AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 02, Issue: 04 (April, 2025)
Available online at http://www.agrimagazine.in
©Agri Magazine, ISSN: 3048-8656

Wheat vs. Drought: Inside the Breeding Battle for Climate-Smart Crops

*Silpa Sahoo
Department of Genetics and Plant Breeding, RLBCAU, Jhansi (284003), India
*Corresponding Author's email: sahoo.silpabhu@gmail.com

Wheat is one of the leading cereal crops globally, serving as a primary food source in various countries. It contributes over half of the calories and protein for more than a third of the world's population. The ever-growing global population has led to an increased demand for wheat. Drought is a significant factor that restricts crop production and yield. Plants exhibit a range of morphological, physiological, biochemical, and molecular adaptations to cope with drought stress. While drought can impact wheat growth at any developmental stage, the reproductive and grain-filling stages are particularly vulnerable. Drought stress occurs when the water lost through transpiration from the leaves exceeds the water absorbed by the roots. This stress is primarily marked by reduced water content, lower leaf water potential, loss of turgidity, stomatal closure, and inhibited cell growth.

Drought Stress in Wheat

In wheat, the impact of drought stress varies according to the timing, stage, and intensity of water deficiency. This leads to numerous abnormalities in morphology, physiology, biochemistry, and molecular processes that reduce crop growth and development. The critical stages most susceptible to drought stress are tillering, jointing, booting, anthesis, and grain filling.

(a) Effect of drought stress on Wheat morphology:

- Decreased water intake results in poor seedling vigour index, delayed germination, inappropriate root and shoot growth, nutrient uptake, and oxidative stress.
- Drought conditions reduce the leaf area index, primarily due to leaf ageing and competition for light.
- Drought conditions result in limited cell enlargement in leaves, hindered growth, and a rise in the rate of leaf abscission.
- The deficiency of water hampers nitrogen uptake in plants, resulting in the migration of nitrogen from the leaves and stems to the seeds, which accelerates leaf senescence.
- Under drought stress, there is a significant drop in photosynthesis, impaired cell growth and expansion, reduced nutrient uptake, increased senescence, and a quick increase in stress hormones such as abscisic acid (ABA), which collectively diminish dry matter accumulation.

(b) Effect of drought stress on Wheat biochemistry:

- When plants undergo drought stress in their vegetative stages, it causes a decrease in chlorophyll concentration.
- Drought stress also induces the formation of superoxide and hydrogen peroxide (H2O2).
- Under drought conditions, the wheat rhizosphere exhibits an increased rate of respiratory carbon loss, which hampers ATP production.
- Drought stress leads to reduced photochemical efficiency and an increase in reactive oxygen species (ROS), which contributes to oxidative damage. It also reduces starch accumulation, stimulates the production of abscisic acid and proline, and enhances

antioxidant enzyme activity, including Catalase (CAT), Superoxide Dismutase (SOD), Glutathione Reductase (GR), and Peroxidase (POD).

- When subjected to 10 days of drought between anthesis and harvest, starch content can decline by up to 45% compared to plants grown under irrigated conditions.

(c) Effect of drought stress on Wheat physiology:

- Drought stress conditions lead to a decrease in relative water content, chlorophyll content, osmotic potential, and leaf water potential, as well as a reduced rate of transpiration in leaves.
- Drought conditions hinder the processes of mineralization, diffusion, and mass flow of nutrients in the soil, leading to decreased nutrient absorption.
- Drought conditions lead to decreased permeability of cell membranes, reduced transpiration rates, and impaired active transport, which ultimately hinders nutrient mobilization in plants.
- A decrease in water potential in plants results in smaller sizes of various parts, including stems and leaves, which affects the storage of reserve food materials.
- Drought conditions lower the moisture requirements of reproductive structures like the style and stigma, which in turn reduces pollen viability and results in poor fertilization.
- Drought conditions impede a plant's ability to absorb water from the soil, leading to a reduction in turgor pressure.
- The occurrence of drought results in incomplete seed filling, which hinders proper seed development and leads to smaller seeds with reduced germination capacity.
- The occurrence of drought damages the photosynthetic components and alters the functioning of several enzymes, such as rubisco, that are critical to the Calvin cycle, thereby diminishing grain yield.
- Wheat reaches its maximum chlorophyll levels during the flowering stage, but these levels drop significantly when exposed to drought stress, leading to a reduction in photosynthesis in the leaves.

Drought Tolerance Mechanisms in Wheat

(a) Morphological tolerance mechanisms:

- Wheat exhibits several key morphological traits that minimize water loss via transpiration. Deep root systems, waxy leaf surfaces, a high trichome density, and sunken stomata on the lower leaf surfaces are a few of these characteristics. Together, these characteristics help the plants maintain elevated water potential and provide resilience against prolonged drought.
- As the search for water continues, the roots become longer and thicker.
- Wheat leaves experience early senescence as a result of drought stress.
- The stay-green trait facilitates carbon assimilation, ensures a continuous supply of sugars to the reproductive organs as they grow, and helps preserve the pollen and ovule viability. It also plays a role in the remobilization of reserves to grains, which enhances production under drought stress.

(b) Physiological tolerance mechanisms:

- Physiological processes including osmotic adjustment, abscisic acid (ABA) synthesis, stomata closure, membrane integrity, and dehydrin synthesis result in higher water potential and drought tolerance.
- Osmotic adjustment generates a range of organic solutes that play a crucial role in detoxifying reactive oxygen species (ROS), stabilizing membrane structures, and supporting the integrity of enzymes and proteins, thereby enhancing tolerance mechanisms to drought conditions.
- The accumulation of osmolytes plays a crucial role in managing dehydration and maintaining cell membrane integrity, thereby boosting wheat's tolerance to drought stress.

- For the signalling pathways involved in plant stress, growth, and development, cysteine synthesis is essential. It is synthesized in the leaves of stressed plants involved in proteolytic activities.

(c) Biochemical tolerance mechanisms:

- The synthesis of RUBISCO, helicase, proline, and carbohydrates strengthens plants' ability to withstand drought.
- The primary types of messengers that convey signals through various pathways include ROS, ABA, phosphoglycerol, diacylglycerol, and transcriptional regulators. These signals trigger the expression of genes responsive to drought, which help mitigate oxidative damage, preserve cell turgor, and facilitate plant adaptation.
- Some genes generate proteins designed to scavenge reactive oxygen species (ROS).
- Transcription factors, including AP2/ERF (ethylene-responsive element binding factor) and bZIP (basic leucine zipper), play a crucial role in activating antioxidant defence genes by binding to their promoter regions.

Breeding Methods to Improve Drought Resilient Wheat

(a) Conventional Breeding:

- Conventional breeding practices are essential for improving the phenotypic characteristics of crops in regions prone to drought.
- The bulk population breeding method allows for the elimination of less fit segregates across segregating generations.
- Modification of bulk breeding is crucial to discard undesirable phenotypes. This is because natural selection generally favours individuals who are better competitors in reproductive terms, which does not always equate to enhanced agronomic performance.
- To enhance the variability of base populations, the crossing of parents with diverse adaptive traits can be employed, followed by the advancement of materials through pedigree breeding, which involves keeping accurate parentage records.
- Backcross breeding is an effective method for enhancing quantitative traits, particularly when there is significant variation in target traits among different genotypes, as it minimizes environmental impacts on selection.
- Conventional breeding methods rely on visual evaluations making them slow, labour-intensive, and prone to inaccuracies due to a high likelihood of errors.

(b) Marker-Assisted Breeding:

- The application of linked DNA-based markers in marker-assisted selection (MAS) enables the indirect selection of traits that enhance drought adaptation, allowing the integration and accumulation of genes that provide drought resistance.
- For example, the simple sequence repeat (SSR) markers wmc603 and barc108 are effective for the indirect selection of wheat genotypes that exhibit high membrane stability linked to drought tolerance. Marker-assisted recurrent selection (MARS) utilizes molecular markers to gather genes for targeted traits from multiple populations.
- Yet, relying on QTL for drought tolerance continues to be challenging due to the inconsistencies in assessing QTL effects related to quantitative traits.

(c) Marker-Assisted Backcross (MABC) Breeding:

- The process of marker-assisted backcross (MABC) breeding is essential for the transfer of quantitative trait loci (QTL) related to drought tolerance from donor parents to elite inbred germplasm during breeding efforts.
- Given that quantitative traits are greatly affected by environmental conditions and epistasis, the approach of backcrossing to transfer one gene at a time is not effective.
- The process involves hybridizing superior cultivated germplasm with a donor parent, a wild relative or a landrace possessing quantitative trait loci (QTL) associated with drought tolerance.

- Subsequently, two or more backcrosses to the recipient (recurrent) parent are performed, along with the selection process aimed at eliminating harmful alleles or undesirable traits from the donor species.

(d) Genome Engineering and Genome Editing:

- By exploring the molecular mechanisms of drought tolerance in desert and resurrection plants, we can improve transgenic-assisted breeding efforts focused on developing drought-resistant varieties.
- The AlSAP gene, sourced from Mediterranean salt grass is one of several foreign genes that have demonstrated effectiveness in enhancing drought tolerance in wheat, as it encodes a protein associated with stress that contains an A20/AN1 zinc-finger domain.
- Genome editing, which minimizes dependence on foreign genes, may provide a viable alternative to conventional genetic engineering methods that are highly regulated especially in the context of food crops like wheat.
- Genome-editing technologies are advancing and becoming more widely accepted in the improvement of crops. This is achieved through the application of sequence-specific zinc-finger nucleases and transcription activator-like effector nucleases, as well as the latest and more accurate clustered regularly interspaced short palindromic repeats (CRISPR) and CRISPR-associated systems (CAS).

Challenges in Breeding for Drought Tolerance

- There is a lack of extensive research that has successfully identified important agro-physiological traits for the selection and enhancement of drought-tolerant crops.
- The primary reason is that most traits associated with drought adaptation and constitutive characteristics are regulated by polygenic and unstable QTL, which are greatly impacted by genotype-environment interactions. Consequently, this results in low efficiency when selecting superior genotypes.
- Genotype-environment interactions are evident through crossover ranking when various indices are employed to identify drought-tolerant genotypes.
- Bridging the gap between theoretical research and practical crop breeding poses a challenge in drought tolerance breeding, particularly in identifying and understanding the expression of genes associated with drought stress resilience.
- With a genome size of 17 Gb, wheat poses significant difficulties in identifying the genetic loci that influence crucial agro-physiological traits associated with drought tolerance, largely because of its complicated genetic background.

Conclusion

One of the significant abiotic challenges resulting in extensive yield losses in wheat globally is drought stress. Although drought poses a serious risk to wheat production, there has not yet been any research into its effects and the mechanisms of tolerance. It is crucial to gain a deeper insight into the different mechanisms that plants respond to drought conditions. Implementing strategies such as the development of high-yielding varieties, advanced phenotyping techniques, and improved irrigation and water use efficiency is crucial. Genetic resources, including landraces, synthetics, and wild relatives, will facilitate the identification of alleles beneficial for breeding and enhancement programs. Wheat's tolerance to terminal drought may be strengthened by novel gene sources. The integration of conventional breeding with physiological traits, genetic and genomic techniques, and transgenic methods may contribute to better drought resistance in wheat.