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Heat and Drought Stresses in Wheat (*Triticum aestivum* L.): Substantial Yield Losses, Practical Achievements, Improvement Approaches, and Adaptive Mechanisms

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Abstract

The major wheat-producing countries have heterogeneous and fragile agro climatic surroundings but frequently restraining wheat yield and quality losses are predominant under heat and drought prone agriculture exclusively when both stresses occur in blend, which looms the food security globally. However, many suggested examples are available in these countries for the mitigation of these two stresses by using different conventional and modern improvement and agronomic approaches. In addition to these approaches, morphological, physiological, anatomical, biochemical, phenological, and physiochemical vicissitudes, which triggered during these stresses, have also been elucidated. There complete deliberation in combination for wheat improvement is still a contest, but a win-win option is a holistic attitude in future.

Keywords: heat, drought, yield losses, achievements, improvement, mechanisms, major countries, wheat

1. Introduction

The global inhabitants expansion proportions have been projected to upsurge and the domain people will grasp 8 billion by 2025 and strength be a slight greater than 9 billion by 2050 Hence, to encounter the ever-growing hassles of the population world sustenance fabrication desires to be doubled by the year 2050 [1].

The aftermath of a universal climate alteration has brought about the enlargement of extreme events. Among these events heat and drought are most multidimensional, vibrant, and shoddier stresses whose occurrences are unpredictable at

any stage affecting wheat productivity. Today, wheat is an essential staple food for more than 2 billion people and is grown on more terrestrial zone than any other marketable produce. The major wheat-producing countries have sundry and flimsy agro climatic circumstances, typologies, wheat production schemes and thereby having an erratic consequence of heat and drought stresses. To combat these resilient, formulations of short- and long-term strategies are dire need for these countries. Heat stress occur when air and soil temperature become beyond a threshold level while drought stress takes place when ambient air temperature is high, soil and atmospheric humidity is low.

This review intended at revealing some of the foremost features and some probable heat and drought tolerance pointers of wheat related to heat and drought robust, which are relevant for agronomic and genetic improvement in wheat. Nevertheless, general triumph of wheat management and improvement depends on the intensive exertions of molecular biologists, physiologists, and modelers in addition to agronomist, geneticist, and breeder since these improvements are incremental in nature due to compound genomes and polygenic traits in wheat.

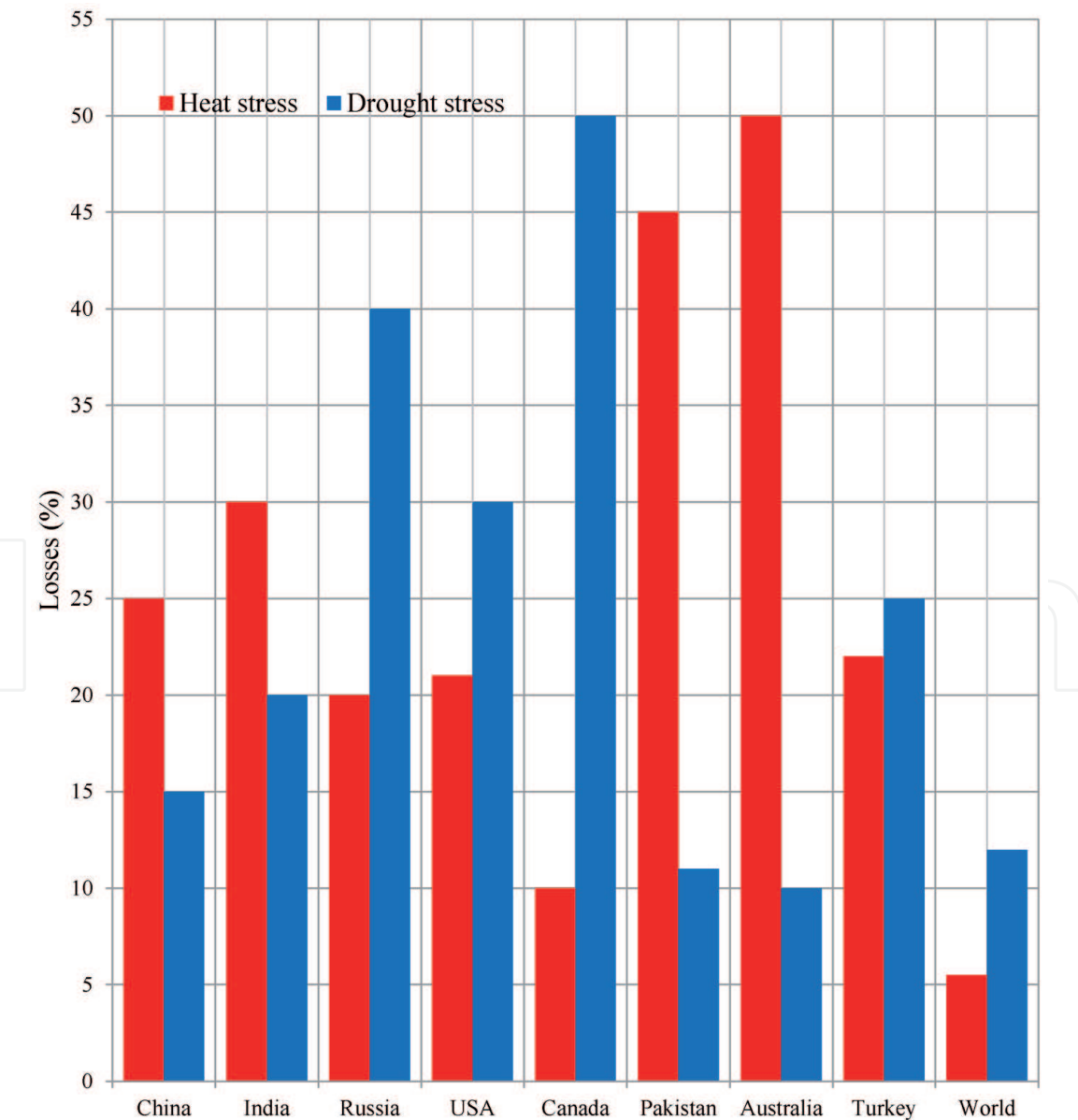


Figure 1.
Estimated yield losses (%) of foremost wheat-producing countries due to heat and drought stresses.

2. Substantial wheat yield losses

Wheat throughput is vanished predominant exclusively or jointly due to abiotic stresses primarily heat and drought with a large portion of potential in major wheat-producing nations and at the same time, globally. Mostly curtailing losses are prevalent due to sensitivity at reproductive phase under heat and drought prone agriculture, which threatens the food security worldwide. Therefore, this urges that these harms should be curtailed in major area of distress for all nations. Yield is an endpoint inclined by stressor therefore it is used as a yard stick for measuring these stresses. A middling appraisal of 50% yield losses in agricultural crops is caused by abiotic dynamics, heat in low latitude zones and drought stress common in most arid and semi-arid zones. Together heat and drought have persuasive effect in Mediterranean climate [2].

The internationally wheat losses due to heat and drought stresses encompasses, 5.5 and 12%, respectively. The actual losses however, varied substantially by region in the foremost wheat-producing countries viz; China [3], India [4], Russia [5], the USA [6], Canada [7], Pakistan [8], Australia [9], Turkey [10], and World [3] (**Figure 1**). The appearance of heat stress accredited to the extraordinary yield loss in Australia and Pakistan followed by India and China while stemming effect for Canada, Russia, USA, and Turkey are visible. Likewise, Canada, Russia, and USA extremely hit by drought followed by Turkey, India, and China while Pakistan and Australia remained at par. The frequency and magnitude of these losses may increase in future because the projections advocate that global temperatures may upsurge by 0.6–2.5°C by 2050 and 1.4–5.8°C by 2100 escort by increased severity of drought condition [11].

3. Practical achievements

Wheat yield increased under productive conditions, but in the regions where heat and drought condition prevail practical, achievements are less prolific due

Countries	Heat resistant	Drought resistant	References
China	Xifeng 9, Qingxuan 15, Changle 5, Bonong 7023, Zhangchun 9, Xinchun 2, Xinchun 3, and Changchun 2		[12–17]
	Gaoyou 9415, Hemai 13, Jimai 22, Kexin 9, Shannong 8355, Taishan 23, Yannong 5286, Zimai 7, and Nongda Heng	Keyi26, Nongda 36, Nongda 183, Shijiazhuang 407, Huabei 187, Taigu 49, Yulin3, Mazhamai, Xuzhou 14, Jinmai 33, Jinmai 2148, Hezuo 2, Hezuo 4, Hezuo 7, Minn 2761, Kefeng 2, Kefeng3, Gaoyuan 602, Xindong 7, Lunkan6, Lunkan 7, Lumai 14, Heimangchunmai, Datouchunmai, Xindong 2, Jinmai 33, Kehan 9, Xinkehan 9, Inmai 47, Shijiazhuang 8, Cang 6001, Cangmai 02, Cangmai 6005, JM-262, Xihan No. 2, Longchun 23, Luhan7, Luhan 2, and Yannong 19.	
India	CPAN 4079 and Nepal 38, Arnej, Ajanta, and Gomti		[4, 18–23]
	HD 4502 (Malvika), AKW 1071, Purna, Parnhani-51, K9644, Atal, K 7903 Halna, DDK 1029, Ventnor, HS-240, K-0-307, and Raj 3765	Shekhar, WH 1142, HD1467, Harshita, N59, and BRW 3723	
Russia	Dustlik, H-104, Sanzar-8, Sanzar4, Hasan-Orif, Bayaut1, Oasis, and Gul DU	Sarrubra, Sarrosa, Saratovskaya 29, Svetlana, Milturum, and Cesium	[24–26]

Countries	Heat resistant	Drought resistant	References
USA	Long Branch	Greer, Joe, Plains Gold Avery, SY Monument, Tatanka, WB-Grain field, TAM112, White Sonora LCS Chrome, LCS Mint, and T158	[27, 28]
Canada	Pelissier	Stettler, Lillian, AC Barrie, and Strongfield	[29–31]
Pakistan	Gold-16, Punjab-11, Fakhar-e-Bhakkar	Chakwal50, NARC 2009, Tijaban-10, Dharabi-11, NRL 2017, Pakistan-13, Pakistan-13, Shahkar-13 and NIFA-Lalma, Shahkar-13, NIFA-Lalma, Hashim-8, Ghanemat-2015, BARS-09, Tatara, AZRC-1, Siran-2007, Raj, Chakwal-87, Rawal-97, Pothwar-93, Kohsar-95, Chakwal-97, GA-2002, Ehsan-16, Barani-17, Fateh Jang-16	[6, 32–45]
Australia	Longsword		[46–51]
	Suntop, Spitfire, GBA Hunter, Livingstone and EGA Gregory	1:ZIZ12, 12:ZIZ12, 56:ZIZ12, 134:ZWB12, Allora Spring, Farmer’s Friend, King’s Jubilee, Steinwedel, Kord CL Plus, drysdale, Wyalkatchem, and Estoc	
Turkey	Bayraktar 2000	Karahan-99, Gerek-79 and Alka quality, Saricanak-98, Altay-2000, Dagdas-94, Katea-1, and Kirac-66	[52–54]

Table 1.
Development of few heat- and drought-resistant wheat varieties by foremost wheat-producing countries.

to tired inconsistency, large genomic decoration with multigenic trait, and multifaceted environmental dealings to these hassles. Even then, in the global milieu, copious efforts to mitigate heat and drought through breeding wheat-resilient varieties are under way and much remarkable advancement has been reported. The most sustainable, encouraging, economically effective, and communally adequate approach is the developing of wheat varieties with in-built heat and drought tolerance. To alleviate these two stresses, the **Table 1** demonstrates most evoked examples of the triumph stories in chief wheat-producing countries.

4. Improvement strategies

4.1 Conventional breeding

Conventional breeding approaches have been tremendously effectual in the development of heat and drought tolerant wheat cultivars on the globe. Conventional plant breeding typically trusts upon fortuitous by hybridization, the succeeding phenotypically selection for loftier desirable traits using Mendelian and quantitative genetics approaches in filial generations and final multi-locational trials valuation. The nitty-gritties of wheat improvement by conventional approaches for these two stresses rely on the varied scale usage of biodiversity, which include wild relatives, landraces, exotic material, advanced lines, isogenic lines, mapping population, and cytogenetic stocks. Among all sources, wild relative and landrace of wheat are potentially most significance for traits of stress adoptive due to the accretion of genes for tolerance to stresses. Therefore, this narrow wheat genetic diversity for higher tolerance to heat and drought stresses can be boost by the use of wild relatives and local land races. Among wild relatives, *Aegilops squarrosa* is

more heat, while *Aegilops tauschii* and *Triticum dicoccoides* are more drought tolerant. Conventional plant breeding has had discriminatory conquest in dying both stresses instantaneously, which may be due to the hurdle linked with traits stressed by polygenic inheritance, masking effect, and environmental interaction. As a magnitude of these confines of conventional breeding, additional genetic advances for developing tolerance against given wheat resilient are becoming progressively problematic (Figure 2).

4.2 Mutation breeding

Mutation breeding does not stance any moral matters regarding human health and sustainability as it become an customary tool in improvement of genepool have momentous impression. In nature, variation occurs chiefly as a consequence of mutations; that is swwhy mutation-based breeding increases desirable variability,

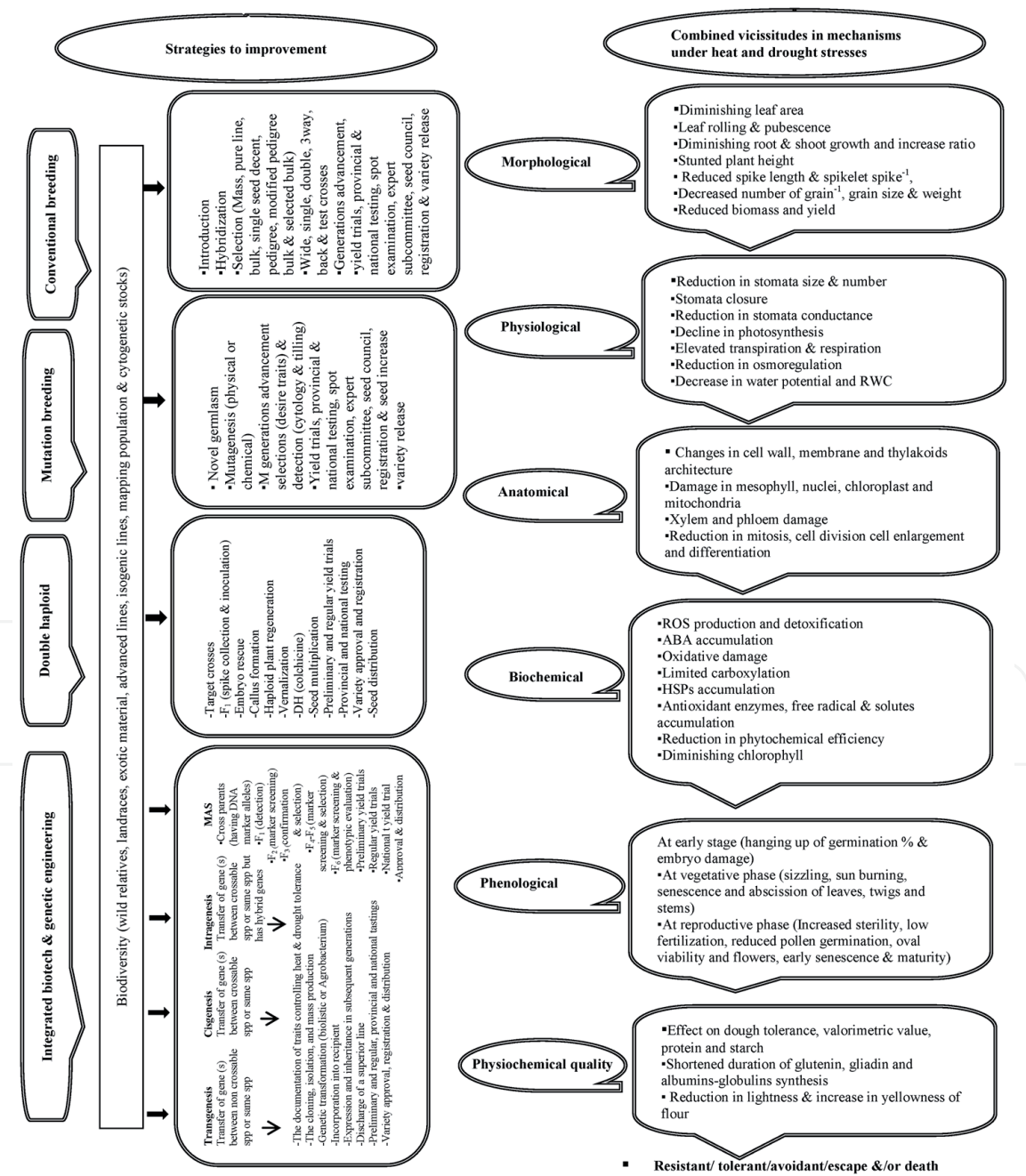


Figure 2.
Combined changes in mechanisms and improvement strategies under heat and drought stresses.

which is not found in nature especially with the help of various physical (X rays, gamma rays, UV light, proton, neutron, alpha and beta particles) and chemical mutagens (alkylating agents, nitrous acid, acridine, base analogue, azide, and antibiotics). By the use of mutation breeding, 254 superior bread wheat varieties including abiotic stress tolerant (26 resistant to drought) have been released globally. Three significant economic impact wheat varieties (Jauhar-78, Soghat-90 and Kiran-95) released through induced mutagenesis in Pakistan [55]. Al-Naggar and Shehab-El-Deen [56] endeavored to induce (gamma rays and EMS) drought-tolerant mutants in six Egyptian bread wheat varieties. These mutants surpassed 20% grain yield over parents under drought condition. Laghari et al. [57] developed and gaged two wheat mutants capable of earlier maturity and higher grain yield than the checks. The mutation wheat varieties (Kievsky and Novosibirskaya 67) were characterized by upright productivity and resistant to lodging in Ukraine [58]. This exhilarated further work on mutation breeding, leading to the release of mutant wheat cultivars expressly the traits linked to heat and drought tolerance. Mutant byzantine screening, difficulty in regulatory the direction and nature of variation, low beneficial mutant occurrence and mutagenic efficacy, mutation breeding approaches have curb and are facing challenges. Owing to this bottleneck, induced mutations have also evidenced valuable in the preparation of genetic maps that will ease molecular marker-assisted plant breeding for developing heat- and drought-tolerant wheat varieties in the upcoming.

4.3 Double haploid

Double haploid counterpart the conventional breeding programs to hasten the release of new varieties tolerant to heat and drought stresses by rapid generation advancement. Therefore, double haploid approach should be unified with convention approaches perceptively for food security. From heterozygous individual haploids are made and converted to diploid, which create instant homozygous lines, which evade fertility obstacles inherent to wide crosses as it is genotypes sovereign. For heat and drought tolerance improvement double haploid have been broadly used to judge allelic variation as it deliver great level of polymorphism by using limited quantity of tested lines through molecular mapping as targets for transformations. Two drought-resistant wheat varieties (Jinghua 1 and Jinghua 764) in China, one in France (Florin), one in Hungary (Gk Delibab), one in Morocco (Malika) were developed and released with the help of doubled haploid technique [30, 59–61]. Moreover, double haploid genotypes (DH1 and 2) under drought and (DH132 and 133) under heat and (DH136, 210, 236, 248, 257 and 263) under both conditions found superior than checks in Egypt, Iran, and USA respectively [62–64]. The high production cost, know-how, restriction on number of crosses and low haploid generation facilities restricted the use of double haploid.

4.4 Integrated genetic engineering and biotechnology approaches

Additional consideration need to be paid now to develop high-yielding wheat varieties by integrated genetic engineering and biotechnology approaches under heat and drought stresses. This will open new opportunities for enhancing existence of narrow genetic base and help for understanding the genetic mechanisms for theses stresses. But this requires the identification of key tolerance genetic determinants underlying these two stresses and introducing into wheat. This introduction includes transgenesis, which holds artificial regulatory order, sexually incompatibility with no barrier but may be safe while cisgenesis and intragenesis are sexually compatibility, contain natural regulatory order and new combination of regulatory

order (hybrid genes), respectively with barrier but are safe. Due to large wheat genome size (17,000 Mb) the complete sequencing is challenging. However, there are few examples for introduction of several stress-inducible genes into wheat, which increased tolerance to heat and drought stresses but due risk of other undesirable traits transfer and reproductive barrier, strategy for tolerance is not much successful yet. Khurana et al. [65] identified and characterized large number of high temperature-responsive genes aiming to functionally validate them in wheat transgenic. Zang et al. [66] identified heat stress-responsive gene (TaPEPKR2), transformed into another wheat cultivar, observed that the transgenic lines exhibited enhanced heat and drought stresses tolerance and suggested that it could be utilized as a candidate gene in transgenic breeding. Karolina et al. [67] analyzed wheat gene (P5CS and P5CR) expression in response to drought stress and found that they have a significant function in controlling tolerance to water deficits. Hua et al. [68] identified target genes in response to drought stress in wheat (*Triticum aestivum* L.) and suggested that these could be exploited via genetic engineering to improve drought tolerance in wheat. Overexpressing of TaNAC69, HVA1, CAT TaDREB2, and TaDREB3 genes the transgenic wheat produced more shoot biomass, yield, and improved water use efficiency drought conditions, which suggested that these have potential for wheat engineering for drought tolerance [69].

Concerning quality, [70] recognized 26 genes to gauge their function and transcript levels for starch synthesis in wheat. Rooke et al. [71] produced and then confirm wheat transgenicline (B73-6-1), which holds additional genes (Glu-1D-1) for high-molecular weight gluten sub units (HMW-GS). Similarly, [72] investigate interactive effects between the transgenically wheat line (B102-1-2/1) with HMW-GS and suggested that by using transgenic wheat lines expressing HMW-GS can improve dough properties. Parallel interpretations are described in transgenic wheat lines (B72-8-11b and B102-1-2) for HMW-Gs by [73]. Ashraf et al. [74] transforms and detects HMW-gene (Dy10) in Egyptian wheat and scrutinized that transgenic grain own higher levels of glutenin compared to control. Alvarez et al. [75] transformed the HMW-GS genes (1Ax1 and 1Dx5) into wheat and revealed that overexpression of 1Dx5 gene upsurges overall protein content.

Genomic assistance breeding (GAB) established on the application of marker assistance selection, which discriminate genetically sundry phenotypes elucidated by the markers were scrutinized. The wheat breeding understanding for abiotic stress tolerance is restricted due to their complex inheritance and wide range of environmental interaction with respect to rate, intensity, timing, duration, and increased genetic gain at early phenological phases of wheat. This issue bounds all conventional breeding efforts. In this situation genomic assistance breeding is very prompt, cost effective, and accurate in harsh unpredictable and unapproachable environmental situation in which individual targeted wheat plants can be selected on phenotypic basis. Furthermore, genomic approaches are welcome for condemnation from social sectors hesitant to the use of transgenic breeding expressly on wheat crop. In amalgamation with the conventional breeding, this unlocked up tangible forecasts for new schemes in wheat breeding for injurious stress tolerance as it bounce greater genetic reply for QTL inveterate in multi-environments because it resulted in the development of next generation sequencing methods. A wide range of population structures can be used for QTL mapping, backcrossing, recombinant inbred, double haploid and F₂ selfing or heterozygous inter crossing of major genes is repeatedly used to lessen the association around the target gene and to recuperate the recurrent parent by using less number of filial generations. Similarly recombinant inbred lines and double haploid, which can be sustained and produced permanently have been extensively used to judge allelic variation as it provide high level of polymorphism by using limited number of tested lines through molecular

Source	QTLs	Markers with co-localization	Ref	Source	QTLs	Markers with co-localization	Ref
Heat stress							
F ₂ population from PBW743/WH1081 under terminal heat stress	Membrane thermostability	Xgwm156-3B	[76]	251 recombinant inbred lines from (heat-tolerant/susceptible) HD2808/HUW510	Heat susceptibility index	gwm122-2A	[63]
F ₁ -F ₂ population from (heat-tolerant/sensitive) Debra/Yecora Rojo	Grain filling rate	Xgwm132-6A Xgwm577-6B Xgwm617-D	[77]	111 recombinant inbred lines from (heat-tolerant/susceptible) WH 730/Raj 4014	Grain filling rate	Xgwm314-6B	[78]
F ₁ -F ₃ population from (heat-tolerant/susceptible) ventnor/Karl 92	Grain filling duration	gwm11-5A gwm 293-1B	[79]	143 recombinant inbred lines from Kauz/MTRWA116	Heat stress susceptibility index	gwm190-1B gwm133-5B gwm63-7B	[80]
BC ₁ F ₂ population from (heat-tolerant/susceptible) HD2733/WH730 and HD2733/HI150	Canopy temperature	barc68-5A	[81]	106 recombinant inbred lines from NW1014/HUW468	Grain weight heat environment	Xgwm972-7D1	[82]
Bi-parental F ₂ population	Stay green under prolong heat	Xgwm533-3B3	[83]	121 recombinant inbred lines from (heat-tolerant/susceptible) Halberd/Karl92	Canopy temperature depression	barc84-3B gwm154-5A gwm179-5A1	[84]
205 F ₂ population from (heat-sensitive/tolerant) YecoraRojo/Ksu106	Grain filling rate under heat stress	wmc326-3B wmc25-2A wmc327-5A	[85]	148 recombinant inbred lines from NW1014/HUW468	Canopy temperature depression	Xgwm1025-7BL	[86]
144 doubled haploid wheat populations bare to heat hassle	Chlorophyll loss and shoot weight reduction due to heat treatment	Xgwm1034-3B Xbarc75-6B	[87]	Genetic population (heat-tolerant accession) derived from Karl 92	Plasma and thylakoid membrane damage	Xbarc113-6A Xbarc121-7A Xbarc49-1D	[23]
RAC875/Kukri doubled haploid population	Canopy temperature	barc0075-3B1	[88]	25 wheat genotypes exposed to heat stress	Kernel weight and grain filling duration	gwm11-5A gwm293-1B	[89]

Source	QTLs	Markers with co-localization	Ref	Source	QTLs	Markers with co-localization	Ref
Drought stress							
F ₃ and F ₄ population derived from drought-tolerant (Oste-Gata) and sensitive (Massara-1) populations	Thousand grain weight	Xgwm408-2B	[90]	127 recombinant lines from (drought-tolerant/sensitive) DharwarDry/Sitta	Grain yield	Xwmc420-4AL	[91]
Two F ₈₋₉ recombinant inbred lines population from (resistant/susceptible) Luohan 2/Weimai 8 and annong19/Weimai 8	Seedling traits under drought	Xmag3356-5D Xbarc158-3B	[17]	167 recombinant inbred lines plus parents derived from (drought-tolerant) Seri/Babax	Canopy temperature under water deficit	gwm388-1B	[92]
Near isogenic lines from (tolerant/susceptible) C306/Dharwar Dry	Grain yield under post anthesis drought	gwm368-4B	[93]	118 recombinant inbred lines from Tabassi/Taifun	Yield under drought stress	Xgwm194-7B	[94]
A panel of 100 lines	Root traits under drought	Xwmc175-2B	[95]	154 accessions development under irrigated and drought-stressed conditions	Plant height	Xgwm495-4B	[96]

Table 2.
Identified QTLs for different traits with lined markers under heat and drought stress environments in wheat.

Water conservation techniques	Residual and nutrients management	Planting time	Biological control	Chemical control	Adaptation mechanism
<ul style="list-style-type: none">• Improve water harvesting techniques• Minimum tillage• Laser leveling• Weed management• Raised bed planting• Seed priming	<ul style="list-style-type: none">• Residue retention alone or in combination with nitrogen and phosphors fertilizers• Straw mulching• Balanced use of nutrients at proper time and stage	<ul style="list-style-type: none">• Early sowing or as soon as adequate rainfall/moisture available or plant early maturing cultivars	<ul style="list-style-type: none">• Inoculation of arbuscular mycorrhizal fungi• Ameliorating plant growth and development	<ul style="list-style-type: none">• Exogenous application of hormones, antioxidant enzymes, biochemical solutes, and osmoprotectants to seed or growing wheat	<ul style="list-style-type: none">• Wheat crop modeling• Meteorological decision support schemes

Table 3.
Agronomy management for heat and drought mitigation.

mapping for heat and drought tolerance improvement. MAS for target traits relied on finding markers linked to quantitative traits loci (QTL). A large number of quantitative trait loci (QTLs) mapping studies have been magnificently applied as a tool for genetic analysis for wheat under heat and drought tolerance. These abolish perplexing effects of the environment throughout selection, permits for unintended selection of traits governing these buoyant and provide footprints of domestication construction on early victories.

Although numerous reports are obtainable for the use of association mapping approaches to categorize the QTLs, linked markers associated with co-localization in wheat for heat (heat stability index, canopy temperature, membrane thermostability, stay green, grain filling duration etc.) and drought (relative water contents, stomatal conductance, grain weight etc.) yet their prosperous placement in the development of superior cultivar has had only limited success (**Table 2**). As the efficiency of MAS is effected by population size with broader genetic base, loci numbers, complexity of traits, and selection approaches, the breeder must evaluate before applying it especially for quantitative traits regarding resilient stressors under single environment because it analyzed one trait and less efficient to determine the effect of each QTL. Therefore, there is an immense need to develop more effective markers associated with the agronomic traits under these stresses for MAS.

4.5 Agronomic approaches

Promotion of agronomic practices can increased wheat productivity and farm income by sustaining and/or defending the production system against heat and drought resilient along with genetic approaches joined with breeding procedures. To overcome the hostile effect of climate change the notion of climate smart agriculture has been anticipated, which embraces many of the agronomic practices based on sustainable crop production and field management. Some of the winning agronomic approaches that alleviate heat and drought in wheat have been presented in **Table 3**.

Among these, water conservation techniques increase water use efficiency and time saving; residual and nutrients management; moderates soil temperature, reduces evaporation losses, reduce pollution by reducing greenhouse gases and CH₄ and N₂O emission; chemical and biological control protect the wheat from damage that resulted due to high temperature and drought stress; pick up of least perilous growing period; adaptation mechanisms are effective for right time by operational management by translating weather information.

5. Adaptive mechanisms

The heat and drought stresses in wheat crop triggers a wide variety of responses, which cause morphological, physiological, anatomical, biochemical, phenological, and physiochemical vicissitudes changes individually or in combination due to direct or indirect injury that leads to significant loss in yield potential. General elucidation of the all discussed mechanisms by wheat reply to heat and drought are deliberated, but there complete consideration in combination for wheat improvement is still a contest.

5.1 Morphological vicissitudes

Under heat and drought stresses most morphological traits (leaf size, plant height, grain size and weight, root length, shoot length, root shoot length ratio,, number of tiller plant⁻¹, spike length, spikelet spike⁻¹ and biomass) show decreasing

trends. The first and prime effect harshly diminish sprouting and seedling. After seedling emerged, cell division, cell enlargement, and differentiation are badly affected due to these stresses, which afterward affect the leaf size and plant height. The retrieval does not take place at the advanced periods but may take place at initial phase of both stresses. Remarkably, the decline in leaf size can oblige as heat and drought avoidance mechanism because it abridged transpiration.

Under serious water shortage, cell elongation is subdued by interruption of water drift from the xylem to the development cells resulted in reduced growth due to decrease in mitosis course. This reduction leads to thwart the development of flower production, grain development, and filling due to a attenuation in the activities of sucrose and starch synthesis enzymes.

Core cause of grain size and weight is the expansion of maternal cells throughout the grain filling phase, which is major parameter upsetting grain size and weight and it rest on the ear and flag leaf and stem reserves as they deliver the pivotal element (carbon). Heat and drought stresses, causes the reduction of spike length, spikelet spike⁻¹ and biomass and positively correlated with each other and also with grain yield. Jaiswal et al. and Hafiz et al. [97, 98] observed a reducing drift in root length ranged from 7.2 to 23.0 cm (normal) and from 5.3 to 17.7 cm (drought) and shoot length from 13.2 to 29.2 cm (normal) and from 11.0 to 25.2 cm (drought) while the root/shoot length ratio ranged from 0.27 to 0.94 (normal) and from 0.29 to 0.92 (drought) among all tested genotypes. Hasan et al. [99] observed root and shoot length under different temperature regimes, the lowest values (2.8 and 1.14 cm) was attained at 15°C, optimum (11.5 and 9.03 cm) at 25°C and thereafter decreased trend (6.41 and 7.53 cm) at 35°C, respectively in all tested wheat genotypes. The increase in temperature, the shoot-to-root ratio was also increased because the adverse effect of higher temperature (35°C) on root length was more than that on shoot length.

5.2 Physiological vicissitudes

Normalized vegetation index (NDVI) and canopy temperature (CT) are good physiological pointer of a genotype's suitability against heat and drought stress environment and these traits may be used as morphological selection tools for developing heat and drought stress-tolerant genotypes. For appraisal of physiological diversity in wheat genotypes under heat and drought environments, [100] revealed the positive correlation of yield with NDVI at booting and anthesis and negative correlation with CT at same stages. A positive association of NDVI advocated the existence of stay-green while negative array of CT at both stages supported cooler canopies genotypes. Likewise, [101] clarified same results for these physiological traits while working on wheat local land races for consecutive 3 years as genetic resources for yield potential and heat tolerance.

Under heat and drought stress conditions, wheat plants improve canopy temperature by closing their stomata swiftly, which resulted in reduced transpiration and water loss. This reduction in stomatal opening causes low amount of CO₂ fixation that lead to reduction in photosynthesis and ultimately chlorophyll content. This reduction resulted due to structural and then adjacent changes in chloroplasts, which ultimately disrupt chlorophyll synthesis and photosynthesis. As compared to 100% control, heat, drought, and combine stress reduces photosynthesis rate by 19, 11, and 79%. Relative water content, membrane stability, and osmotic potential are maintained by osmoregulation physiological mechanism, which losses their viability under both stresses. As an indicator of water status, relative water content is the meaningful determinant of heat and drought tolerance because it signifying the membrane stability and balance between water supply and evapotranspiration. The relative water content was reduced by 55, 26, and 61% under drought, heat, and

combined stress, respectively. Membrane stability index was affected most by combination of drought and heat stress (60%) than by heat stress (55%) and finally by drought stress (43%). Transpiration rate under high temperature stress compared to control slightly increased. However, drought stress decreased transpiration rate while under combine effect the reduction rate is 60–63% [102, 103]. Photosynthesis is also extremely sensitive under heat and drought prone conditions as the reduction in the ratio and quantity of chlorophyll (a and b) and carotenoid occurred upon increasing intensity of heat and drought.

5.3 Anatomical vicissitudes

Anatomical changes like reduced leaf anatomy, cell size, damage in mesophyll, cell membrane stability, plasma membrane permeability, chloroplast, nuclei, changes in xylem and phloem are vital reflection under both stresses. Cell membrane stability shields the plant from ROS that causes significantly decrease in membrane stability under both stresses. Tolerant and susceptible genotypes retain more than 70% and less than 50%, cell membrane stability values, correspondingly. Leaf anatomy under heat stress causes development of higher leaf area with thinner leaves while leaves that develop under drought generally have smaller cells with higher stomatal density. Under heat stress chloroplasts become round and stretched from ellipse-shaped with destroyed wrappers and fully developed grana lamella become loosely organized with abundant layer on it. The appearance of more osmophilic particles occurred, thylakoids also become inflated and resultantly chloroplasts swelled to altered extents and some of their external membranes vanished entirely at advanced periods of pressure. While in the drought stress there was decrease in the number of granal thylakoids of chloroplasts. No starch granules in chloroplast stroma were found under combine stress. Concerning mitochondria, a few multi vesicular body's lipids are formed due to appearance of spoiled double membranes mitochondria, which signposted the process of mitochondria degradation. These discrete membrane variations also befell in nuclei, representing augmented senescence process under heat stress. Under drought, leaf mitochondria were less preserved than normal conditions. But in combine stresses large size mitochondria, devoid of cristae and similar to vacuoles were observed than individual stress.

5.4 Biochemical vicissitudes

Biochemical traits are another important constituent for developing heat-and drought-tolerant genotypes with higher yield and disease resistant. But the mechanisms of these mutually stresses on a biochemical basis is not relatively well-understood, research on this voyage in wheat is desirable in future. Temperature stress causes membrane injury to wheat due to of reactive oxygen species (ROS). To cope with ROS under heat stress, wheat plant own sequence of detoxification systems to limit oxidative damage by breaking toxic with the help of antioxidant enzymes (peroxidase, superoxide dismutase, catalase, and glutathione reductase), metabolites (glutathione, carotenoids, and ascorbic acid), and biochemical solutes (proline, glycine betaine, salicylic acid, starch, potassium, and abscisic acid). The buildup of these shields the damage caused by oxidative stress. Moaed et al. [104] estimated antioxidant enzymes and metabolites at three stages of wheat. The varieties that showed significant increase in the activity of these during vegetative and anthesis phase (in the late and very late planting) showed minimum reduction in membrane injury index. Likewise under heat and drought stresses, superoxide dismutase, peroxidase enzymes protect the cellular systems of plants from cytotoxic effects of the active oxygen species. A significant increase effect of superoxide

dismutase (12–52% and 28%) and peroxidase (40–44% and 21%) enzymes was renowned under heat and drought stresses, respectively [105, 106]. Likewise, biochemical solutes are accumulated that gives advantage to wheat plant against under heat and drought stresses. Among all, proline, glycine betaine, and salicylic acid are key biochemicals that are significantly accumulated in plants including wheat when exposed to heat and drought. The higher accumulation of three forages reactive oxygen species conveys strong antioxidant defense system, increased relative water content, reduces the rate of transpiration and membrane injury. That is why, to reduce the effect of heat and drought stress, exogenous application of glycine betaine and salicylic acid has been found [107]. Amarsheerwar and Berad [108] revealed that biochemical and yield traits of wheat were significantly influenced by heat stress with regard to values of increase in proline contents and decrease in starch contents albumins, globulins, and yield contributing traits. ABA is a naturally occurring compound that helps to regulate plant growth and development. The ABA level increased during heat and especially drought stresses and is therefore an essential arbitrator as it refunded the plant to pre stress condition. Quarrie and Jones [109] exogenously applied ABA to investigate its effects on the changing penalties of water under stress and found that ABA application decreased the mean cell size, increased the production of trichomes, and reduced the number of stomata. These changes reduce the transpiration rate and ultimately bound the water losses. Likewise under heat stress, little is known about ABA accumulation in wheat regardless of the fact that its level is increased however, enhanced levels of ABA in leaves increased leaf resistance under high (38°C) air temperature, which play an important role in thermo-tolerance. Zhao et al. [110] six heat-induced MYB genes in wheat and studies their gene regulation by exogenous abscisic acid under heat stress scenario. By heat stress (40°C), the expression of the two MYB out of six was not vividly up delimited by application of exogenous ABA levels.

In addition, internal and external signals were the chief basis of transit surge in the calcium concentrations inside the cytosol in supporting the normal level of Ca^{2+} under heat stress. This sustainability resulted in transduction of heat shocks proteins (calmodulin, calcineurin, and annexin), which induces the thermos tolerance defensive ability in wheat. A total of 39 heat shock proteins and 33 drought stress-responsive proteins are identified in different wheat cultivars, which trigger, maintain, and recover stresses [111]. The heat shock proteins are further classified in to five groups (Hsp100, Hsp90, Hsp70, Hsp60, and small Hsps) on the bases of their molecular masses. Late embryogenesis abundant protein represent a wide range adaptation to water deficit involved in desiccation tolerance and slow down the rate of water losses under drought condition These are accumulated at later stages and are classified in to seven groups on the basis of specific domain. Transgenic approaches showed that over expression of these proteins improve abiotic stresses especially drought in wheat. However, their exact and precise molecular function is not clear yet.

5.5 Phenological vicissitudes

To stirring heat and drought stresses multi-modeling collaborative phenological approaches were experienced. The acquaintance of the duration, timing, and sequence of growing changes in wheat is vital for effective management else it has generous errors. Many models can predict phenology accurately built on the main driver of temperature and/or directly spoke these retorts to drought and appropriate photoperiod. Under heat and drought conditions, phenological vicissitudes are utmost significant attribute intricate in adaptation and final yield because these stresses effects are apparent at all development stages of wheat. Wheat threshold temperature at germination (10–30°C), vegetative, reproductive (15°C), and post anthesis (35°C) phases cause

irrevocable hurt to plant growth and development. During the first week of growth, under heat stress (45°C), hang-up of germination leads to cell death and embryo damage. At vegetative phase sizzling, sun-burning, senescence and abscission of leaves, twigs, stems, stunted plant height and less tillers and finally reduced biomass results. During reproductive phase of terminal heat stress intense discount occur in fertilization efficiency due to pollen grains damage, reduced number and weight of grains spike⁻¹ due to less anthesis, reduces the grain filling period and early maturity which finally resulted in reduced harvest index [112]. Akbar et al. [5] found cutback in grain yield from 7.7 to 15.7% for every 1°C ascend in mean air temperature during booting to maturity phasic development. Similarly under drought stress condition, water-use efficiency increased at early stage of stress. At vegetative stage causes multiple effects are visible such as stomatal closure, reduced swelling, loss of leaves, reduction in tillering and sheath and prevention of some tillers from producing spikes. At reproductive phase, flowering occurs starting in the apical part of the spike chiefly on the main stem and decline in transpiration due to relative evapotranspiration deficit and the period of maturation eventually resulted in reduced number, weight of grains spike⁻¹ and yield. Oviedo et al. [113] estimated the grain production was reduced 23, 42, and 9% at water stress tillering, booting, and grain filling phenological stages.

The correlation of growing degree days with the phenology of wheat plant is a best climate impact indicator. High temperature attached with increase magnitude dry spell causes sweeping changes on wheat phenology reliant upon stage, time, duration, and rate of stresses occurrence. Heat shocks and early monsoon shifted the wheat sowing as compared to past scenario. For instances, under both heat and drought shortening the length of vegetative and reproductive phases allow the crop to escape the stresses. Therefore, early flowering, long grain filling period and late maturity period should be taking into account while selecting under these stresses on phenological bases.

5.6 Physiochemical quality vicissitudes

Heat and drought are determinant factors on wheat end-use quality. Under amplified temperature protein quantity, which persisted high due to intensity of essential amino acids, sedimentation index, and condense effect. Dough strength however is reduced due to early maturity, which resulted in shortened duration of glutenin synthesis [114]. Similarly, under drought condition, valorimetric value, protein, and starch are negatively affected, which ultimately effect dough properties for bread making [115]. Balla et al. [116] found that both drought and heat in combination or drought alone have a much greater influence on a better protein ratio than heat alone. In case of drought alone a noteworthy negative correlation was pragmatic between granule sizes of starch and relative protein content telltale that this parameter contributes significantly for the baking quality of the flour because heat stress can reduce grain set and combined with abscisic acid build up can increase the response compared to just one stress. All this suggest that effects of heat and drought stresses are beneficial for some quality traits like ash and protein but on the outlay of seed yield because quality and quantity have inversely proportional with each other. Therefore, evaluation, selection, and development under these three environments should be done with average good quality traits to meet end user requirement. Among protein components (glutenin, gliadin, and albumins-globulins), albumins-globulins have only a trivial impact on the dough quality but glutenin and gliadin are responsible for the flexibility and extensibility of the dough. They reported reduction in the glutenin and gliadin proportion of the flour while the ratio of albumins and globulins did not increase proportionately in response to heat, drought, and in combination after anthesis.

6. Conclusions

1. The best step forward and future predominant ultimate approaches are imperative to develop new wheat varieties for more tolerant against these two robust episodes. The identification, characterization, and screening of broad based genetic resources through conventional breeding along with the use of modern genetics protocols and agronomic management will pave the way for efficient and accurate screening at each phenological stage of wheat. Controlling patterns for accountabilities of risk management and valuation must be framed regarding transgenic wheat development for these two stress factors.
2. Crop modeling system testing (in natural and artificial buoyant environments) for susceptible zones are still a big room for understanding the genetic and environmental interactions and improvement of all the mechanisms which bloom in these syndromes.
3. Heat and drought are major drivers of climate variability, can last much longer than other weather events and cannot be detect easily especially in combination. For understanding their vigilance, a reliable decision-support system and forecasting should be used.
4. For exploiting reliability and genetic stability for wheat yield both stresses should be contemplated together for traits having the main influence on yield. Therefore, a win-win possibility is a holistic attitude in future. In more prone areas however, if the problem does not resolve, relocating to new areas and growing different crops are the alternative range of options.

Acknowledgement

The authors gratefully acknowledge financial support from textbook and academic association and harvest plus international.

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