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RESEARCH ARTICLE

GENOMIC ADVANCEMENT OF WHEAT FOR CLIMATE-SMART AND DROUGHT-RESISTANCE VARIETY: A REVIEW

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Abstract

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Global wheat production and productivity are facing threats due to recurring droughts caused by climate change. To combat these challenges, it is important to develop drought-tolerant wheat cultivars that can withstand drought and heat stress in marginal production environments. This can be achieved by exploring wheat crops' inherent genetic variations and environmental adaptations. Understanding the various mechanisms such as genetics, physiology, biochemistry, and environment and their interactions is crucial in improving drought tolerance in wheat. This paper will summarize the genetic gains and future perspectives in breeding drought-tolerant wheat. This information will serve as a valuable resource for wheat breeders and agronomists to guide the developing and deploying high-performing, drought-adapted wheat varieties.

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Introduction:-

Wheat *(Triticumaestivum L.)* is the most important cereal crop, providing food for billions of people. In 2017 the global annual production of wheat was 757 million metric tons. The inheritance of drought resistance in wheat is a complex process that is influenced by multiple genetic and environmental factors. This decreases the heritability of drought-resistance traits[3]. Drought resistance traits can also be controlled by quantitative trait loci (QTLs), which are regions of the genome that control the expression of multiple genes involved in a particular trait. To identify QTLs for drought tolerance in wheat, researchers often use mapping populations, such as doubled haploid lines or F2 populations, to perform genome-wide association studies. In these studies, the genomes of individuals from the mapping population are genotyped, and the phenotypic data (such as plant survival, growth, and yield) is collected under different levels of drought stress[4]. One of the main areas of focus in this field has been identifying candidate genes associated with drought tolerance. This has been accomplished through a variety of methods, including genome-wide association studies (GWAS), transcriptomics, and functional genomics. These studies have revealed a complex genetic network that regulates drought tolerance in wheat, with many different genes and pathways involved [5]. Agriculture and climate change are closely linked and significantly impact each other. Climate change is causing biotic and abiotic stresses that negatively affect agriculture, resulting in fluctuations in annual rainfall, temperature, pests, CO2 levels, and sea levels. These changes are causing a threat to food security and ecosystem resilience, and climate-smart agriculture is the only way to reduce the impact [6]. The authors of this review paper provide a summary of climate change's causes and effects on crops and agriculture, as well as contemporary breeding techniques and biotechnological approaches to cultivating crops that can withstand climate change. The

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difficulty of developing drought-tolerant wheat crops, which is required to meet the growing global demand for wheat products, was also the subject of discussion.

Impact of climate change on wheat production

Wheat production is being negatively impacted by climate change, with several studies indicating potential yield losses due to rising temperatures, and shifts in precipitation patterns. Climate change is expected to have a significant negative impact on wheat production. Crop yields, grain quality, pest and disease pressure, and precipitation patterns can all be impacted by rising temperatures [8]. Furthermore, extreme weather events like droughts and floods can have a negative impact on wheat production [9]. One study, published in the journal Nature Climate Change in 2014, discovered that every 1°C increase in temperature above the optimal growing temperature reduced global wheat yields by 6% [10].Another study, published in the journal Nature in 2018, discovered that due to rising temperatures and changes in precipitation patterns, the area suitable for wheat production could shrink by up to 30% by 2100 [11]. A 2020 study published in Nature Climate Change found that temperature increases and changes in rainfall could reduce wheat yields by up to 30% in India, Bangladesh, and Pakistan by 2050 [12].

Impact of Drought Stress on Wheat Production

Wheat production can be significantly reduced by drought stress. It has the potential to reduce crop growth, grain filling, and yield. Drought stress can also make crops more susceptible to disease and pests [15]. Drought stress during the grain-filling stage of wheat growth can reduce grain weight and number, resulting in lower yields. Drought stress during the vegetative stage can reduce biomass, leaf area, and root growth, all of which can reduce yield [16]. Overall, drought stress can reduce wheat production and yield while also making the crop more susceptible to disease and pests. Numerous additional studies have examined how drought stress affects wheat production. During the reproductive stage of wheat growth, drought stress, for instance, can lower yields by reducing the number of spikes per unit area, the number of grains per spike, and the grain weight per spike [17]. During the vegetative stage, drought stress can reduce photosynthesis and stomatal conductance, affecting growth and yield negatively [18].Furthermore, drought stress can make wheat more susceptible to diseases and pests like Fusarium head blight (FHB), which can result in significant yield losses. Drought stress increased wheat susceptibility to FHB and reduced the effectiveness of fungicides in controlling the disease [19]. Drought stress can also have an impact on wheat grain quality. Another study published in the journal "Environmental and Experimental Botany" in 2019 discovered that drought stress can affect the accumulation of micronutrients like zinc, iron, and manganese in wheat grain, lowering the nutritional quality of the grain [21]. In addition to these studies, numerous others have looked into the effect of drought stress on wheat grain quality. Drought stress also increased the concentration of abscisic acid (ABA) in the plant, which is a plant hormone associated with stress responses, according to the study [23]. Drought stress can have a significant impact on wheat production, yield, and quality in general. It can reduce crop growth, grain filling, and yield, make the crop more susceptible to disease and pests, and have a negative impact on grain quality [24].

Challenges in breeding for drought tolerance and climate change

Drought is the principal cause of decreased yields and grain quality. Several issues have been raised as criticisms of wheat breeding for drought resistance [25]. To combat the challenges of drought stress, which lowers agricultural yield and productivity, it is crucial to produce drought-resistant varieties [26]. Several quantitative trait loci have been identified that contain genes with additive and non-additive effects (QTLs). The large number of genes involved in drought tolerance, the vastness of the wheat genome, the instability of some QTLs, and the epistatic QTL interactions all make it challenging to discover QTLs for tracing drought tolerance. It is not easy to tell if molecular markers may be used to select quantitative traits [25] because the vast majority of marker techniques are essentially qualitative measurements that merely indicate the existence of a gene without providing any extra information. Because of these differences in response, it's challenging to discover and select drought-tolerant genotypes. Thus, it's important to work on creating kinds that can grow without a certain growth stage [26]. Processes of adaptation to drought stress involve the genetics of abiotic variables at the molecular, physiological, biochemical, and biological levels. Much genetic, genomic, and molecular research is required to discover the genes responsible for these features and the mechanism by which they function.

Methods and technologies for drought resistance and climate-smart breeding

There are different opportunities and technologies for drought resistance like phenotyping of wheat for drought tolerant: in this different traits affect drought, those traits which are 26positively co-relate with drought tolerance are selected are reduced plant height [28], reduced number of days to anthesis and maturity for early maturity [29]. so that crops can't bear drought, roots are evenly distributed and root length density also affects[30]. Moreover, traits that are associated with transpiration and Phyto-assimilation like leaf rolling, stomatal conductance, and canopy also selected based on phenotyping associated with drought tolerance. High throughput phenotyping is also used for resistance to drought[31]. More methods for drought resistance in wheat are the use of biochemical markers which enhance resistance to drought, the use of QTLs/genes which controls drought resistance, and such type of genes that are introduced through different techniques. Next-generation sequencing and genome engineering technologies are used for drought tolerance. integration of proteomics, transcriptomics, metabolomics, and phenomics approaches are also used as a method for resistance to drought. classical breeding is also used in past but now different molecular markers are used for drought resistance. In addition to ZFN and TALEN an efficient bacterium-based system called CRISPR/Cas is introduced[32].

The phrase "change in climate due to natural or anthropogenic activities and this change remains for a long period" is used to describe **Climate Change**. The daily shifts in climate are caused by a variety of natural and human processes. One of the primary causes of climate change is the accumulation of carbon dioxide in our atmosphere [32]. Burning fossil fuels, releasing smoke from cars, using air conditioners or refrigerators that emit chlorofluorocarbons, and volcanic eruptions all contribute to the atmospheric buildup of carbon dioxide. When we breathe, we exhale carbon dioxide into the atmosphere[33].Because carbon dioxide is one of the most significant gases in greenhouse gases, the greenhouse effect intensified when it accumulated in the atmosphere. With the development of settlement, deforestation started, and cultivated or agricultural land was converted into housing communities. The amount of carbon dioxide in the air rises as a result of vehicular emissions [34]. The nutritional value of wheat products decreased due to an increase in atmospheric carbon dioxide, and some crops began to produce carcinogens due to changes in their chemical composition in some situations [35]. Wheat production, grain weight, and grain size after the growing season are strongly impacted by these drastic temperature swings during crucial phases like blooming, anthesis, and milking stage. when the temperature was $36 \pm 2°C$ during anthesis yield was reduced by 13 percent and most grains were sterile. Production decreases in high-temperature spikes and becomes more susceptible to disease stress. Temperatures exceeding 32°C at the time of anthesis cause the grain to become smaller and lessen the time grain fills the spikes, both of which have an impact on wheat output [36]. Wheat production in rain-fed locations is particularly impacted by changes in rainfall patterns as rainfall decreases and directly affects wheat yields, which reduce by 5-7 percent with each degree of temperature increase. Therefore, climate change affectsthe yield of wheat [37]. Due to heat stress, there is a great reduction in yield and many diseases associated with it affect the output, so it's dire need time to overcome this problem for food security. As we know the population is increasing day by day so in the future there is a food shortage issue we need to produce climate-smart crops with the advent of different technology. To tackle the problem, we need the following strategies: [38]The main issue of climate change is global warming. Scientists must therefore develop seeds that can withstand heat.Climate change has the potential to alter rainfall patterns, levels, and directions. As a result, seeds that can withstand drought must be produced quickly.More acreage must be cultivated to meet the growing demand for wheat. It is necessary to upgrade the irrigation infrastructure and water management practices.Temperature increases may reduce the period of growth for the wheat canopy. As a result, the timing of wheat cultivation needs to be altered.

Exploring drought tolerant mechanism

There are various drought response mechanisms, such as drought tolerance, drought avoidance, and drought escape [39]. Plants may employ a variety of response mechanisms to adapt to drought stress, including different agro-morphological traits responsive to drought stress like early growth prevents soil moisture loss and ample water available for growth [40], root architecture, long and thick internodes, long coleoptile, tiller number, heading and anthesis, long grain filling, reduced plant height, stomatal conductance are also related with drought tolerance [41]. The presence of awns is also helpful in drought stress condition by photosynthesis and increase grain size and length in stress condition. Leaf rolling also prevents water loss [32].Moreover, canopy temperature, late leaf senescence, and chlorophyll content are also associated with drought.Special characteristics to avoid dry spells include an early heading, flowering, and maturity, a shorter growth cycle, and a lower plant height [32]. Drought-resistant plants have root systems that are either longer or deeper, allowing them to consume more readily available nutrients and water [43]. Slow growth and improved root architecture—longer, deeper roots and leaves with small or closed stomata and lower transpiration—are linked to this mechanism. While the capacity of a plant to continue growing, developing, and reproducing despite severe stress circumstances is known as drought tolerance [45].

Exploring selection indices for drought tolerant

Still essential methods for reducing drought are target selection, production settings, and water stress management [46, 47]. Three strategies for breeding drought tolerance were described by a scientist. These consist of: Breeding for higher yield in conditions free of stress,breeding for maximum yield in environments that are prone to drought,and Utilizing selection indices (traits) in breeding for drought tolerance.This is because these environments may change the pathways in the body and genes, as well as the genes needed for better performance. As a result, we observed in a different setting. Indirect selection selects the target trait through another means, whereas direct selection selects the target attribute directly. For wheat grain production and drought resistance, these features have been exploited in direct or indirect selection[25]Different source populations respond to drought in different ways. Therefore, it is essential to evaluate each population to simultaneously enhance yield and drought resistance.Stay green traits is the tendency of a plant to remain to stay green for long period due to excess chlorophyll and more photosynthesis occur even in drought condition also. Osmotic regulation also when there is a difference in molecular weight at different positions so translocation takes place from one place to another. The osmotic state of cells and the movement of water from plant shoots determine the level of leaf water [50]. The membrane is stabilized and nitrogen fixation is controlled by the proline content. Synthetic derivatives (SYN-DERs) increased their concentrations of proline, soluble sugars, and superoxide dismutase when subjected to drought stress. The development process relies heavily on the root-and-shoot system. The ability is impacted by the shoot systems [51]. While roots are used to extract minerals and water from the soil. Larger and deep roots perform well than small and shallow roots in case of drought and give more yield as compared to shallow roots. In addition, grains with deep roots yield more because of their larger size and weight [52]. Grain yield and grain size were reported to be 35% and 9%, respectively, higher in deeper-rooted genotypes. In the case of drought plant response depends upon soil condition and water availability. Some respond by increasing root structure and decreasing shoots while some showing enhancement in shoots and decrement in roots. The reduced root is due to low water status in the soil and low oxygen level [47]. So early sowing ensures water is available and roots grow profoundly even in drought conditions. Within a small gene pool dominated by elite lines, directional selection poses a danger to genetic variation for phenotypic flexibility [38]. However, to create drought-tolerant and high-yielding cultivars, it is crucial to take into account the various and divergent sources of genetic diversity. The selection effectiveness of traditional breeding programs will be improved through research on trait-marker relationships and biomass allocation [53].

Drought Resistance Variety

Genetic variation as a source of drought resistance and climate-smart:

Genetic variation serves as the foundation for improving quantitative characteristics like drought tolerance and yield components [54]. Hybridization, mutation breeding, importation of existing varieties, and development of other strategies can all be used to improve genetic diversity [55]. These genetic resources are adaptable, highly cross-compatible, and possess numerous attributes that farmers and consumers value [25].

Landraces:

Breeding stocks that are genetically diverse and adaptable to local ecologies and agricultural practices are called landraces. They are great sources of genes that can withstand drought [42, 61].Throughout the 1940s, one of the landraces chosen for its resistance to drought was Aragon 03, which is now widely grown in Spain. Rht1 and Rht2 were present in the Japanese variety "Norin10" [25], whereas the Aka Komugi landrace carried the Rht8c dwarfing allele, which is associated with drought tolerance [63]. This cultivar has improved characteristics such as increased parenthesis biomass production under a variety of conditions and long-lasting drought tolerance [62]. Landraces have not been frequently used in a lack of descriptors and the loss of crucial alleles as a result of domestication and evolution. Prioritizing the use of landraces can help breeding programs produce crucial alleles and traits, such as drought tolerance.

Synthetics

The need for synthetic is due to narrow genetic variation in the D genome so to increase genetic diversity in the D genome synthetic wheat is developed. As a result, SHWs result from crossings between tetraploid wheat and any subspecies of Ae. tauschii contain untapped genetic variety that must include beneficial genes for bread wheat breeding. Synthetic hexaploidy wheat formed by crossing between Triticumturgidum (AABB) and Ae. Tauschii hasa (DD) genome formulated by applying colchicine for the chromosome doubling of the hybrid F1[65]. Utilizing modern synthetic backcross lines or synthetic derivatives, useful genes are found and introduced (SBLs). Due to the tight similarity between the D genomes of A. tauschii and hexaploid wheat, there is a higher likelihood that polygenic characteristics would be transferred. A study was also conducted at CIMMYT to check the contribution of the D genome of Tauschii and genetic variation and concluded that there is almost a 25% increase in grain yield and genetic variation[66].North of 1,500 SHWs has been made universally starting from the primary SHW produced during the 1940s. To create 1,300 SHW on a wide scale, around 900 Ae. tauschii increases were utilized at CIMMYT (Mexico) somewhere in the range of 1988 and 2010. In contrast with the D genome of bread wheat, the hereditary variety of the Ae. tauschii populaces were a lot higher for a few sicknesses and bug opposition, isozymes, and seed capacity proteins. 1577 SHWs, or 21% of the germplasm, were created because of CIMMYT's endeavors to increment hereditary variety somewhere in the range of 2000 and 2018. Twenty countries saw the presentation of 86 sorts, with China (34%) and India (7%) having the most elevated paces of uptake[67]. Various SHW lines and their variations have been created, tried, and useful qualities and elements have been found during the beyond 20 years. The fundamental yield parts, for example, huge piece size, high biomass, high over-the-ground biomass, and an enormous root foundation that catches water from profound soil zones, as well as the illness obstruction qualities and characteristics that add to expanded yield both under a rainfed-dry spell or dampness restricting circumstances and ideal yield articulation, are among these. Saltiness, waterlogging, and sodicity resistance are different characteristics that are incorporated. The accessibility of lines with different illness opposition is one of SHW's significant qualities (MDR). This potential has not yet, by the by, been completely understood. Moreover, it has been shown that SHW and their derivate SBLs (i.e., when crossed to privately adjusted assortments) display striking yield increments and in this way superior yield execution across various conditions, exhibiting their true capacity for use in raising wheat efficiency worldwide. This is particularly clear in regions with low dampness [66].

Wild relatives and their progenitors:

The genes for drought resistance in wheat were originally sourced from wild relatives such as emmer wheat (Triticumdicoccoides) and Aegilops (Aegilopstauschii) [68, 69]. In wild comparable species, physiological characteristics and chlorophyll inflorescence parameters declined less [59]. The main challenge when using wild relatives, like landraces, is the linkage drag brought on by the epistatic and pleiotropic effects of specific genes linked to uncommon alleles. Crossing elite lines to spread drought-tolerant genes while reducing the transmission of unusual alleles can prevent this. This strategy will open up possibilities for QTL mapping and drought tolerance engineering in the future.

International Research Collaborations

Thousands of winter bread wheat genotypes from breeding programs in the Great Plains and Pacific Northwest of the United States, Eastern Europe, the Soviet Union, China, and CIMMYT/Mexico were tested for their ability to adapt to conditions that appeared to be comparable on the central Anatolian Plateau of Turkey over thirty years of collaboration between the government of Turkey and CIMMYT. This work was carried out under the auspices of the international winter wheat improvement program. The objective was to find lines that could be made into better cultivars. However, due to a lack of expectations, introductions have never been widely accepted. This failure demonstrated that the use of direct introductions may have been hampered by unidentified factors that may have diminished the introduced cultivar's CAP performance. The yield performance of unadapted bread and durum wheat increased by up to 100% when zinc was applied. Since then, it has been established that zinc deficiency is a significant and widespread constraint on cereal production on the central plateau. The first case of field zinc deficiency was found in 1999 at the agriculture Research Institute in Eskisehir[70, 71]. The CIMMYT wheat program has made a significant contribution to the growth of agriculture and wheat production in Mexico, helping the country become self-sufficient. CIMMYT wheat has greatly enhanced the genetic material in seed banks and helped introduce previously unknown varieties. Over the past five decades, the southern cone of South America has increased the strength of its wheat breeding programs by extensively utilizing CIMMYT germplasm. As a result, production and productivity have always improved [72].There is strong evidence that unique breeding technologies can be developed by combining potent new techniques in genetics and remote sensing. The immense and mostly untapped pool of wheat genetic resources held in collections around the world can also be used to find features related to climate resistance[73]Being the most commonly produced grain in the world and providing 20% of all human calories and protein, wheat is a crucial cornerstone of global food security. However, numerous other field-based crops, including wheat, are threatened by environmental issues. Food security is now being affected by these changes with "high certainty." In addition, the future is expected to see a significant increase in people migration due to climate-related decreases in agricultural productivity.This unusual partnership has produced extraordinarily high returns on public investment, stable genetic gains for spring wheat, avoidance of dangerous disease pandemics like stem rust, and protection of natural ecosystems from farming owing to food sufficiency. Although the majority of less developed countries have historically served as the foundation for investment in the IWIN, get their disease resistance, as is where the majority of the wheat produced in Australia gets its disease resistance. However, wheat breeding efforts require a significant expansion in light of the numerous new obstacles they must overcome. The scientific literature makes it clear that many intriguing plant discoveries do not result in improvements to breeding methods. The bottleneck between discovery research and breeding as a whole, which limits the societal utility of massive investments in the former, is one of the main causes. Based on combining cutting-edge scientific discoveries with tried-and-true breeding methods, the following are a few potential solutions to this problem. Among the discussed research objectives are: gene discovery and gaining access to previously untapped genetic resources; enhancing and putting innovative breeding practices into practice, crowdsourcing innovative ideas and technology for testing and validation in a real-world breeding context, to increase genetic benefits in harsher environments[73].Across wheat-growing regions, an ensemble of many crop models and multiple global climate models can be used in a gridded format to calibrate and validate the response of the model simulation to heat and drought. The crop modeling community will also have access to a set of curated big data and metadata. Increase the breadth of the wheat gene pool for abiotic stress adaptation by locating additional genetic resources that are climate-resistant. Through the mining of exotic gene pools, numerous successes have been made in wheat in locating novel sources of characteristics that are primarily associated with disease resistance but also have some accidental effects on yield. The introduction of rye chromosome 1's short arm, which allowed for widespread adaptability and great yield performance, is the best example to date. Although the genes behind this are mainly unknown, current research has revealed that one element is connected to root architecture. While representing unique pools of allelic variability, landraces, and synthetic hexaploids are much easier to cross than wheat's wild relatives. Despite limited screening during periods of heat and drought, the impacts of cross-pollination with these sources have been demonstrated. CIMMYT's breeding and research efforts have fueled numerous global advancements through the IWIN nurseries. The principal wheat-growing nations in Asia, Africa, and Latin America have profited from this.

Breeding Methodologies and technologies:

Inbred breeding lines must be created to reproduce them for further testing and variety release in wheat breeding projects that aim to create variations. The four primary ways for line formation are pedigree, bulk, single-seed descent, and doubled-haploids. Backcross breeding is typically viewed as a helpful complement to these procedures. No matter whatever line development technique is employed, the first step is normally to conduct crosses between several parental plants to produce novel genetic combinations. The F1 progeny will be identical if the two parents who were employed in the crossing are also inbred. Genetic and phenotypic diversity, or "segregation," will occur in the F1 progeny if one or both crossing parents are not inbred. A breeder can create fresh genetic variety as an alternative to crossing by deliberately causing genetic mutations in one or a few plants. The subsequent steps depend on the line development technique used after F1 seed or mutagenized plants are produced. A breeder may decide to release one or more lines as varieties after several generations of line development or a multiline variety made up of several selected inbred lines. Due to the high cost of selection, pedigree breeding is not frequently applied in wheat breeding. Bulk breeding techniques are easy and economical. The fundamental benefit of the SSD approach is the ability to quickly develop lines in a greenhouse or nursery during the off-season. The high expense of doubled-haploids prevents breeders from producing homozygous genotypes from heterozygous genotypes in a single generation [74].Traditional breeding methods take a lot of time and are inefficient when trying to achieve high-yield targets in a changing climate. Wheat breeding has undergone a molecular revolution thanks to next-generation sequencing for efficient selection. For sustainable production, the application of genomic techniques in wheat breeding is becoming necessary.

Breeding climate smart wheat by Gene editing technologies and Biotechnology Approaches

There has been substantial use of linkage mapping to discover genomic areas in wheat that are connected with drought and heat tolerance. Many studies[76] have demonstrated that quantitative trait loci (QTLs) influence a variety of attributes throughout the vegetative and reproductive stages. Some of the initial research utilized substitution lines from the Langdon background to identify areas related to heat tolerance. In the following research [77, QTLs on a number of chromosomes have been associated with yield components and physiological features, such as wheat's propensity to remain green and senescent [78]. In the wheat industry, current research aims to create genetically modified spring wheat with improved traits, develop molecular markers for important traits, use markers from global research, and characterize wheat germplasm collections to find valuable alleles[79].The foundation for locating the gene(s) responsible for the manifestation of key traits is laid by the creation of genetic linkage maps [80]. This has been demonstrated in wheat, where such maps have allowed for the comparison of mapping between species that are related and confirmed previous cytological observations of significant chromosome rearrangements [81].

Progress in breeding Climate smart Wheat

The first step taken by CIMMYT in the field of wheat genetic engineering was to locate top-performing wheat varieties that could not only be rejuvenated but also genetically modified. Through their research, bread wheat cultivars such as Attila, Kauz, Baviacora, and Bobwhite, as well as durum wheat genotypes Minimus, Ariza, Altar, and Bajio were discovered to be highly receptive to rejuvenation and ideal for transformation initiatives [82].Despite the efforts made by breeding programs, not all tactics have achieved the desired progress. While the process of genetic mapping has revealed the intricate nature of responses to heat and drought, it has not produced useful selection markers. This could be due to an unrealistic belief that there are only a few major genes that are responsible for stress responses that could be applied in various environments and an oversimplified view of tolerance. Through the incorporation of landraces and wild relatives, stress adaptation has been successfully enhanced in some instances. However, only a small amount of the germplasm that is available has been utilized. There is a lot of potential in incorporating wild germplasm into breeding programs and advanced screening methods [83]. Despite these efforts, it has been difficult to simultaneously achieve drought tolerance and high yield because key breeding traits are difficult to identify, phenotyping techniques are inadequate, and the expression of multiple genes and QTLs can vary greatly depending on the environment. The extensive and intricate wheat genome adds further complexity to this. Exposure to a variety of biotic and abiotic factors has contributed significantly to the documented improvement in grain yield under harsh environmental conditions, such as drought stress. However, selection under ideal conditions accounted for a significant portion of this increase. Despite this, the rate of genetic advancement is not fast enough to meet the expected demand for wheat by 2050, so specialized breeding programs that target drought and heat tolerance are needed [84].

Breeding Climate Smart Wheat for Drought Tolerance – Conventional Approaches

The diverse germplasm can be searched for valuable genes that can later be utilized in breeding programs [86]. These genes can be found in crop wild relatives or landraces. Crop varieties can use these genes to adapt to shifting climates and environments. When compared to domesticated wheat, wild emmer wheat (Triticumdicoccoides) is more drought-tolerant [87]. However, it takes a significant amount of time, resources, and manpower to introduce genes from wild species. The number of varieties that have been made available does not necessarily indicate this strategy's success. It should also be taken into consideration for its contribution to the genetic diversity of particular crops. Unfortunately, gene banks do not adequately represent many species' wild relatives and landraces, so their potential is not fully utilized [88]. The breeding of wheat to withstand saline conditions, which will also improve its performance in arid conditions, has made significant progress [89]. By selecting for yield stability under stressful conditions, conventional breeding methods can significantly increase crops' drought tolerance. However, the characteristics associated with enhanced drought performance are intricate and frequently controlled by multiple genes [90]. Major crops' wild relatives have been given drought tolerance through conventional breeding methods. The following are examples of wheat cultivars that were developed from wild cultivars: Aegilops kitschy, Aegilopsvariabilis, Aegilopsspeltoides, Aegilops umbellate, Aegilopstauschii[92].

Breeding Climate Smart Wheat for Drought Tolerance – Genomic Resources

Modern molecular techniques have made it possible to map specific QTLs for drought resistance in crops [93]. Marker Assisted Backcross Breeding, or MABB, has been used to modify a no with success. of crops like rice, wheat, maize, and others. without affecting their ancestry [94]. Conventional breeding is time-consuming, laborious, and heavily influenced by the environment when compared to Molecular Assisted methods. Marker-Assisted breeding (MAB) can be used to determine how wheat's drought tolerance QTLs function [95]. Breeding for drought tolerance has been revolutionized by genome editing[96]. The CRISPR/Cas9 technique can be used to alter wheat structural genes that control stress tolerance [97]. Breeding now has access to more cost-effective, simple, viable, and efficient platforms for phenotyping morphological, physiological, and phenological traits thanks to the advent of phenomics. The tools of genetic engineering can be used to examine and modify the structure and functions of a candidate gene. However, this tool has some limitations when it comes to drought stress resistance [2]. It is possible to identify the genes, transcription factors, miRNAs, hormones, and proteins that are responsible for drought stress and other traits that are related to it and to modify their function.

Breeding climate smart wheat by Gene editing technologies and Biotechnology Approaches

Linkage mapping has been extensively used to identify genomic regions in wheat that are associated with drought and heat tolerance. Quantitative trait loci, or QTLs, have been found to have an impact on a variety of traits at both the vegetative and reproductive stages [76]. Substitution lines from the Langdon background were used in some of the earliest research, revealing regions associated with heat tolerance. Homologous group 3 in the wheat cultivar

Hope was linked to heat tolerance in subsequent studies [77]. In the wheat industry, current research aims to create genetically modified spring wheat with improved traits, develop molecular markers for important traits, use markers from global research, and characterize wheat germplasm collections to find valuable alleles [79].The foundation for locating the gene(s) responsible for the manifestation of key traits is laid by the creation of genetic linkage maps [80]. This has been demonstrated in wheat, where such maps have allowed for the comparison of mapping between species that are related and confirmed previous cytological observations of significant chromosome rearrangements [82]. Furthermore, we can conduct in-depth proteomics and metabolomics studies of the plant's response to drought to improve our comprehension of wheat's mechanisms for drought tolerance.

Progress in breeding Climate smart Wheat

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Conclusion and Remarks:-

In conclusion, wheat breeders and agronomists have focused on increasing yield because of the global need to support a growing population by increasing grain yield. However, it is difficult to simultaneously improve drought tolerance and yield because current breeding pipelines are not optimized for selecting constitutive and drought-tolerant traits. Multi-environment phenotyping assays, high-throughput phenotyping tools, improved molecular markers, and genomic technologies are all necessary for overcoming these obstacles. To identify the most important genes and QTLs that are responsible for significant breeding traits, it will be essential to have access to wheat sequence reference genomes and to make advancements in data analysis methods. To produce drought-tolerant and high-yielding wheat varieties, the breeding cycle can be shortened, and more effective breeding pipelines established.

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