BBASR PUBLISHERS

Biological and Agricultural Sciences Research Journal
eISSN: 2959-653X; pISSN: 2959-6521
www.basrj.com
DOI: https://doi.org/10.54112/basrj.v2023i1.18
Biol. Agri. Sci. Res. J., Volume, **2**: 18

BASRJ

Review Article

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AN OVERVIEW OF DROUGHT TOLERANCE CHARACTERS IN COTTON PLANT: INCREASING CROP YIELD WITH EVERY WATER DROP

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(Received, 7th January 2023, Revised 24st July 2023, Published 28th July 2023)

Abstract *Drought stress is a major factor limiting cotton productivity and quality worldwide. Understanding the physiological and inheritable mechanisms underpinning failure forbearance in cotton is essential for developing strategies to ameliorate cotton yield under water- limited conditions. This review paper summarizes recent advances in our understanding of the physiological and inheritable mechanisms contributing to failure forbearance in cotton. We punctuate cotton's crucial physiological and biochemical responses to failure stress, including changes in photosynthesis, water use effectiveness, and bibulous adaptation. We also review recent progress relating genes and molecular pathways involved in failure forbearance in cotton through transcriptomics and genome-wide association studies. Although significant progress has been made in relating genes and physiological mechanisms involved in cotton failure forbearance, important work remains to completely understand the complex relations between factory responses to failure stress and the inheritable factors that govern these responses. This review paper underscores the need for continued exploration of the physiological and inheritable mechanisms underpinning cotton failure forbearance and the development of new strategies for perfecting cotton productivity and sustainability under water-limited conditions. Finally, we bandy implicit strategies for perfecting cotton failure forbearance through inheritable engineering, parentage, and agronomic practices. Overall, this review provides a comprehensive overview of the current knowledge on physiological and inheritable failure forbearance in cotton and identifies crucial exploration requirements and openings for unborn progress.*

[*Citation: Haraira, A.A., Mazhar, H.S.U.D., Ahmad, A., Shabbir, M.S., Tahir, A.R., Zulifqar, W. (2023). An overview of drought tolerance characters in cotton plant: increasing crop yield with every water drop. Biol. Agri. Sci. Res. J.,* ***2023****: 18. doi:* https://doi.org/10.54112/basrj.v2023i1.18]

Keywords: Drought stress, drought tolerance, cotton molecular genetic basis, *Gossypium hirsutum*

Introduction

Climate change is a global issue, and all the countries on earth have been affected by it to some extent. It has a direct effect on crop plants and causes issues like yield loss and food security problems; because of the increase in temperature, different abiotic stresses have hindered plants growth out of which drought stress is a prominent one (Fahad et al., 2013; Naeem et al., 2018). It depends on several factors like the distribution and amount of rainfall, evaporation rate and soil's ability to hold water in it (Ullah et al., 2019; Zhang et al., 2016a). An increase in temperature causes an increase in evaporation, which leads to drought stress, and crops like cotton are highly affected by it. According to report by (Comas et al., 2013), in USA, drought stress alone caused 67% reduction in cotton lint yield. It devastates the field crops, with abiotic stresses causing 73% decline in cotton production worldwide (Mahmood et al., 2019). Drought and heat stress are the major issues being faced by cultivated crops.(Anwar et al., 2022). In recent years drought has attracted many geologists, ecologists, and environmentalists (Mishra and Singh, 2010).

Drought refers to the water shortage for a specific period which affects the crop production (Abdelraheem et al., 2019). Global study proposes an increase of 4–5.8 °C in air and surface temperatures for upcoming decades. From 1979 to 2003, an increase of 0.35 and 1.13 °C has been recorded, courtesy climate change (Khan et al., 2018). Cotton is the most important crop grown in 76 countries for its fiber. Drought can drastically affect cotton fiber quantitatively and qualitatively (Sekmen et al., 2014). It is necessary to study and identify all characteristics that can provide cotton plant with tolerance against drought stress. These can be used as markers in future breeding programs(Quevedo et al., 2022). Drought stress affects plant growth by reducing photosynthesis and cell expansion. Cotton crop is very sensitive to abiotic stresses, and they mostly cause loss of cotton lint which is an important yield yield component of the cotton crop (Khan et al., 2017; Magwanga et al., 2018a). Countries like Pakistan are one of those countries which are adversely affected by climate change and high-temperature issues. Crops like cotton require an adequate amount of water to produce a good yield. Still, because of the insufficient water and high temperature, cotton crop is often affected by drought stress and ultimately causes yield loss (Nagamalla et al., 2021; Xiao et al., 2020). Because these issues are increasing day by day so, it is the need of the hour to produce environment friendly and stress tolerant cotton varieties to tackle the drought stress in a best possible manner. Under drought stress crop photosynthesis reduces by both stomatal and non-stomatal factors (Zahoor et al., 2017a).

Drought is a major abiotic stress affecting more than 40% of agricultural area. Reduced N assimilation has been observed in crop plants affected by drought stress (Zahoor et al., 2017c). Studies on cotton tolerance for abiotic stresses would help to increase cotton production and will produce great economic value. Drought affects cotton plant's both metabolic and biological pathways (Wang et al., 2013). Cotton growth is considered to be divided in five different stages as per irrigation requirements (Bauer et al., 2012). For germination on a plantation, irrigation is crucial. Drought stress has little effect from emergence to the first square. Still, the following two stages, such as first square to first flower and first flower to peak bloom, are extremely vulnerable to abiotic stress, particularly drought stress. (Bauer et al., 2012; Ul-Allah et al., 2021). At last stage i.e., peak bloom to first boll open, drought stress doesn't have much effect on cotton crop but can affect fiber quality (Hussain et al., 2020). Studies have revealed that cotton Photosystem II's quantum efficiency decreases under drought stress (Massacci et al., 2008). Due to drought, losses in the proportion of payment in cotton crop have been estimated as 40.8% (Saleem et al., 2016). Cotton is called as 'white gold' as it is cultivated for its excellent fiber, but cotton production has adversely been affected by the increase in heat and water deficit (Abdelmoghny et al., 2020). Cotton may be considered as a well adapted crop to high temperature and water deficit, but study reveals that temperature above optimum has negative effects on the yield and quality of fiber (Loka and Oosterhuis, 2020). The cotton crop's yield is a multi-factor trait that is primarily influenced by a variety of variables. The ability to withstand or tolerate abiotic stresses, particularly drought stress, is a more complex feature that largely depends on two physiological and environmental components. (Abdelmoghny et al., 2020; Sun et al., 2021). Therefore, in-depth knowledge of morpho-physiological process, genetic components and adaptive mechanisms against the cotton crop's drought is essential for a plant breeder to develop drought-tolerant varieties. Cotton plant, like many other plants adapts to the drought by producing HSPs. HSP are a group of gene products that help the plant by preventing protein denaturation (Maqbool et al., 2010). ABA hormone, is considered as the regulator of plant response to abiotic stresses, especially drought(Zhao et al., 2010). As different hormones perform different functions, thus collective application of different hormones can have synergistic and antagonistic effects (Hu et al., 2021; Mittal et al., 2014; Ullah et al., 2017). Many genes like overexpression of AtLOS5 increases the drought tolerance in cotton (Mazhar et al., 2023; Yue et al., 2012; Zahid et al., 2021). Study of genes of the cultivars that have previously been characterized for their drought tolerance provides framework for the breeding for drought tolerance (Cottee et al., 2013; Iqbal et al., 2019). Drought tolerance is the ability of plant to prevent dehydration under water deficit conditions (Ilyas et al., 2020).

There are several traits that contribute towards drought tolerance i.e., stomatal size, stomatal number and osmotic adjustments etc. (Ahmad et al., 2009). Another mechanism that plant uses is the 'drought avoidance', it is continuation of plant physiological process even during drought (Ilyas et al., 2020; Manavalan et al., 2009). As the world population is increasing, demand for quality fiber is also increasing, but climate change is a strong challenge to meet the needs of growing human numbers (Esmaeili et al., 2020). Cotton genotypes, tolerant for heat and drought are pre-requisite for breeding programs. We need to identify genetic basis of all those morphological, physiological and biochemical traits that can contribute towards the tolerance in cotton against abiotic stresses (Saleem et al., 2021). (Qamer et al., 2021)

This study was concerned compile the published literature in recent years in a brief manner so that, in future, if a plant breeder wants to work on developing drought tolerant cotton varieties, he can have a thorough knowledge of the previous literature and save his time of searching and reading more than a ton of a papers. This study includes several morphological, physiological and biochemical traits that can contribute toward drought tolerance in cotton plant. In this review, we have also focused on the molecular approaches i.e., candidate genes for drought tolerance and QTLS identification. Despite the complexity of drought tolerance, a huge progress has been made to understand its mechanism. Several morpho-physiological and molecular adaptations can be helpful for breeder to develop a drought-tolerant cotton variety

Drought stress and lint production

The complicated phenomena of lint production in cotton crops is under the control of several physiological processes and genes. Since cotton is an indeterminate crop and requires water continually for growth and output, water availability is the main factor influencing these physio-genetic processes. Effects of drought stress are mostly correlated with its duration, severity degree, and stage of plant growth. It results in the uptake of carbon and the buildup of biomass. (Zahoor et al., 2017b), decreased or sometimes no carbohydrate production (Galmés, Flexas, Savé, & Medrano, 2007), and reduced supplies to reproductive organs ultimately leads to small boll size (He et al., 2013) and reduction in lint yield (Figure. 1). Continuous increase in drought stress causes significant decrease in growth of the plant which ultimately reduces the final yield so, in cotton morpho-physiological play crucial role drought stress (Pettigrew, 2004).

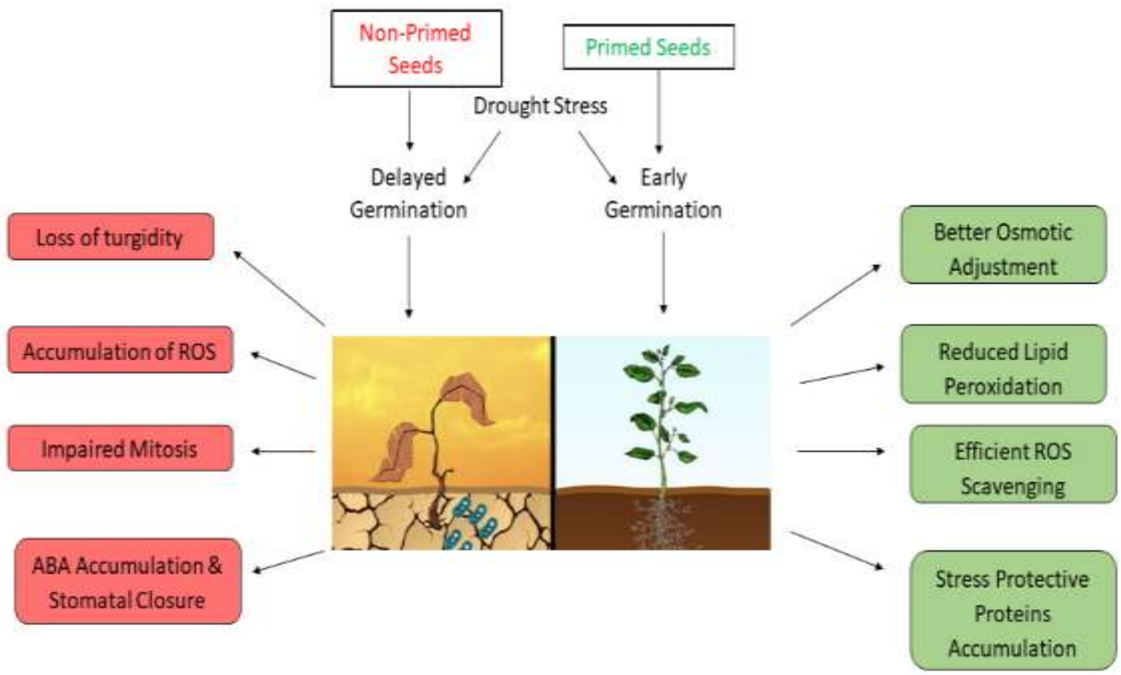

***Figure 1**: Difference between growth patterns of primed and non-primed seeds upon drought stress*

Morpho-Physiological Traits, contributing towards drought tolerance in cotton

Continuously increasing drought stress results in a severe plant growth slowdown, ultimately lowering the output. There are various morpho-physiological characteristics that cotton plants have that make them resistant to drought. (Pettigrew, 2004).

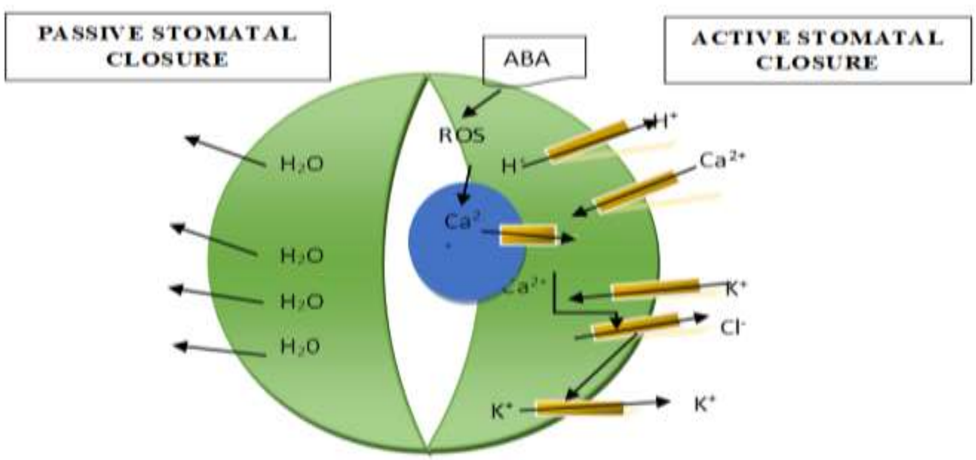

***Figure 2**: Stomatal mechanism upon drought stress*

Roots

In the cotton plant, roots are the second-most significant vegetative organ after leaves. Due to their direct connection to soil water content and role as a supplier to other plant body parts, roots are the first organs to experience drought stress. Because it is challenging to examine roots from a dried soil, there is a dearth of data accessible for a thorough understanding of the mechanisms occurring in roots.

The final output of the cotton crop is directly correlated with root growth. The amount of moisture available to roots influences the growth and development of upper plant body parts. (Zhang et al., 2017a). Soils with low water content mostly have longer plant roots and vice versa for soils with more water content (Hulugalle et al., 2015). Drought stress reduces plant growth by decreasing root mass and length densities. Plant breeders are more interested in rooting systems with many short and cylindrical roots because of their efficiency in response to drought stress. Sometimes a mild drought stress can trigger cotton plants to unlock their full yield potential (Niu et al., 2018) . If plants have long and deeper roots, they can easily look for the moisture and nutrients from water (Luo et al., 2016).

Leaves & Photosynthesis

Leaves are the most important organ of a plant in a battle with drought stress. Photosynthesis takes place in the leaves through which plants produce energy and food for themselves. When a plant faces drought stress, its stomata gets close, resulting in decreased rate of the photosynthesis process and decreased levels of CO_2 in the leaves (Zhang et al., 2017b).Stomata are closed to inhibit water from going outside of the plant to tackle the water deficit hence cell activities are disturbed, a mild or drought stress for a short period can be tackled by a plant but prolong exposure to drought stress can severely effects plant. Response to drought to depends on its intensity and age of the cotton plant (Li et al., 2013). Up to 66% photosynthesis rate reduction was observed in mature leaves of a cotton plant as compared to its younger leaves (Chastain et al., 2016).During drought stress plants usually adopt to various morphological phenomenon to tackle it i.e., accumulation of wax on leaves, rolling of leaves, thickening of cuticle, small leaves, tiny and dense number of stomata, and formation of vascular bundle sheath (Fang et al., 2015). Plants release heat using three major phenomena i.e., re-radiation, sensible heat loss and transcription. Transpiration is responsible for losing the most water contents from plants, i.e., up to 90% (Wan et al., 2009).Closing of stomata is the first step taken by plants to reduce water loss in unfavorable conditions. Stomatal conductance can be a possible morphological signal of drought tolerance induction (Figure. 2).

Genetic basis of drought tolerance in cotton

Genes are the key regulators of the mechanisms that occur in living organisms. They are often termed as the key to start any biochemical reaction in the living organisms because these entities have all the information regarding growth and development of living beings. Not just in normal conditions, their role remains the same if any unwanted conditions suddenly develop. In case of drought stress, they also play a crucial role in survival of plants. Previously using bioinformatics studies, it was reported that some genes i.e., *Gh-D01G0514* (Mehari et al., 2021), *GhHDT4D* (Zhang et al., 2020), *GaNCED3a* (Cai et al., 2021), *StDREB2* (El-Esawi and Alayafi, 2019), *GhTRX134* (Elasad et al., 2020), *GhACX3* (Shiraku et al., 2021), *ABP9* (Wang et al., 2017), *GUSP1* (Hassan et al., 2021), *GhJUB1L1* (Chen et al., 2021), *LEA Protein* (Magwanga et al., 2018c), *Gh-D06G0281 (DTX)* (Lu et al., 2019b), *GhGA2ox1* (Shi et al., 2019), *GhNAC79* (Guo et al., 2017), *GhEXLB2* (Zhang et al., 2021), and *Gh-A08G0694* (Shiraku et al., 2022) had upregulation in their expression when cotton plants are exposed to drought stress. Some gene functions are confirmed with the help of performed experiments; list of these genes given in the (Table. 1).

Table. 1*: Candidate genes for drought tolerance in cotton*

Gene	Specie	Function	Reference
GaTOP6B	*Gossypium arboreum*	Promotes Leaf and root development and act as a positive regulator in drought stress	(Shi et al., 2019)
GhSLAC1	*Gossypium hirsutum*	Controls Stomatal closure in drought stress.	(Ren et al., 2021)
GhGLK1	*Gossypium hirsutum*	Controls leaf damage in drought stress	(Liu et al., 2021a)
GhFAR3.1	*Gossypium hirsutum*	Increases wax content and on leaves and helps in retention of water under drought stress	(Lu et al., 2021)
Gh-A08G1120	*Gossypium hirsutum*	Increases plant tolerance ability against drought and salt stress conditions	(Kirungu et al., 2019)
GTOM1	*Gossypium hirsutum*	Increases efficiency of cotton plants to tackle drought and cold stress	(Lu et al., 2019a)

Cot-AD24498	*Gossypium hirsutum*	Promotes root growth and help plants in tackling drought stress	(Magwanga et al., 2018b)
Ac1-SST	*Gossypium hirsutum*	Increase photosynthesis rate and plant de under drought stress	(Liu et al., 2021b)

Transcription factors and other candidate genes

Proteins known as transcription factors have unique qualities and capabilities not present in other proteins. They typically cooperate in networks or pairs to modify particular regulatory pathways. They attach directly to the DNA, while some also use ligands. There are a lot of insightful facts about TFs for drought resistance in cotton crops that can be applied to new developments (Table. 2).

Table. 2*: Various transcription factors found in Cotton crop and their function*

TF/Gene	Primer Sequences	Function	Reference
HSP101	FP: GGAAGTGGAATCTGCGATAGT RP: GATTTTGTCCCACCACTCTTTG	NAC protein	(Yoshida et al., 2011)
HSP3	FP: AGAAAAGTTGACCCTGACCGC RP: AACCTCCTCTTCGAGACCAAAC		(Zhang et al., 2016b)
HSC70	FP: TTGTTACCGTCCCTGCATACTT RP: GACATCAAAAGTACCGCCACC		(Qi et al., 2011)
GhNAC2	FP: ATGTGCATCGCAGTCCATC RP: CTCCGTACAACGCCAAATCT		(Gunapati et al., 2016)
GbMYB5	FP: GACATCAATGGTTCAAAAGACAGC RP: ATTGAAGAACAGAAGTTGAATCCC	MYB protein	Chen et al., 2015
GhWRKY41	FP: CTTACAGTGGAAGGAAAGAAGA RP: TGAAATGAAAGGGAGATGTATTGT	WRKY protein	Chu et al., 2015
GhMKK1	FP: GAAGAAGAAGCAAAACCTCAGATG RP: GTCATCACTACAGCCGCTC	MMK protein	Lu et al., 2013
GhMKK3	FP: CTGCGTCGGATTGGGAAG RP: GAACTACTAACCTCAAGCGG		Wang et al., 2016
GhMPK2	FP: GGATCCCAGGAAAATGGCAACTCCAG RP: GAGCTCCAGTGGTAAGACAACATCGT	Mitogen activated protein kinase	Zhang et al., 2011
GhMPK17	FP: GTTGCAAGCATCCGTGGAACCAGAAT RP: TAAGACAGATTAAGAACCTCCAGAGG		Zhang et al., 2014

Conclusion

Based on the research and analysis in this review paper, it is clear that cotton product failure is a significant limiting factor, and that mastering failure forbearance in this crop is essential for maintaining yields and enhancing global food security. Examining the state of our understanding of the physiological and inherited causes underlying failure In the subject of forbearance in cotton, the important factors that contribute to the factory's capacity to withstand water stress have been underlined. The intricacy of the inherited and molecular mechanisms involved, as well as the high expenses and length of time required for screening and selecting, are just a few of the significant obstacles and constraints in breeding failure-tolerant cotton varieties that the review has connected. Despite these obstacles, the review has also uncovered some promising directions for future research and invention in this area, such as the use of cutting-edge genomic tools and strategies to pinpoint key genes and molecular pathways linked to failure forbearance as well as the creation of more efficient and affordable webbing designs for tying failure-tolerant cotton lines together. Overall, this review has provided insightful information. into the physiological and inheritable base of failure forbearance in cotton crop, and has stressed the significance of continued exploration and development sweats in this area. By perfecting our understanding of the complex mechanisms involved in failure forbearance in cotton, we can develop new kinds that are more suitable to repel water stress and insure a more sustainable and flexible future for cotton product.

Declarations

Conflict of interest

The authors have no conflict of interest.

Data Availability statement

All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate

Not applicable

Consent for publication
Not applicable
Funding
Not applicable
Author Contributions
All authors contributed equally in this study.

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