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IMPACT OF ABIOTIC STRESS ON COTTON PRODUCTIVITY AND STRATEGIES TO AMELIORATE THE EFFECTS

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Abstract *Cotton has been grown as an important fiber cash crop, which has most significant impact on economies and livelihoods throughout the world. However, its development and productivity are significantly impacted by abiotic factors like drought, high temperatures, waterlogging, and salinity of the soil. Reduced yields result from these environmental issues that interfere with physiological activities as photosynthesis, metabolism, and fiber growth. While water and salt stress affect cellular processes and nutrient intake, high temperatures speed up evaporation and change reproductive growth. These stresses can be mitigated with the use of efficient management techniques, such as improved irrigation techniques, genetic innovations, and cultivars resistant to drought. Functional genomics and marker-assisted selection offer encouraging paths toward enhancing cotton's resistance to abiotic stress. Addressing these challenges is crucial for sustaining cotton production under climate change and resource limitations.*

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Introduction

Cotton is an indeterminate crop (Constable and Bange, 2015). In order to continue producing lint and cottonseed yield more effectively and profitably, producers need a greater understanding of cotton growth and development in commercial production. The negative impacts of abiotic stress on cotton must be reduced. Human food production uses more than half of the fertilizers, and this demand has grown exponentially each year to reach over 7.3 million tons globally. China has been the world's top producer of cotton for the past six years, with the United States, India, Pakistan, Brazil, Uzbekistan, and Turkey (Khan et al., 2017). Cotton is contributing a major portion of the gross national product (GNP) for many countries around the Globe. The accumulation of greenhouse gases, along with carbon dioxide in the atmosphere at a soaring rate, might pose a threat to agriculture soon. It has been mentioned that global warming (GW) will result in more environmental fluctuations in the majority of agricultural zones of the globe (Zahid et al., 2016). Additionally, millions of people who work directly or indirectly in the textile business depend on the cotton harvest for their livelihood. Recognizing the crop's contribution to Pakistan's economic development, efforts to increase its yield under various environmental conditions, and make the better use of resources which are available for effective crop plant production have always been ongoing (McAlavy, 2004).

An abiotic stress is always a detrimental impact due to non-living elements to living things. Because of sessile nature, plants must endure a variety of pressures throughout their lives in order to grow, survive, and produce new generations. High temperature is among the most significant hazard for global food security among all abiotic stresses. It has been demonstrated that a temperature increase of 17% (in degrees Celsius) can impact agricultural yield throughout a growing season (Lobell and Asner, 2003). Abiotic stresses caused a significant impact to reduce cotton development, growth, as well as its production. It is a crop used for fiber. Around the world, it is grown in various nations. Cotton crops are processed to make clothing, household goods, and medications. Cotton meets the need for human oil consumption and as raw material in textile industry. The three main abiotic stresses that are thought to be the key contributors limiting cotton productivity are extreme temperatures, salt stress, and water deprivation. Abiotic stress has caused a 50% global decrease in cotton production (Bita and Gerats, 2013). Like other field crops, cotton crops need ideal growing conditions to produce their highest yield. For instance, the cotton crop prefers a temperature between 27 and 32°C when the boll is forming (Bibi et al., 2010). Alkalinity and salinity have the most effect on plant development and productivity. Because salt functions as an osmoticum, cotton experiences water stress. Another significant factor contributing to this crop's poor yield is specific ion toxicity. Another important factor is nutritional inequality. The photosynthetic process and membrane thermostability are impaired by high temperature control, which has an impact on plant metabolism. Higher temperatures have the potential to denature proteins and increase the sensitivity of enzyme activity. The reduction in turgor pressure in cotton crops is a result of drought stress and affects cell growth. Photosynthesis and glucose metabolism effected by drought stress directly or indirectly to damage plant health (Leakey et al., 2009).

Types of abiotic stress

Numerous environmental abiotic parameters, such as temperature or heat, soil salinity, drought, and waterlogging, impact crop productivity by interfering with all plant metabolic processes.

Waterlogging stress

Waterlogging is a condition in which the soil surface has a lot of water and becomes saturated with water as a result of excessive drainage and rainfall in places that are level or have poor drainage. Approximately 10% of the world's geographical area experiences waterlogging each year (Volkov et al., 2016). Because microbial and plant activity use the most oxygen, there are two conditions: anoxic (absence of oxygen: the energy is gain due to fermentation), and the hypoxic (caused due to low oxygen concentration: mitochondrial metabolism or photorespiration is reduced due to which fermentation takes place). Due to less oxygen present when the soil is wet, its physicochemical characteristics such as its pH and redox potential are significantly altered (Pezeshki et al., 1990). Waterlogging has a number of negative effects on cotton plants, including possible termination of growth and death of root apices, as well as potential changes in nutrition patterns. Waterlogged conditions are fatal for cotton growth because they prevent gas exchange and generate energy issues (Voesenek and Bailey-Serres, 2013). Cotton growth and yield formation are significantly impacted by the waterlogging process. However, these procedures are also intricate and still unknown. According to reports, cotton has very little capacity to adjust to waterlogging stress (Brodrick et al., 2012).

Temperature

Temperature is a key factor for crop cultivation since all crop plants required the ideal temperature or heat for their healthy growth, development and health. Temperature is the primary determinant of cotton crop growth rate. Although cotton is a tropical plant which can withstand high temperature or under heat, exceptionally hot weather conditions reduced cotton production (Ullah et al., 2016). Whether too hot or too cold, extreme temperatures can cause a major impact on cotton crop growth and development, either postponing or lowering total production. For example, a temperature increase of only 2 to 3°C over the ideal will impede growth, lower yield and biomass, and increase fiber micronaire. Even minor departures from ideal conditions can have a significant impact on plant growth (Majeed et al., 2021). Heat or high temperature caused direct or indirect impact through leading drought and salt stress conditions in the soil. Increased evaporation from the fields frequently causes drought stress. High temperatures have been linked negatively to cotton production, according to research done in Arkansas, USA (Oosterhuis, 1999). They discovered that the biology (vegetative and reproductive stages) of cotton is consistently disrupted by high temperature. Eventually, this impact causes cotton plants to produce more vegetative portions and fewer reproductive portions (Reddy et al., 1991). Other severe impacts of heat stress can also have a substantial influence on the cotton crop's reproductive stage; in general, the maturation of reproductive parts may be more affected, which could result in a lower yield. The first square formation, or blooming start, and the boll opening or formation rate, dropped when the temperature rose over the ideal or typical level. Under high temperatures, the retention phase for the bolls and squares and largely decreased. Similar to high temperatures, low temperatures harm cotton growth. Extreme temperature decreases below 11°C may slow the growth of cotton, which in turn may prolong its growth cycle (Bange et al., 2016). In addition to physiological responses and methods for cold tolerance, Yadav talks about how plants respond to cold stress (Yadav, 2010).

Drought and Salinity Stress

The average annual temperature has increased due to global climate change, which eventually causes more water to evaporate from soils and causes drought. Drought and salinity stress are referred to as osmotic conditions (Rani et al., 2021). Drought stress is currently regarded as one of the main causes of the global decline in cotton yield. Scientists predict that in the modern period, the number of agricultural lands severely affected by drought stress will double (Deeba et al., 2012). They also predicted that there would be intense competition for water resources and that urban, industrial, and agricultural areas would experience water shortages (Tombesi et al., 2015). Drought and salinity stress caused a significant effect on cotton production; the primary causes of the decline in cotton yield and lint quality degradation are drought and salinity (Abdelraheem et al., 2019; Sharif et al., 2019). When exposed to extreme abiotic stressors, cotton plants exhibit noticeable morphological and physiological alterations. The aforementioned pressures have a detrimental effect on every parameter, from seed germination to boll development. Furthermore, by reducing the mass and fiber development of the boll, prolonged exposure to such abiotic conditions would ultimately result in a decrease in yield and harm to lint eminence. As a result, it already confronts unfavorable effects, and disruptions to its catabolic processes, such as photosynthesis, result in a decrease in yield (Abdelraheem et al., 2019; Majeed et al., 2021; Sharif et al., 2019). Plants often use a number of internal mechanisms to adjust to drought stress or other water-scarcity situations, but many crops' primary reaction is the closure of their stomatal glands (Tombesi et al., 2015).

Management of Abiotic Factors

Drought Stress

Drought of the one of the main abiotic factors preventing sustainable and high cotton production worldwide. In this sense, a thorough understanding of soil conditions through in-depth research is necessary to effectively combat the consequences of drought (Whitmore and Whalley, 2009). In arid regions, upland cotton is commercially grown consistently which shown a good correlation with a sufficient irrigations or water supply (Constable and Hearn, 1980). As a fundamental agronomic strategy, cotton farmers always use a modified field row layout in reducing the effects of water deficit or drought stress conditions (Payero et al., 2012). Crop rotation with cereal crops, on the other hand, may help to improve soil health through increasing the soil's ability in storing water as well as makes it accessible to the crop plants (Hulugalle and Scott, 2008). These characteristics should be taken into consideration by molecular technologists or botanists studying plant physiology when they are creating novel strategies for managing drought stress. Drought caused adverse effect on plants growth and physiological reactions (Farooq et al., 2009). It has also demonstrated that the most effective way to mitigate the impacts of drought and boost cotton production can only be achieved by the prudent or suitable use of soil and water, two essential natural resources (Ostle et al., 2009).

Temperature or heat stress

Climate change is a worldwide concern. This immediately causes abiotic pressures, which in turn challenge the environment as a whole. The atmosphere's excess carbon dioxide content is the primary cause of global warming. As a result of global warming the average increase in annual global temperature or heat has caused to increase water evaporation from the soil, which eventually causes drought and salty soils (Rani et al., 2021). Despite being a tropical crop that can absorb intense solar radiation, temperature stress causes direct harm to cotton's reproductive and vegetative phases, resulting in reduced yield (Reddy et al., 1991). Due to higher solar light intensity the canopy temperature of crop plants increased which leads to increase phto-inhibition. However, various crop plants have ability to develop waxy surfaces which minimize the sun's intense radiation. In case of cotton, the plants absorbed more solar energy, which increased the osmotic pressure to combat with heat and drought stress. To bear higher temperature or heat stress different varieties with desirable characteristics, like deep hairs to reduce heat stress and a dense cuticle structure, may be beneficial. Water stress may be mitigated by frequent irrigation. Temperature-sensing remotes via the canopy have recently been used to create some new and creative plant-based irrigation systems (White and Raine, 2008). The stomata closure at night, leads to prevents cooling action in leaves is another harmful plant growth habit of cotton. In this regard, biotechnologists and plant breeders can concentrate on creating cultivars or varieties that are resistant to heat stress. Since the roots play a crucial role in providing water to the entire plant, understanding their composition and function is just as important as understanding the different kinds of soil. This may further exacerbate heat and water stress because sandy soils are less able to hold water for extended periods of time (Hussain et al., 2023).

Management Strategies of Salt Stress

Marker Assisted Selection

A complex quantitative trait, salt tolerance is regulated by numerous genes, each of which has a minor impact. Its genetic regulation cannot be clarified by a single gene-based study. Quantitative trait loci (QTL) investigations have provided an explanation of the genetic basis of salt tolerance in a variety of plants (Wang et al., 2012). A promising method for indirect selection of salt-tolerant genotypes is marker-assisted selection. Ten salt-tolerant traits in cotton were mapped using association analysis using 145 SSRs. Of these, 95 SSRs demonstrated significant associations with salt-tolerant characters, of which 41 were linked to the physiological index at the seedling stage, 37 to the biochemical index at the four-seedling stage, and 17 to the germination index (Du et al., 2016).

Functional Genomics

Gossypium davidsonii is a wild cotton species that can withstand salt stress (Zhang et al., 2016), however, *G. barbadense* was categorized as more salt-tolerant among several cultivated cotton species (Ahmad et al., 2002). Salt tolerance in *G. hirsutum* is mostly attributed to the D-subgenome (Li et al., 2014). Cotton germplasm exhibits considerable variation, and studying this variability may help create cultivars that can withstand salt. In order to control the expression of genes, transcription factors are essential. Only a small number of salt-resistant genes have been documented in cotton, although many salt-responsive genes have been found in other plants. DREB (Guo et al., 2009), MPK (Zhang et al., 2011), NAC (Meng et al., 2009), MKK (Lu et al., 2013), and ZFP (Guo et al., 2009) are a few of these. Using transcriptome sequencing data, (Fan et al., 2015) discovered 109 WRKY genes (GarWRKYs) in the wild salt-tolerant *Gossypium aridum*. RT-PCR analysis verified that 27 of these genes were expressed in the roots.

Management of water stress

Plants experienced severe water stress when the soil's water content decreased. Under such stressful circumstances, gene expression might change (Chen et al., 2017). Gene expression may be directly triggered by water stressors or indirectly impacted by secondary stresses or damage response. Water stress tolerance is thought to be a complicated process that involves multiple genes with high levels of activation (Cattivelli et al., 2008). Using microarray technology, it has been discovered that the genes triggered by water stress may be divided into two groups: regulatory and functional genes. This division is based on how well the genes' products function (Zhu, 2002). Functional genes produce functional proteins, which include membrane proteins, enzymes, late embryogenesis abundant (LEA) proteins, antifreeze proteins, molecular chaperones, essential enzymes for the biosynthesis of osmolytes, and detoxification enzymes like proline and betaine. Although membrane transporters and water channel proteins are directly associated with plants' defense against the negative consequences of environmental stressors (Akhtar et al., 2012), regulatory proteins are made by transcriptional factors and other regulatory genes (Zhou et al., 2010).

Conclusion

In conclusion, cotton growth and yield are greatly impacted by abiotic factors such as salinity, drought, high temperatures, and waterlogging, leading to the need for efficient management techniques for ensuring sustainable production. Innovative strategies to increase cotton's stress tolerance include functional genomics, marker-assisted selection, and better irrigation methods. Further research should concentrate on using biotechnology to develop genetically resilient cotton types, improving soil and water management strategies, and using climate-smart farming methods. It will be essential to combine these strategies with remote sensing and precision farming technology in order to reduce environmental issues and ensure that cotton is produced worldwide for future generations.

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Declarations

Author Contribution statement

NN conducted research and wrote the initial draft of manuscript. QA and JA helped in data collections and write up, The final editing was carried out by all authors. All authors read and finally approved for publication.

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

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Regarding conflicts of interest, the authors state that their review was carried out independently without any affiliations or financial ties that could raise concerns about biases.