential in the vacuoles against ion toxicity accumulated in the cell compartments.

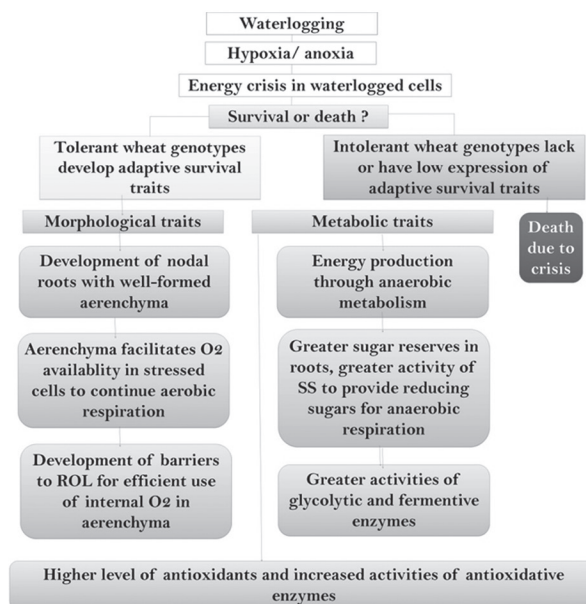
Many solutes including proline, glycine betaine, abscisic acid and polyol in the plant cell are required to retain the osmotic potential in the vacuoles against the ion toxicity accumulated in the cell compartments. These are also known as compatible solutes or metabolites as they help in protection of plant against salt stress (Sharma and Garg (1983). Identification of genotypes which overproduced these enzymes and solutes are

helpful in selection of salt stress tolerant genotypes. Devi *et al.* (2018) demonstrated that low Na<sup>+</sup> concentration and high proline and chlorophyll content at seedling stage are vital physiological traits contributing towards yield under salt stress and thus can be employed as selection criteria in breeding programmes. Recently, Manohara *et al.* (2020) performed genetic analysis of grain yield and its associated traits in diverse salt-tolerant rice genotypes under coastal salinity condition and emphasis on the need of selecting salt related traits under saline environment to bring sufficient genetic improvement in plants.

#### *5.4 Selection and characterization for Waterlogging Tolerance*

Water logging tolerance is characterised as the ability to maintain relatively high grain yields under waterlogged conditions as compared to no or minimal waterlogging. (Setter and Waters, 2003). Tolerance to waterlogging allows plant species to develop unique morphological traits and biochemical modifications that allow crops to change their metabolism in response to oxygen scarcity in order to survive or maintain their development (Fig. 3). The mechanisms of water logging or hypoxia tolerance include: (i) the maintenance of high internal aeration through constitutive aerenchyma and the formation of an oxidised zone around root tips through radial O<sub>2</sub> loss (Armstrong *et al.*, 1994), (ii) metabolic adaptation that maintains energy output under hypoxia (Brandle and Crawford, 1987) with significant carbohydrate storage for fermentation under hypoxia (Brandle 1991). The developments of morphological adaptive traits to make plant water logging tolerant are growth of seminal roots and production of numerous adventitious roots with aerenchyma which increases root porosity and helps the plant to respire aerobically and to maintain growth under hypoxic conditions (Huang *et al.*, 1994). The metabolic adaptive traits are anaerobic respiration, maintenance of carbohydrate supply for anaerobic respiration, avoidance of cytoplasmic acidification and development of antioxidative defense system (Drew, 1997; Setter *et al.*, 1997). This system includes ascorbate (AsA), glutathione (GSH), phenolic compounds, superoxide dismutase, catalase, peroxidases, glutathione reductase and ascorbate peroxidase (Garczarska, 2005) etc. These morphological and biochemical adaptive traits have been identified as selection indices for selection of water logging tolerant genotypes.





**Fig. 3:** Schematic diagram showing morphological and metabolic adaptive traits for waterlogging tolerance in wheat (Hossain *et al.*, 2011)

### 5.5 Traits for Characterization of Pre harvest Sprouting (PHS) Tolerance

There are a number of methods to measure the PHS. The falling number (FN) is the most commonly used approach to quantify PHS. It indirectly measures the activity of the enzyme  $\alpha$ -amylase that breaks down starch in germinating grains. Falling-number tests are conducted by creating slurry of flour and water in a test tube. The time required for a plunger to fall through the slurry is measured. Sound, starchy grain produces thick slurry (and a bigger falling number). Sprout-damaged grains will result in a flour and water mixture that is thinner or less viscous, because  $\alpha$ -amylase has begun to break down the starch. The faster the plunger falls to the bottom of the test tube, the lower the viscosity of the mixture and the smaller the falling number. Lower falling numbers indicate there have been higher levels of  $\alpha$ -amylase activity. Falling numbers, thus, are an indirect but quite accurate measure of PHS. In general, falling-number values less than 250 seconds to 300 seconds indicate flours that are of poor quality for milling and baking. Similar methods are amilography which determines the effect of viscosity of the  $\alpha$  amylase enzyme and the rapid visco analyzer (RVA), which is also based on the ability of  $\alpha$  amylase to liquefy a starch gel. Germination index estimates the rate of seed germination under controlled conditions with higher values associated with more seeds germinating earlier in the evaluation.

## 6. Strategies to mitigate abiotic Stresses

### 6.1 Plant hormones

Hormones play a significant role in acclimatizing the plant during stress conditions. There are six primary group of hormones, specifically auxin, cytokinin (CK), gibberellic acid (GA), abscisic acid (ABA), ethylene, strigolactones, brassinosteroids and jasmonic acid (Fig 4). Among all plant hormones, ABA assumes particularly significant function to maintain physiological processes under stress and hence subsequently named as 'stress hormone'. Stress-induced senescence and abscission are the key processes interceded by ABA.

Under drought stress conditions, ABA-altered root architecture is an approach to take-up more water from soil. It promotes the advancement of more profound root system alongside upgrading hydraulic conductivity in plants, maintenance of cell turgor which finally contributes to desiccation tolerance. The ABA acts as the primary signaling molecules under salinity stress and its concentration increases in plant parts exposed to salt stress. Over synthesis of ABA under stress induces stomata closure which brings about diminished stomatal conductance, photosynthetic rate and transpirational water loss Wei *et al.* 2017. It has also been suggested that male fertility is impacted by accumulation of endogenous ABA levels within the anther tissue (Ji *et al.*, 2010). Other hormones, such as auxin, ethylene and cytokinins (CKs), may change the effect and biosynthesis of ABA. The higher ABA concentration in grains might result from auto synthesis within the grain and partly by the translocation from leaves and roots during drying. ABA increases the endogenous content of proline under drought conditions. Auxin is positively and ABA is negatively correlated with the activity of *expansin* protein under oxidative stress condition. Under stress condition, it shows down regulation of cell division and elongation (Kosova *et al.*, 2012, Tromas *et al.*, 2013), led to pollen sterility (Sakata *et al.*, 2010). Pre-sowing treatment of wheat seeds with growth regulators (IAA and GA) inhibits the effect of salinity. Plant growth-stimulating compounds such as gibberellic acid, zeatin, and ethephon have been found to help mitigate the effects of salinity. (Afzal *et al.*, 2005). On the other hand, it down regulates the seed germination and stem elongation (Fleet and Sun, 2005). Recently, Khobra *et al.* (2010) reported



that exogenous application of Melatonin (N-acetyl-5-methoxytryptamine) as a promising molecule to improve seedling vigour and drought tolerance in wheat.

Cytokinins (CKs) play a supportive role during water deficit conditions by stimulating osmotic adjustment while down regulating the cell division and proliferation, endosperm development, photosynthetic reserve and apical shoot meristem development. It was hypothesized that CKs could increase salt tolerance in wheat plants by interacting with other plant hormones, especially auxins and ABA. Exogenous application of kinetin overcomes the effects of salinity stress on the growth of wheat seedlings.

Ethylene is a gaseous hormone generated from S-adenosyl methionine (SAM, the same precursor for polyamines) and largely acts as a negative growth regulator (Kosová *et al.*, 2012; Yang *et al.*, 2017). Ethylene is primarily involved in the late stages of plant growth and development, particularly senescence, associated leaf abscission, fruit ripening, seed maturation, drying, and dispersal (Wilkinson and Davies, 2010). Ethylene release has been associated with the inhibition of root growth and leaf expansion and, if induced by severe or extended stresses, can promote extensive plant senescence, embryo abortion, and reduce grain filling (Wilkinson *et al.*, 2012).

Brassinosteroids impart resistance to plants against variety of abiotic stresses, and are thought to have pleiotropic effects because they affect a variety of developmental processes such as seed germination, seed growth, rhizogenesis, flowering, and senescence.

Salicylic acid (SA) is an endogenous plant hormone that regulates various processes including: growth and development, germination, photosynthesis, and antioxidant regulation (Fardus *et al.*, 2018). Exogenous application of SA in wheat led to an increased production of antioxidants, leading to reduced instances of oxidative damage under heat, drought, and saline conditions (Noreen *et al.*, 2017). Exogenous applications of SA were used to mitigate damage caused by abiotic stresses by increasing the production of H<sub>2</sub>O<sub>2</sub> in an NADPH-oxidase-dependent manner (Agarwal *et al.*, 2005a; b).

Jasmonic acid (JA) signaling may play an important role in bridging abiotic and biotic stress tolerance. Exogenous application of 2 mM JA in wheat seedlings led to an increase in salt tolerance. It leads to increased expression and enzymatic activity of superoxide dismutase, peroxidase, catalase, and ascorbate peroxidase (Qiu *et al.*, 2014). This resulted in the reduction of H<sub>2</sub>O<sub>2</sub> and other ROS, which would otherwise be harmful to cellular survival.

Hormone response	Drought	Salinity	Cold	Heat
<b>Abscisic Acid</b>	↑	↑	↑	↑
1. Accumulation of stress related metabolites (Zhang <i>et al.</i> , 2010) 2. ABA mediated stomatal closure (Wei <i>et al.</i> , 2017)				
<b>Auxins</b>	↓	↓	↓	↓
1. Positive regulator of cell division and elongation (Tromas <i>et al.</i> , 2013). 2. Important pollen viability, led to pollen sterility (Sakata <i>et al.</i> , 2010). 3. Reduce growth, resources allocation for reproduction (Wilkinson <i>et al.</i> , 2012)				
<b>Cytokinins</b>	↓	↓	↓	↓
1. Promotion of cell division and proliferation (Sun <i>et al.</i> , 2014). 2. Endosperm development critical to wheat yield (Abid <i>et al.</i> , 2017). 3. Regulate shoot apical meristem (Sun <i>et al.</i> , 2014).				
<b>Gibberellic acid</b>	↓	↓	↓	↓
1. Cell wall extension in wheat (Keyes <i>et al.</i> , 1990). 2. Regulation of germination, stem elongation, flowering (Fleet & Sun, 2005).				
<b>Ethylene</b>	↑	↑	↓	↑
1. Role in senescence, leaf abscission, fruit ripening, seed maturation, negative growth regulation (Hays <i>et al.</i> , 2007, Wilkinson <i>et al.</i> , 2012, Xu <i>et al.</i> , 2007) 2. Difficult to measure because of its gaseous nature therefore generally look at ACC synthase activity as a measure of ethylene biosynthesis (Habben <i>et al.</i> , 2014, Yang <i>et al.</i> , 2017a)				



<b>Salicylic acid</b>	↑	↑	↑	↑
1. Activate antioxidant enzymes reducing stress related ROS (Chen et al., 2016) 2. Protection of photosynthetic thylakoid membranes (Khan et al., 2013) 3. Accumulation osmoprotectant molecules e.g., proline (Khan et al., 2013). 4. Modulate ice nucleation to reduce freezing stress (Tasgin et al., 2006).				
<b>Strigolactones</b>	↓	↓	NA	NA
1. Establishment of biotic interactions in rhizosphere (Cheng et al., 2013). 2. Modulation of shoot and root architecture (Jansen et al., 2014). 3. Response to abiotic stress (Visentin et al., 2016, Gou et al, 2017).				
<b>Brassinosteroids</b>	↓	↓	↓	↓
1. Exogenous application increased photosynthate accumulation and CO <sub>2</sub> fixation (Braun and Wild, 1984). 2. Exogenous application reduced level of ABA and IAA (Avalbaev et al., 2010). 3. Exogenous application enhanced resistance to heavy metal (Kroutil et al., 2010). 4. Over-expression of wheat BR11 receptor leads to thermotolerance (Singh et al., 2016).				
<b>Jasmonic acid</b>	↑	↑	↑	↓
1. Activate antioxidant enzymes to reduce stress related ROS (Qui et al., 2014). 2. JA may play important role mediating stomatal closure along with ABA (Zhao et al., 2014). 3. Modulate cross-talk between hormones under abiotic stress (Zhao et al., 2014).				

**Fig 4:** Summary of hormonal responses [upregulated (green), down regulated (red)] following exposure to various abiotic stresses (Abhinandan *et al.*, 2018)

## 6.2 Agronomic Interventions

Some agronomical practices are also helpful in the crop management under abiotic stresses condition.

### 6.2.1 Heat Stress

Under heat stress condition conservation agriculture has shown promising results. It involves significant reductions in tillage particularly zero tillage, mulching and adopting diversified and economically viable crop in rotations. Resource-conserving practices like zero tillage (ZT) allow early sowing of wheat after rice harvest so that the crop is able to fill the grains before the onset of heat stress (Mehla *et al.*, 2000). Sprinkler irrigation helps in cooling of plant canopy on exposure to high temperature beyond 30 °C and reduces the adverse impact of heat stress (Shankar *et al.*, 2015). Effect of heat stress in early growth stages like tillering or booting stage can be minimized by providing a need-based light irrigation. By moderating temperature fluctuations, conserving soil moisture, and improving soil organic matter status, conservation agriculture practises

helps in the mitigation of temperature stress. Wheat sowing by zero tillage method just after harvesting of previous crop helps in early sowing and utilization of residual moisture available in soil which helps in escaping terminal heat stress and saving water required for pre-sowing irrigation in wheat crop (Rane *et al.*, 2007).

### 6.2.2 Drought Stress

Different methods of irrigation like furrow irrigation in furrow-irrigated raised bed (FIRB) planting system, sprinkler and drip irrigation help in efficient management of scarce water resources. Combined application of plant growth-promoting rhizobacteria (PGPR) formulated bio-fertilizer (BF) and salicylic acid (SA) enhances plant biomass, photosynthetic pigments, relative water content, osmolytes, and activities of the defense-related system under drought stress condition. It have been observed that plant treated with SA and BF together under drought stress had significantly increased leaf water status, Chl a, Chl b, and carotenoids synthesis. Moreover, the co-



application of SA and BF showed maximum SOD, POD, APX, and CAT activities in the leaves and roots under drought stress which makes plant more tolerant to stress (Azmat *et al.*, 2020).

### 6.2.3 Salt stress

Saline soils are reclaimed by scraping of salts by using mechanical ways; flushing is used in crusting and low permeability soils to wash away the surface salts using good quality water to remove salts, leaching works well on saline soils having good structure and internal drainage. The alkali/sodic soils are generally reclaimed by leaching of the excess sodium, by deep ploughing to incorporate the calcareous subsoil into the topsoil and by adding acidifying minerals like pyrite and gypsum.

It has been reported that Sulphur (S) assimilation plays a pivotal role in the metabolic modifications that occur under salt stress, and increased S levels have been shown to increase salt tolerance in plants (Astolfi *et al.*, 2013). S-adenosyl methionine is the precursor of polyamines (PAs), which are closely associated with plant resistance to salinity stress (Chen *et al.*, 2014)

### 6.2.4 Waterlogging

Application of organic manure improves soil physical factors, reduces soil surface crusting, enhances plant rooting and alleviates the effects of pan formation on yield. Increased soil organic content aids in resolving the problem of water logging caused by a higher infiltration rate. Ridge and furrow system or sprinkler irrigation have been shown to reduce the problem of water logging. Growing the plants on ridges helps in keeping the roots away from waterlogged areas while the furrows facilitate proper drainage of fields. It has been observed that adopting conservation agriculture and furrow-irrigated raised-bed planting system also helps to reduce crop lodging.

### 6.2.5 PHS

Weathering of grain mainly due to rainfall after maturity, can lead to PHS. To minimize PHS and test-weight losses the wheat is harvested and dried wheat the first time it reaches when the moisture is at 20 percent, harvesting is done when it contains it the first time it reaches 15 percent moisture. It must be ensured that combine and all other critical equipment including hauling capacity are “ready to roll.”

## 6.3 Genetic and biotechnological management

### 6.3.1 Drought management

Drought stress tolerance is a complicated trait that is affected by genetics, as well as a number of quantitative trait loci (QTLs) and environmental influences. Polygenes control the genetic basis of drought resistance, with each gene having a limited and cumulative effect with a high GXE interaction, resulting in low heritability. Drought tolerance has been studied genetically in wheat through the discovery of molecular markers and genome sequencing (Wani *et al.*, 2020). Such analysis includes several approaches e.g. QTL-mapping, association-mapping, genome-wide analyses and expression analysis which aim to identify QTL or gene-related traits for drought stress tolerance. Different DNA molecular markers have been used to genotype the populations and identify QTL (Maccaferri *et al.*, 2008). Recently, a high-density genetic SNP map (SNP array or genotyping by sequencing (GBS)) have been used to genotype the population (Obasa *et al.*, 2016). Numerous QTLs for grain yield on chromosomes one, three, and six, for grain number per spike on chromosomes two, three, and six, and for spikelet number per each spike on chromosomes two, five, and six have been identified. Major QTL monitoring grain yield can be used in marker-assisted selection for yield improvement under drought stress. Wheat varieties DBW 14, K 9107, HD 2733 etc for North Eastern Plain Zone and NI-5439, Raj-3765, WH-147, HD-2733 etc. are identified as drought tolerant for North Western Plain Zone (Meena *et al.*, 2015) of India.

### 6.3.2 Heat stress management

Heat tolerance is obviously a polygenic trait, and the molecular techniques also help in understanding the genetic basis of plant thermo tolerance. Recently several QTLs for different yield component traits have been identified which can be used for developing heat tolerance in wheat. For example, QTLs for heat tolerance has been identified for grain weight and grain-filling duration, senescence related traits and canopy temperature. These QTLs may prove useful for improvement of such traits using Marker Assisted Selection (MAS). Among the wheat varieties Halna is most tolerant wheat genotype followed by K-8962 and Raj-3765, DBW-14 and NW-1014 (Singh *et al.*, 2020; Singh *et al.*, 2019).



### 6.3.3 Salinity stress management

The available studies led to identification of ~ 500 QTL (excluding those involved in digenic epistatic interactions and QTL x treatment interactions); these QTL are spread over all the 21 wheat chromosomes and could prove useful resource for MAS intended at improving salt tolerance in wheat. Wheat gene TaAOC1, encoding cyclase involved in jasmonic acid synthesis, was induced by high salinity. Constitutive expression of TaAOC1 in both wheat and Arabidopsis restricted root growth, but enhanced salt tolerance and Jasmonic acid content. Wheat lines highly tolerant to salinity are Kharchia (from Rajasthan; eg., KR 375, KR 378), Rata (from Bhal, Gujrat), KRL 213 and KRL 210 from CSSRI Karnal.

### 6.3.4 Pre-harvest sprouting/dormancy management

Pre-harvest sprouting (PHS) is a quantitative characteristic controlled by various genes. About ~ 250 QTL were identified, among them just 29 QTL were major and stable across environments; these QTL are conveyed on 11 unique chromosomes (1B, 3A, 4A, 5A, 6A, 2B, 3B, 4B, 7B, 2D, 3D and 7D); the most noteworthy PV explained by an individual QTL range from 23% to 78.3%. In a report it has been observed that the major PHS resistance QTL *Qphs.usask.4A* carries three diagnostic SSR marker alleles, DuPw004 (200 bp), *barc170* (158 bp) and *wmc650* (109 bp) inherited from the dormant parent, while non-dormant parent contributed DuPw004 (300 bp), *barc170* (177 bp) and *wmc 650* (90 bp) alleles. A survey of pedigrees analysis of number of western Canadian wheat cultivars revealed that the parental line RL 4137 is a major source of increased PHS resistance (Singh *et al.*, 2012).

### 6.3.5 Waterlogging management

Water logging tolerant cultivars of wheat were identified (Vijayalakshmi *et al.*, 2010) which unlocks the potential of water logging tolerant variety research of wheat. Presence of *Adh* gene in wheat which is also found in barley and rice are associated with water logging tolerance to ensure the presence of tolerance mechanism in wheat. It has been reported that possible crosses between water logging tolerant cultivars of spring wheat were made which in turn suggested that water logging is controlled by a few number of genes (Boru *et al.*, 2001). It also has been reported that new allele for aerenchyma formation under waterlogging condition was identified from a wild barley genotypes. This allele showed a good potential in forming aerenchyma

and was the major contributor to waterlogging tolerance (Zhang *et al.*, 2017). A high-density linkage map helped identify several co-segregating markers linked with QTLs for aerenchyma formation in wheat and that can be directly used in breeding programs.

## 7. Future Prospects

The abiotic stresses significantly affect the crop productivity either directly or indirectly. However, the level of crop yield loss due to stresses depends upon the growth stage and period of stress. Stress tolerance potential of genes may differ depending on environmental conditions and their interactions. A systematic and integrative approach of physiology, biology, genomics, and genetic engineering is needed to explain the complex mechanisms of these stresses that are controlled by a large number of genes. To speed up wheat improvement program, the wheat genome sequence information can be used to classify candidate genes responsible for complex agronomic traits. Pyramiding and combination of different QTLs and transgenes through marker-assisted breeding approaches may lead to biotic and abiotic tolerant wheat varieties. Understanding the signalling pathways that are triggered in response to abiotic stress would provide useful knowledge for developing new technologies to reduce yield loss caused by abiotic stress. Plant hormones may also be used as a foliar application or as a pre-seeding therapy. Genome editing with CRISPR/Cas technology will be used during the isolation of suitable mutants to increase overall yield and resistance to biotic and abiotic stresses. Editing of genes like TaGW2, TaGARS7, and TaDEP1 has already demonstrated the usefulness of this process (Liang *et al.*, 2017; Wang *et al.*, 2018a, b; Zhang *et al.*, 2016; Zhang *et al.*, 2018). The use of base editing (a changed CRISPR/Cas approach) in the development of climate-resilient improved wheat cultivars has also been suggested.

### Ethical standards

Not applicable with this article.

### Conflict of interest

The authors declare that they have no conflict of interest.

### Author contributions

SK, SM1 and SM2 designed the concept of the article. SK and SC prepared the figures used in the article. SK, SM1 and SC wrote the manuscript, SM communicate to the journal time to time. SK and SM1 make the final editing of the review article.



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