Bread Wheat (*Triticum aestivum* L.) Under Biotic and Abiotic Stresses: An Overview

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Abstract Wheat, a major cereal crop, is subject to several biotic and abiotic stresses. These stresses affect the crop's yield globally. Different mechanisms have been adopted by plants to counter the wide range of biotic and abiotic stresses faced. The scarcity of irrigation water leads to moisture stress in the wheat crop. The quantitative trait loci tool is used to map the moisture-tolerant inherited genes. Genes that are drought tolerant have been identified in other crops and scientists are planning to introduce them into the wheat genomes. Similarly, understanding the heat stress tolerance pathway is underway. Moreover, cryoprotectant genes that code for proteins which help the plants gain tolerance to severe cold can be transformed into commercial wheat varieties to tackle cold stress. Several genetic engineering techniques are being developed to minimize micronutrient and waterlogging stress. Biotic stresses include parasitic and nonparasitic diseases. In order to ward these off, plants use systemic acquired resistance and induced systemic resistance, but these are not sufficient when stress reaches its extreme. Seedborne diseases result in lightweight shriveled kernels resulting in an overall reduction in the crop yield. There is also a range of pathogenic fungi and viruses that cause various leaf and root diseases in wheat. Disease control strategies are underway to limit the damage to the wheat crop. Furthermore, soil moisture level, the depth of seed plantation, PH control for fungal growth reduction, and use of certain antibiotics in the soil can greatly reduce the risk of biotic stress-related wheat diseases. In addition to all of these aspects, pivotal to maximize wheat productivity is genetic improvement where harnessing and exploiting smartly via state-of-the-art technologies pointing towards genetic resource diversity is paramount as a means for providing high levels of allelic variation around all major stress constraints.

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1 Introduction

Wheat, the third largest cereal crop, is grown globally under spring, winter, and facultative environmental habitats. Modern wheat cultivation started in the Middle East about 9000–11,000 years ago and as a consequence of increased geographical farming, bread wheat became a common staple food from China to England (Heun et al. 1997; Nesbitt 1998; Dubcovsky and Dvorak 2007). Wheat is the sole source of energy for nearly 35 % of the world population (Dreisigacker 2004). Its success depends partly on its wide adaptability plus high yield potential and also on the gluten protein fraction that confers the viscoelastic properties which allow dough to be processed into bread, pasta, noodles, and other food products. Wheat also contributes essential amino acids, minerals, vitamins, beneficial phytochemicals, and dietary fiber components to the human diet. Two important characteristics of wheat are its gluten content and low amylase activity; properties that allow wheat to be blended with other flours such as rye and oats for specific purposes (Tatham and Shewry 2008). Wheat varieties are characterized by hardness, kernel colors, and their planting time. Each wheat class has its own relatively uniform characteristics related to milling, baking, or other food use (Taylor et al. 2005). Wheat is classified into six groups such as

(a) Hard red winter wheat
(b) Durum wheat
(c) Hard red spring wheat
(d) Hard white wheat
(e) Soft red winter wheat
(f) Soft white wheat

Wheat is one of Pakistan's major cereal crops and essential for ensuring food security projections for the nation. According to the Food and Agriculture Organization (FAO), Pakistan is the ninth largest wheat-producing country, accounting for 3.04 % of the world's wheat production from an area of 3.57 % of the world. Wheat is the leading food grain of Pakistan and a diet staple of the people. It occupies a central position in the formulation of agricultural policies. It contributes 14.4 % to the value added in agriculture and 3.1 % to the gross domestic product (GDP). The national productivity level of wheat in the year 2012–2013 was 24,231,000 tons showing 3.2 % increase as compared to year 2011–2012 which gave 23,473,000 tons (Source: Pakistan Bureau of Statistics). Factors that influence yield outputs are various biotic and abiotic stress constraints augmented by environmental factors which adversely affect growth, metabolism, and yield. Drought, salinity, low and high temperatures, floods, pollutants, and radiation are the important stress factors limiting the productivity of crops (Lawlor and Cornic 2005). There is sufficient

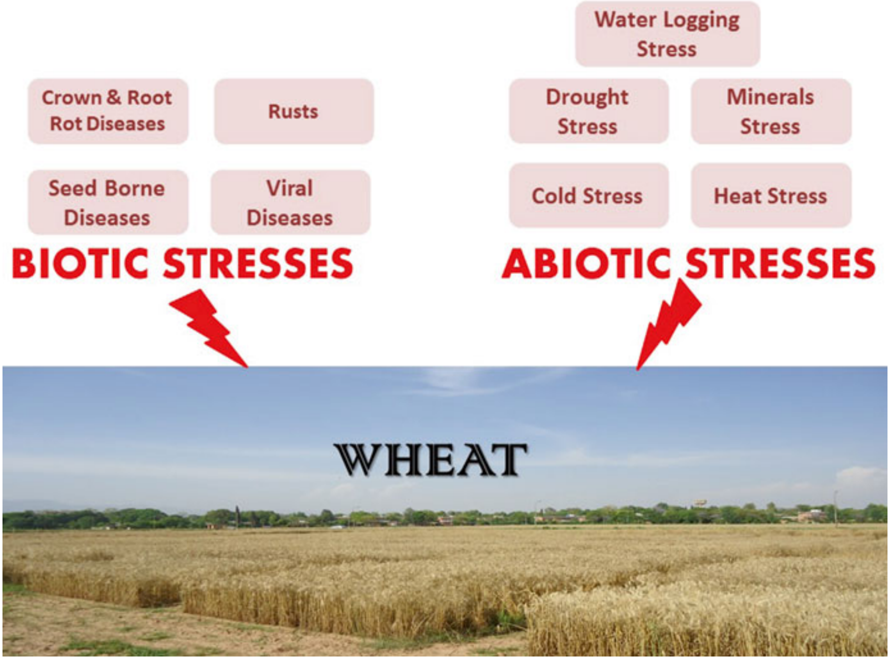

Fig. 1 Major biotic and abiotic stresses to wheat

genetic variation in the wheat gene pool that can be ensured for continued improvement of wheat adaptation to abiotic stress (Trethowan and Mujeeb-Kazi 2008). The diverse biotic (insects, bacteria, fungi, and viruses) and abiotic stress constraints (light, temperature, water availability, nutrients, and soil structure; Lichtenthaler 1996) interact to affect wheat yield and production across the world. Several biotic and abiotic stresses that influence wheat productivity are represented in Fig. 1. Biotic stress refers to plant and pathogen interaction. Plants and pathogens, throughout their life cycle, interact with a wide variety of organisms that significantly affect plant health in various ways. Organisms always require some form of indirect or direct contact in order to infect (Peterson 1974). To understand the main mechanisms of biological control that could be mutualism, neutralism, protocooperation, predation, commensalism, competition, amensalism, and parasitism, there are a number of environmental stimuli, comprising light, gravity, physical stress, temperature, nutrient availability, and water to which plants respond actively (Pal and Gardener 2006). Along with these, a wide range of chemical stimuli generated by the type of soil and plant-associated microbes also serve as vital stimuli. Such stimuli are responsible for either conditioning or inducing plant host defenses that ultimately increase resistance against infections by the wide range of pathogens through biochemical changes. Host defense induction can be local and/or systemic in nature, depending on the type, source, and amount of stimuli (Vallad and Goodman 2004; Lichtenthaler 1996).

Systemic acquired resistance (SAR) occurs where the pathogenic infection is initiated by salicylic acid production, a compound that usually gives rise to the expression of pathogenesis-related proteins which may include a diversity of catalysts and enzymes regulating different defense mechanisms (Thakur and Sohal 2013). Induced systemic resistance (ISR) of plants against pathogens is a widespread phenomenon that has been intensively investigated with respect to the underlying signaling pathways as well as to its potential use in plant protection. Elicited by a local infection, plants respond with a salicylic-dependent signaling cascade that leads to the systemic expression of a broad spectrum and long-lasting disease resistance which is efficient against fungi, bacteria, and viruses. Changes in cell wall composition, de novo production of pathogenesis-related proteins such as chitinases and glucanases, and synthesis of phytoalexins are associated with resistance, although further defensive compounds are likely to exist but remain to be identified (Clarke et al. 2000; Heil and Bostoc 2002).

2 Abiotic Stresses in Wheat

The land per capita and water resources are depleting rapidly and will diminish during the coming decade. To meet the increasing global demand for wheat, yield must be increased up to 1.6 % per annum. Some ways must be found to cope with this problem of keeping pace with the population increase and alleviating world hunger or by elevating crop production in an ecosystem that fosters sustainable intensification. Crop management research (CMR) can also contribute towards resolving this problem by generating high-yielding varieties that can support in enhancing production up to 50 % (Lynam 2004). One of the major limiting factors in wheat growth and production is abiotic stresses. The major objective of scientists in the twenty-first century is to increase and stabilize crop production more or less in those areas with a highly variable and fragile climate which poses one of the paramount challenges for agricultural exploration (Mahajan and Tuteja 2005). Eventually, crop management, a combination of tolerance/resistance to various abiotic and biotic stresses, adaptive traits, and production economics will determine the productivity in stressed environments (Brown and Rieseberg 2005). Therefore the focal points for research should be improving the understanding and characterization of the target climatic variables, identification of efficient selection and screening methodologies, selection of morphophysiological stress adaptive traits, and the practice of most sustainable crop management assays.

2.1 Heat Stress

Another global stress in wheat is heat stress. As global warming intensifies, heat stress may gain huge mass. Heat stress in wheat is known to cause an array of physiological, biochemical, and morphological changes that affect its growth and development. For a decade, heat stress has caused a significant decrease in wheat yield and has made the world struggle to match the record production figures, thus posing a critical challenge in maintaining food security. Usually types of spring wheat are more fragile than winter types. Heat stress above 30 °C may significantly reduce the percentage of germination which may double germination time. This also influences root production which drastically reduces the normal amount. High temperatures, typically above 34 °C, affect final grain weight by reducing the duration of grain filling due to suppression of current photosynthesis (Fokar et al. 1998; Brestic et al. 2014), and by directly inhibiting starch biosynthesis in the endosperm (Telfer et al. 2013).

2.1.1 Effect of High Temperature During Vegetative Phase

A rise in temperature during the vegetative growth phase may have no significant negative impact on plant growth. However, during anthesis and grain-filling stages huge alteration in metabolic and growth processes occurs.

2.1.2 Effect of High Temperature During Reproductive Phase

During the reproductive phase, high temperatures may result in decreased seedling leaf mass or pollen sterility. Irreversible damage originated by prolonged exposure to high temperatures as sudden heat shocks may damage the thylakoids resulting in leakage of cellular contents. This is why the reproductive phase is regarded as the most sensitive phase, because just a few degrees elevation in temperature is closely associated with reduction in biomass, rate of grain filling, and yield (Bita and Gerats 2013).

Higher plants exposed to excess heat, at least 5 °C above their optimal growing conditions exhibit a characteristic set of cellular and metabolic responses required for the plants to survive under the high-temperature conditions (Guy 1985). High stomatal conductance and maintenance of cell wall stability are the characteristics possessed by varieties that show the best tolerance under heat stress (Shah and Paulsen 2003). Biochemically, the gliadins tend to increase whereas the HMW (high molecular weight) glutenins in the grain reduce during the high temperature, accompanied by accelerated transcription and translation of heat shock proteins (Bray 1994), the production of phytohormones such as abscisic acid (ABA), antioxidants, and other protective molecules (Maestri et al. 2002).

2.1.3 Wheat Tolerance to Heat Stress

Within the gene pool of wheat, large genetic diversity is present for most traits. The following strategies can be employed to develop heat tolerance in wheat:

1. The T1BL.1RS translocation in wheat may also bestow heat tolerance (Zhao et al. 2012). In a recent study, screening of 102 Pakistani wheat cultivars and candidate lines was done in order to identify the rye T1BL.1RS translocation. This rye 1R chromosome short arm has contributed enormously to increase genetic diversity in wheat. Many varieties were found to have this translocation (Tahir et al. 2014).
2. Despite the importance of wheat as a significant cereal crop, current information of its genome sequence is inadequate for functional genomics. Sequencing of the wheat genome is quite a challenge because of its large genome size (16,000 Mb) but is already underway. However, mapping and characterizing ESTs (expressed sequence tags) offers a manageable approach to the complex architecture and functioning of the wheat transcriptome and helps in unraveling the genetics of the heat stress response. To understand the regulation of heat stress tolerance, detailed information about these ESTs and their functional annotation is necessary. Therefore expression profiles have been analyzed under different hormones/elicitors and various developmental and growth stages.
3. It is well worth considering exploring the underlying mechanism and practicing different breeding tools that may bear fruit in the near future.
4. Genetic engineering and producing transgenic wheat with a heat-tolerant gene is also under consideration.

2.2 *Drought Stress*

Drought is one of the major constraints to wheat production worldwide affecting its growth, development, and yield. About 45 % of wheat production is affected by drought. The scenario should be that the productivity per area of the crop is not just maintained but also increased substantially (Fedoroff et al. 2010). Drought stress retards plant growth, inhibits formation of primary and secondary roots, and encourages formation of stout roots thus affecting grain yield. In Pakistan, out of 22.45 million ha cultivated area, only 6.34 million ha land are irrigated by canal water, and about 12.52 million ha are cultivated through tube well and other sources, whereas no water is available for the remaining 3.59 million ha (Khalil et al. 2014). For this we should focus on the strategies regarding genetic solutions, that is, wheat germplasm with drought tolerance or enhanced water efficiency and development of water-use efficient varieties with refined agronomic practices.

2.2.1 Wheat Tolerance to Drought Stress

The wheat plant has naturally evolved diverse responses to drought stress that help the plant to minimize the damage caused by it and to maintain cellular homeostasis. Drought tolerance studies on the genetic level are not often conducted because a trait that offers drought tolerance in one location or year may not especially confer tolerance in other years or locations. This is because complex hypothetical combinations of various traits are responsible for the tolerance (Yang et al. 2007). The following strategies are under consideration to improve drought tolerance in wheat:

1. Quantitatively inherited genes are basically responsible for controlling drought tolerance in any environmental condition. In wheat the detection of such tolerance is explored by using the quantitative trait loci (QTL) tool. Understanding the genetic basis of complex traits affecting yield under drought is crucial for sustainable improvement of wheat in breeding programs. Enormous advancements in genomic resources and tools in recent years have greatly assisted mapping and cloning QTLs and the corresponding genes (Borevitz and Chory 2004; Bray 1994).
2. Molecular marker systems for crop plants were developed to create high-resolution genetic maps and exploit the genetic linkage between markers and important crop traits (Edwards et al. 1987). A large number of marker × trait associations have facilitated the use of molecular markers for marker-assisted selection (MAS) in bread wheat and are gaining momentum in several countries (Gupta et al. 2008).
3. Many specified proteins synthesized under water scarcity have been isolated and characterized. The water stress-specific proteins (stress induced) have been described by different groups such as

   (a) Dehydrins (polypeptide),
   (b) LEAs (late embryogenesis abundant),
   (c) RABs (responsive to ABA),
   (d) Storage proteins (in vegetative tissues).

   These protein formations are encoded by many genes. One of the stress-induced genes among several of the candidate genes frequently involved in tolerance is rd29DREB1A. Such an abscisic-acid–dependent pathway-induced gene is expressed under cold stress and dehydration conditions in rice. The introduction of this gene from rice to wheat may manipulate the biochemical pathways converting wheat into a drought-tolerant crop (Hu et al. 2007).
4. Normally a plant can withstand about 30 % of water loss. Scientists proposed that resurrection plants or desiccation-tolerant plants can be used as model plants for drought studies as they can withstand about 90 % of water loss (Bartels and Salamini 2001).
5. Genetic engineering of wheat can be done to help develop drought tolerance by altering gene expression or by accumulating those metabolites that help coping with drought such as ABA, largely hydrophilic proteins, largely hydrophilic proteins, and osmotically active compounds (Ramachandra-Reddy et al. 2004).

2.3 Cold Stress

Wheat, being the most adaptable crop, can withstand temperatures as low as 1–4 °C which is considered to be the minimum temperature for growth. Cold stress is commonly referred to as plant response to freezing temperatures (Gusta and Chen 1987).

Table 1 Effect of temperature on different biological processes and physiological phases in wheat

Processes	Temperature minimum (°C)	Temperature optimum (°C)	Temperature maximum (°C)
Lethal limits	−17.2	–	47.5
Leaf initiation	−1	22	24
Shoot growth	3.0	20.3	>20.9
Root growth	2.0	<16.3	>25.0
Grain filling	9.2	20.7	35.4

Approximately 80 million ha of the total wheat growing area are affected by cold stress globally. Areas near the equator and spring wheat face more damage and as night temperatures fall below 10 °C, shoot and root growth diminish completely. Before flowering, cold conditions can delay anthesis or cause severe sterility (Xin and Browse 2000; Sanghera et al. 2011). In the case of winter wheat, low temperature greatly reduces root growth with increased fructan and sugar levels along with a dramatic drop in osmotic potential. Winter wheat leaves are usually smaller and transpire less. To withstand much lower subzero temperatures, the expression of proteins, lipids, and sugars doubles in the cold-hardened wheat (Fowler 2001). Under very low temperature the critical adaptive mechanism improving survival is cold hardening or acclimatization. During cold hardening, the level of several proteins is considerably increased (i.e., proline, glutathione, TaADF and dehydrins), which play a significant role in decreasing the osmotic potential and serve as cryoprotectants (Abdin et al. 2002). The effect of temperature on different biological processes and physiological phases in wheat is summarized in Table 1.

2.3.1 Wheat Tolerance to Cold Stress

As many as 15 out of 21 chromosomes in wheat have been found to influence tolerance to low temperatures (Stushnoff et al. 1984). Polymorphism exists between different wheat varieties for cold stress tolerance. The *Fr1*-frost tolerance gene is located on the chromosome 5AL, close to vernalization factor Vrn1 and *Fr2* is linked to Vrn 3. Both of them are linked together but can be separated (Snape et al. 1997). The heritability of these genes is very high, approximately 60–90 %. For cold tolerance an absolute level can be improved by finding genetic diversity among the wild wheat relatives (Sãulescu and Braun 2001). The physiology of tolerant lines is highly understood, whereas the genetic variability is low especially in the present gene pool which also renders it difficult to move forward swiftly beyond the current level. However, the transformation of existing genes into commercially acceptable wheat varieties can fairly improve cold stress tolerance in them (Kobayashi et al. 2002). Frost tolerance of ten Bulgarian winter wheat and five foreign cultivars was studied by Ganeva et al. 2013 with different effects of chromosome 5A and their association with microsatellite alleles (Ganeva et al. 2013).

2.4 Waterlogging Stress

The common occurrence of waterlogging stress in both high rainfall and irrigated environments is more than 10 million ha globally. In sensitive varieties, up to 50 % massive decrease in root mass, three quarters in the shoot with a significant drop in stomatal conductance occurs. In roots, mineral concentration increases, especially sugars whereas in shoots mineral content decreases. Genotypes with well-developed parenchymatous tissues for transportation are considered to be tolerant in waterlogged conditions (Belford 1981; Drew 1983; Smirnoff and Crawford 1983; Justin and Armstrong 1987; Barrett-Lennard et al. 1988; Thomson et al. 1990; Huang et al. 1994). Genetic variability among varieties for tolerance involves large differences, although its occurrence is relatively lower. However, the inheritance is additive and relatively simple.

2.4.1 Wheat Tolerance to Waterlogging Stress

This stress can be highly minimized by utilizing breeding and engineering solutions. It is recommended that to achieve waterlogging tolerance, an incremental process be followed by first incorporating adaptive traits from local, national, or international germplasm with known tolerance, and then combining other adaptive traits relevant to the target environment. Screening of “primary synthetic hexaploid wheat” has been done to discover tolerance against waterlogging (Villareal et al. 2001).

2.5 Mineral Stress

Mineral stress is the suboptimal availability of essential nutrients or toxicity of nutrients or nonnutrient materials such as aluminum, cadmium, sodium, manganese, or some other heavy metals (Jonathan and Samuel 2004). About 40 million ha of wheat area experience mineral stresses globally, mainly due to soil alkalinity and acidity. Mineral stress is due to the amendment of chemical fertilizers, sludge and sewage irrigation, and atmospheric deposition (Ranieri et al. 2005).

2.5.1 Wheat Tolerance to Mineral Stress

The techniques of amendments that have been developed until now are often quite costly and impractical. The following approaches can be applied to confer tolerance against micronutrient stress:

1. Breeding of such plants that are mineral stress tolerant can be an alternative approach with the integration of farming strategies.

2. In spite of that, ecological, biological, and economic considerations have proven to be more efficient than the breeding solutions.
3. Single dominant genes are responsible for controlling tolerance and efficiency to various nutrient stresses. Thus easy genetic gains can be projected by conventional breeding.
4. Genomics can be used as a tool in understanding plant responses to mineral stresses in a changing environment.

For exhibiting good expression of variability of such tolerance at the genomic level, the location and alteration of specific mineral-tolerant plants are identified. Through one survey analysis in 1990, 190 soils from 15 countries were tested by Sillanpaa (1990).

3 Biotic Stresses to Wheat

Common wheat and durum are attacked by numerous diseases and pests but it is an amazing fact that only 5 % of pests and less than 20 % of diseases are of significant importance posing a real threat to wheat productivity (McIntosh 1998). Plant diseases are basically divided into two types, nonparasitic and parasitic. Nonparasitic diseases are mainly caused by mutagens and environmental factors whereas parasitic diseases are caused by living organisms such as bacteria, fungi, viruses, and the like. Wheat is largely affected by fungal species. Most commonly these diseases are wheat rusts which are stem, leaf, and stripe. Wheat diseases can be classified into three categories:

(a) Seedborne diseases
(b) Viral diseases
(c) Wheat rusts

3.1 Seedborne Diseases

Seedborne diseases infect seeds from infested grain or soil, resulting in a poor stand or seedling blight making them toxic for human use. Common seedborne diseases are *Stagonospora nodorum* leaf blotch, head blight or scab, loose smut, common bunt, karnal bunt, leaf spot diseases, and crown and root rot diseases (Kumar et al. 2008; Majumder et al. 2013).

3.1.1 *Stagonospora nodorum* Leaf Blotch

Leaf blotch is caused by *Stagonospora nodorum*. The fungus requires warm and humid weather to grow. It is both a seedborne and foliar pathogen. It infects many varieties of wheat but mainly white winter wheat. As a result of infection, lightweight, shriveled kernels with molds are produced hence affecting yield (Bai and Shaner 1994).

3.1.2 Head Blight or Scab

It is caused by *Fusarium* spp. that not only reduces yield but also produces the toxin deoxynivalenol which is lethal for consumption (Nedelnik et al. 2007). It is found that up to 17 *Fusarium* spp. can cause head blight but the most common are *F. graminearum*, *F. avenaceum*, and *F. poae* (Bai and Shaner 1994).

3.1.3 Loose Smut

Loose smut is caused by *Ustila gonuda* tritici. It is an asymptomatic disease that reduces yield and production of wheat by converting grain and parts of the head to smut spores. As a result, the infected plant has no grains left to harvest (Agarwal 1981). Recent research has been conducted using PCR and ELISA techniques in the assessment of loose smut incidence in seed lots (Wunderle et al. 2012).

3.1.4 Common Bunt

Likewise, common bunt can also be devastating. It is caused by *Tilletia foetida*, *T. contraversa*, and *T. caries*. It is also known as stinking smut. It gives a foul fishy odor to the grain, making it unfit for the milling process (Mathre 2000). Smut-infected heads have a bluish-green cast instead of whole green color (as in the case of normal heads). Producers are strictly condemned for selling smutty grain (Klem and Tvaruzek 2005).

3.1.5 Karnal Bunt

Karnal bunt is caused by *Tilletia indica*. Common wheat and durum are its major hosts. Seeds with reduced viability and quality are produced thus making them unfit for human consumption due to chemical changes in the seeds (Rai and Singh 1978). Pakistan, Nepal, Iraq, Iran, Afghanistan, and Mexico are the major countries facing this disease (Matsumoto and Bell 1989; Majumder et al. 2013; Kazi et al. 2013). International wheat trading has an infection permissible limit of less than 3 % (Mujeeb-Kazi et al. 2006).

3.1.6 Leaf Spot Diseases

Leaf spot diseases include powdery mildew, leaf rust, glume blotch, *Septoria tritici* leaf blotch, and spot blotch. All of these diseases are weather and humidity dependent. To develop a disease, they require the leaf surface to be wet or the humidity level to be near 100 % for a certain period of time (McMullen and Adhikari 2009; Bolton et al. 2009).

- Symptoms of powdery mildew include white or grey powdery growth on leaves. It doesn't kill the plant but weakens it (Stromburg 2010).
- Leaf rust occurs in mid to late May in many parts of the world as it requires warm and humid weather (Bolton et al. 2008; Zhang and Meakin 2003).
- Glume blotch occurs in the hot and humid weather of June (Leonard and Bushnell 2003)
- *Septoria tritici* leaf blotch and powdery mildew occur in the early spring and are favored by cool and humid weather (Goswami and Kistler 2004).
- Of global significance in warm tropical areas is *Cochliobolus sativus* (spot blotch) which is the major wheat production biotic stress constraint in Bangladesh. Of national importance, this disease emerged in 2009 and warrants attention as we move forward to maximize wheat yields. Its molecular elucidation has recently surfaced and mapping initiatives are being harnessed (Zhu et al. 2014).

3.2 Crown and Root Rot Diseases

Crown and root diseases include *Cephalo sporium* and take-all. Both are caused by soil-residing fungi. In take-all, the base and stem of the premature plant appear bland and scurfy. In *Cephalo sporium*, the entire length of the leaf blades is covered by alternating yellow and brown stripes. These diseases are caused by planting wheat year after year in the same field. The extent of the disease is increased if grass weed, such as quack grass, becomes established in the field. The root rots of wheat, oat, and barley are among the least conspicuous but are destructive diseases, and are caused by many species of fungi living in soil, seed, and dead plant refuse. Root rots refer to diseases that affect roots and basal portions of culms. It should also be noted that seasons and climate have a large impact on disease type. *Cercosporella* root rot is prevalent in winter wheat areas whereas *Helmintho sporium* and *Fusarium* root rots are prevalent in spring wheat regions. Several species of bacteria and fungi have been isolated from barley kernels and wheat. Most of them are saprophytic showing weak pathogenicity, however, some species of *Alternaria* are nonpathogenic and are commonly associated with kernels of grain (Jones and Sutton 1996).

3.3 Viral Diseases

This category includes wheat spindle streak mosaic and barley yellow dwarf disease.

3.3.1 Wheat Spindle Streak Mosaic (Wheat Yellow Mosaic)

Wheat spindle streak mosaic is a soilborne viral disease that usually appears in early May in most parts of the world. The upper leaves of the affected plant show short, spindle-shaped, yellow streaks. That is why it is also called yellow mosaic disease.

If the weather is persistent and cool, the disease symptoms may intensify over time, otherwise disappear (Hershman 2011; Jianping 1993).

3.3.2 Barley Yellow Dwarf Virus

Barley yellow dwarf is a vector-dependent disease, transmitted by aphids. Symptoms include a stunted shoot with reddish or yellowish leaf tips and no heads. Yield loss can be up to 50 % (Miller and Rasochova 1997). The virus can be characterized on the basis of serotype difference (Ali et al. 2013). Molecular markers are being identified and used for the detection of barley yellow dwarf virus in bread wheat (Ayala et al. 2001).

3.4 Rusts

Wheat and other *Triticum* species are attacked by eight different species and subspecies of rust fungi. Wheat can develop the following types of rusts:

1. Stem rust (*Puccinia graminis* f. sp. *tritici*)
2. Stripe rust (*Puccinia striiformis* f. sp. *tritici*)
3. Leaf rust (*Puccinia triticina* causes “black rust”, *P. recondita* causes “brown rust”, and *P. striiformis* causes “Yellow rust” (Cummins 1971; Horst 2013; Bennett and Scott 1971)

These rusts include many different races but are very host specific. They produce five kinds of spores, but only urediospores and aeciospores can infect grain and grass. In view of the fact that a single rust pustule produces 350,000 spores, rust spread is therefore quite rapid and deadly (Peterson 1974). Crop damage is caused by the growth of rust fungus and development of spores on wheat leaves and stems. As a result, essential nutrients and water needed for the development of wheat kernels are used by the pathogen (water requirements in rusted wheat are much higher than in healthy wheat). Consequently, kernels are shriveled to such a prodigious extent that many of them become so chaffy and light that they blow away with the chaff during the process of threshing. The rest of the kernels obtained are shrunken to half or one third of normal size (Schumann and D’Arcy 2010).

3.4.1 Stripe Rust

This type of rust lives all year round and is also known as yellow rust and glume rust of wheat. Its scientific name is *Puccinia striiformis*. This disease poses a serious threat to wheat production in cooler regions; warm spring temperatures reduce the development of this disease and the risk of yield losses. Stripe rust epidemics occurred in 1999 and 2005 in Kansas, United States (Basnet et al. 2014a, b) and the

Table 2 Taxonomy of *Puccinia striiformis*

Kingdom	Fungi
Phylum	Basidiomycota
Class	Pucciniomycotina
Order	Puccinales
Family	Pucciniaceae
Genus	Puccinia
Species	Striiformis

most recent in 2010 in Central Asia and the Caucasus (CAC; Ziyaev et al. 2010). Research indicates that a new population of the stripe rust is becoming adapted to the hot environment therefore it is likely to remain a potential threat. Scientific classification of *Puccinia striiformis* is summarized in Table 2.

Symptoms of Stripe Rust

Infection can occur at any stage of plant life. Symptoms include chlorotic patches on leaves, orange or yellow blister-like pustules called uredia. Basically it is a disease of leaves but it also affects awns and base. Large amounts of spores are produced in blister-like lesions (Williams PG, Ledingham GA 1964). They stick to the clothes of individuals as orange dust when someone walks through heavily diseased fields (Wellings et al. 2007). Modification of stripe rust symptoms occur due to genetic resistance. Its symptoms match bacterial black chaff and Septoria leaf blotch. It is also sometimes confused with leaf rust and stem rust but lesions of stem rust are a little bit darker as compared with stripe rust and its lesions are not well arranged but are distributed all over the leaf. Stripe rust uses water and nutrients at the expense of the host plant and dries out the plants (Line 2002; Ehrlich and Ehrlich 1963).

Control and Genetic Resistance to Stripe Rust

The most cost-effective way to control stripe rust is the planting of disease-resistant varieties. Pakistani wheat production is also threatened by stripe rusts and researchers are trying to develop a resistant variety of wheat by using molecular markers (Sobia et al. 2010). The fungus that causes stripe rust has the capability to mutate itself due to which it continuously changes. This can overcome the other resistant varieties. Foliar fungicides have the ability to control stripe rust. It is applied when the plant is at an active stage of development; it provides protection to the upper leaves which are involved in the production of grains and energy (Chen et al. 2009). The strobilurin class of fungicides is used which is most effective against stripe rust if applied before infection. A premix of two classes or the triazole class of fungicides is used if infection is already present. The triazole class of fungicide has more remedial activity (Horst 2013). Recently, DNA markers closely linked with the resistance locus of stripe rust were identified and validated by Indian scientists in collaboration with an Australian team working in Australian Winter Cereal Collection (Randhawa et al. 2014; Espino et al. 2011).

3.4.2 Stem Rust

Stem rust is basically caused by the fungus *Puccinia striiformis*. It is also known as black rust (Cook and Veseth 1991). Stem rust was known to be one of the most recently feared diseases (Boyd et al. 2013). Resistance has been developed against stem rust but new pathogens may arise, and therefore resistance to new pathogens has not been developed and is still a threat to the cereal crop worldwide. It is very important to maintain resistance against stem rust in wheat in order to have food security (Chaves et al. 2013a, b; Schumann and Leonard 2001). The taxonomy of *Puccinia striiformis* is summarized in Table 3. Basically stem rust is heteroecious in that it needs two hosts to complete its life cycle. An alternate host for this rust fungus is *Berberis vulgaris* which is found in the northern hemisphere (Barnes 1979). The plant itself has been very useful to humans because of its wood, bark, and fruit production. The alternate host became a major contributor of new combinations of genes in the pathogen which made it more virulent than the previous strain. The variation in the pathogen made the resistance mechanisms against it difficult, and thus new pathogen variations arose every year (Singh et al. 2008a, b).

Favorable conditions for stem rust are:

1. Hot days with temperatures ranging from 25 to 30 °C
2. Wet leaves either by dew drops or rain
3. Mild nights with temperature ranging from 15 to 20 °C (Schumann and Leonard 2001; Chen 2005; Roelfs 1989; Roelfs et al. 1992; Leonard and Szabo 2005)

Symptoms of Stem Rust

Infections that occur in cereals and grasses mainly occur on stem and leaf sheaths. Infections may also be located on leaf blades (Roelfs 1988). The initial symptom seen is the yellowing or whitening of the leaf a few days after infection. A pustule, a few millimeters long, is produced by damage of the host's epidermis because of

Table 3 Taxonomy of *Puccinia graminis*

Kingdom	Fungi
Phylum	Basidiomycota
Class	Urediniomycetes
Order	Uredinales
Family	Pucciniaceae
Genus	Puccinia
Species	Graminis

pressure of dark red urediniospores formed during infection (Leonard 2001). The pustules, usually diamond shaped, grow up to 10 mm long and as time progresses, infection persists and forms black teliospores, because of which stems appear black in later seasons (Farkas and Király 2006).

Genetic Resistance to Stem Rust

Genetic resistance is the common mechanism used to counteract stem rust. New races of the fungus arise from mutations due to which resistance genes become ineffective but a few genes have been identified that were effective in producing a resistance to stem rust. The *Sr31* gene became famous worldwide (Pretorius et al. 2000; Rohringer et al. 1979). The *Sr31* gene occurs on a segment of the chromosome in rye that was transferred to wheat by interspecific hybridization. This hybridization became really popular because the *Sr31* gene gave a good quality yield for wheat crop production and it also gave extra additional genes for resistance against rust diseases (Sharma et al. 2013). But unfortunately, in Uganda 1999, a new race rendered the *Sr31* gene susceptible (Pretorius et al. 2000). This new stem rust race was highly virulent. Uganda, Kenya, Ethiopia, Yemen, and some parts of Iran faced this epidemic (Singh et al. 2011a, b). Ug99 generation of the stem rust fungus has been through mutations and has increased its virulence allowing it to cross the resistance barrier and thus affect wheat crops worldwide posing a great threat to wheat production across the globe (Sharma et al. 2013; Kolmer 1996; Singh et al. 2011a, b).

3.4.3 Leaf Rust

The most common rust disease in wheat is leaf rust which is caused by a fungus, *Puccinia triticina* (Bolton et al. 2008). The specie is heteroecious, so it requires a uredinial/telial host and substitute aecial/pycnial host to complete its full life cycle. The uredinial host is most commonly wheat and the aecial host is *Isopyrum fumaroides* or *Thalictrum speciosissimum* (Singh et al. 2008a, b). Loss of wheat yield due to *P. triticina* infection usually results in low kernel weights and decreased kernel numbers per head (Samborski 1985; Goyeau et al. 2007). Currently the fungus is recognized as a very important pathogen globally, causing major yield losses over enormous geographical regions and areas (Basnet et al. 2014a, b). The taxonomy of *P. triticina* is summarized in Table 4. Globally, the main host of *P. triticina* is the common hexaploid *Triticum* spp. *P. triticina* also infects durum, *T. turgidum* ssp., *T. dicoccoides*, and *T. dicoccon* (Saari and Prescott 1985). A form of *P. triticina* has been found on diploid *A. speltoides* in Israel, which is not usually present on wheat. Infections of *P. triticina* have not been found in natural stands of wild races of wheat. However, these species can be infected when they are inoculated with *P. triticina*, which is pathogenic to normal wheat (Sears 1956).

Table 4 Taxonomy of *Puccinia triticina*

Kingdom	Fungi
Phylum	Basidiomycota
Class	Urediniomycetes
Order	Uredinales
Family	Pucciniaceae
Genus	Puccinia
Species	Triticina

Molecular Aspects of Pathogenicity of Leaf Rust

Research has still to be taken into consideration to find out more information about the molecular and biological studies of *P. triticina*. *P. triticina* cannot be cultured in vitro, and because of that there is a scarcity of molecular information (Mains and Jackson 1926). *P. triticina* has a large genome size, about 100–124 Mbp (Chen 2005). Transient expression and insertional mutagenesis were carried out on *Puccinia triticina* using biolistics (Webb et al. 2006) and transformed species were selected which change from avirulence to virulence (Kolmer and Liu 2000). Two mutants showed virulence in wheat carrying *Lr21* which encoded a calmodulin binding protein and a chitin synthase. The calmodulin-dependent signaling pathway shows important roles in virulence and the life cycle of the fungus. Disruption of the chitin synthase gene causes a decrease in fungus virulence (Kumar et al. 2014). Many research strategies have been used to study the transcriptome of *P. triticina*. An expressed sequence tag was developed that represented every stage of the life cycle of *P. triticina*. Thirteen cDNA libraries were made from urediniospores, germinating urediniospores, and the haustorial phase. More advances are being made to look more closely at the molecular pathogenecity of *P. triticina* (Hu et al. 2007).

4 Disease Control and Management

High-quality and disease-free seeds are planted to control a disease. To attain resistance, crops are grown in disease gardens where naive crops are exposed to different pathogens. The crops that grow normally in the disease location are picked and further tested. After approval and field testing, they are introduced in the market. More root-rot resistant spring wheat includes Apex, Thatcher, and Marquis whereas Kota, Kubanka, and McMurachy selections are moderately resistant (Pugsley 1971). Production fields should be inspected from head emergence level through harvest to check any possible contamination. Seed should be cleaned thoroughly to remove shriveled and lightweight kernels and should go through a germination test. Only seeds with 80 % or more germination capability should be introduced to fields (Chaves et al. 2013a, b). Pathogens with a higher evolutionary rate are prone to develop genetic resistance and are difficult to be fought by plants (McDonald and Linde 2002). It was studied by Bolley (1909) that fungal wheat diseases were caused if crop rotation is not practiced. Many pathogens survive in soil, on refuse of crops, and on wild grasses. So, crop rotation and summer fallow are necessary to avoid pathogenicity (Bolley 1909). Greenhouse and field tests show that deep digging and seeding increase pathogenicity and decrease the yield. Seeds should be adequately and properly planted in seed beds, ensuring soil moisture level and temperature. They should also be planted after Hessian fly safe date (time of pest arrival in area) to avoid possible seedling diseases. Certain fungicides are effective foliar diseases. Adding large amounts of specific antibiotic organisms or their extracts can greatly reduce/eliminate some soilborne diseases. Seedling bight of wheat and barley (*Helminthosporium*) can be decreased by applying antibiotic organism cultures at the time of plantation. S. D. Garrett recommended acid phosphates for *Pythium* infections as an unbalanced phosphorus nitrate relationship predisposes its attack to wheat. Most fungi live in an acidic habitat; pH can also be increased to avoid fungal development. Proper liming of soil can increase pH above 6.2, which prevents *Cephalosporium* stripe formation. Genetically modified wheat races can be introduced that are resistant to certain fungal and viral attacks (Bushnell 1972; Chen et al. 2013).

5 Conclusion and Future Prospects

Scientists have been trying for centuries to develop tolerance in wheat for all stresses. One method is to transfer genes for stress tolerance in plants that can convert a stress-susceptible plant into a tolerant one. Strategies of this system are explained in Fig. 2. No matter what strategy is adopted, the main and final goal is to get the highest yield as the world's population is increasing day by day and providence of food security is the primary issue of this era. In addition to a lot of research, there is still much to explore to get the best genotypes with more tolerable traits and higher yields. For biotic stresses, the current scenario is to obtain durable resistance that is based upon minor genes.

These wheat varieties have been a continuous feature in wheat improvement programs globally. Biotic stresses have kept researchers more concentrated in their efforts due to changing scenarios of pathogen virulence where fungal race shifts throw off variants that are a perpetual hazard and one can never become complacent with any promising variety under cultivation. Varietal resistance sooner or later gets overcome. Rusts are the most destructive with a dynamic nature. As said by Dr. N. E. Borlaug, "Rust never sleeps." Contrary to that, abiotic stresses are more under environmental control where long-lasting tolerant varieties can be obtained. Abiotic stresses therefore come under "static system." The progress made in yield enhancement, biotic and abiotic stress constraints control, and innovativeness will generate new efficient technologies that will allow optimism to reign and forecast a 2050 picture with high hopes to feed the global populace of 9.2 billion swiftly growing to 10 billion by 2055. As we are setting our sights towards the future 2050 vision, our optimism is high because new technologies have emerged on the working platforms

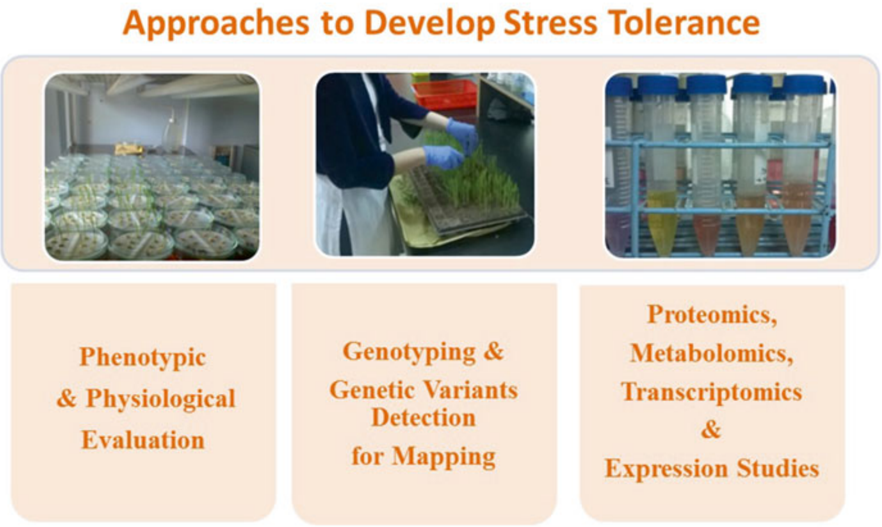

Fig. 2 Major approaches to develop stress-tolerant varieties

that will intensify output efficiency. Elucidations are the molecular sequencing developments that embrace *DArT* genotyping and also 9 K plus 90 K. These technologies shall set up class genotypic platforms and define global partnerships to target phenotypic aspects both working in tandem and in a holistic way.

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