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Abiotic stress responses of cotton: A review

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Abstract
The growth and yield of many crops, including cotton, are affected by water deficit. Cotton has evolved drought specific as well as moderately salt tolerant. The basic morpho-physiological, biochemical responses to drought, salt, temperature and light are discussed in this review. The key physiological responses against drought stress in cotton, including stomata closing, root development, cellular adaptations, photosynthesis, abscisic acid (ABA) and jasmonic acid (JA) production and reactive oxygen species (ROS) scavenging, have been identified by researchers. High temperatures under water deficit leads to photo oxidation, and temperature fluctuations also influence the phenology of crop. The blue and red light has maximum positive influence on photosynthetic reactions. The current review article highlights the abiotic stresses and the responses of the plant towards stress.

Keywords: Cotton, high density planting, abiotic stress, abiotic stress tolerance, rainfed cotton

Introduction
The first ever evidence of cotton production was found about 6000 B.C. in India and Pakistan. The cotton is grown mostly in tropical countries as a *Kharif* crop, takes 6 to 8 months to mature. The crop in India is mostly grown in April – May and harvested in December – January, before the frost damage risk. The crop grown in India is closely related to deep black soils of Deccan and malwa plateaus in Gujarat. It can come up well up to 500 m mean sea level.

India, followed by China is the largest producer of cotton and second largest exporter of cotton. Gujarat is the largest producer of cotton, contributing about 35% of production (110.9 lakh tonnes), Maharastra (70.2 lakh tonnes) and Andhra Pradesh (Ministry of agriculture, GOI). The major cultivated varieties of cotton are S-6 & S-4 in Gujarat, MCU-5 & DCH- 32 in Andhra Pradesh.

Cotton is popularly perceived as reasonably exhaustive crop and mostly not completely mechanized in India. The development of varieties should emphasize on early boll formation along with yield improvement and yield stability. For crop improvement, one of the most commonly used strategy, is breeding of stress-tolerant crop for any water-scarce based calamity (Khan *et al.*, 2018) [9].

Cotton has been a fascinating crop to work with. It is highly responsive to environmental signals.There are three basic types of cotton *i.e.*, long staple cotton (24- 27 mm), medium staple cotton (20-24 mm) and short staple cotton (< 20 mm). The crop has historic importance also. It is primarily being grown as lint crop and also has many bi products.

Cotton and its responses towards various abiotic stresses
Its indeterminate growth habit and severe sensitivity towards the abiotic fluctuations make the crop unique.

A. Moisture and cotton
Cotton requires an annual rainfall of 50-100 cm. The crop is moderately drought sensitive. Two thirds of crop grown as rainfed in India. Within one third of irrigated crop in India, 80% is grown in Punjab, Haryana, Gujarat and Rajasthan.

Moist climate coupled with heavy rainfall particularly at stages of boll opening and picking, increases infestation of sucking pests and fungus. A set of high rainfall at early stages and sunny dry weather at ripening stage is highly desirable and leads to good boll setting.

Water deficit is the major abiotic factor limiting plant growth and crop productivity around the world (Kramer, 1983) [11]. Survival of a plant depends upon proper water balance.

Photosynthesis, respiration, transpiration and any taken metabolic activity which have enzymes involved will need proper water status for homeostasis. And net production is decreased in case of moisture stress. Protein breakdown, production of ROS are also results of moisture stress. To mitigate such stress plants develop anti oxidants to fight ROS. The hormone ABA acts as stress hormone. Proline is an aminoacid increases accumulation at cellular level upto 100 folds under severe moisture stress.

Water-deficit stress reduces cell and leaf expansion, stem elongation, and leaf area index (Gerik *et al.,* 1996) [6, 7]. Addicott and lynch 1955, reported a linear relationship between the rates of leaf abscission and the levels of the imposed water stress. They also speculated the importance of required water quantities for formation of abscission layer. This stress of water has influences at biochemical level. The plants exposed to moisture stress had shown the changes in chemical composition of epicuticular was and lipid contents. The wax from water-stressed leaves contained more long-chain alkanes compared to the control (Oosterhuis *et al.,* 2011; Bondada *et al.*, 1996) [14, 2].

Moisture deficit has a prominent effect on physiological attributes of the cotton. And the effects are quit complex and cybernetic. As the relative water content and leaf water potential decreases photosynthetic rates decreases (Lawlor and Cornic, 2002) [12]. The stomatal closure, inhibition of metablic processes, gas exchange and reduced ribulose bis phosphate synthesis are maybe attributed to the low photosynthetic rates. Boyer, 1970 found that stomatal resistance due to stomatal closure increased dramatically at between -0.8 and -1.2 MPa in cotton. Regeneration of Ribulose 1,5-Bis Phosphate (RuBP) is the limiting factor for photosynthesis under drought.

Around the world, the "American long-staple cotton," or upland cotton, is cultivated on 90 percent of the land. In some parts of India, especially states like Maharashtra Andhra Pradesh odisha are very much drought prone and this results in poor crop establishment and bellow average crop yields. Episodic drought events are causes of severe lint yield penalty and may become a greater challenge for sustainable crop production. On other hand, even a small but adequately timed irrigation can significantly improve water-stressed crop (Zahoor *et al.,* 2017) [18]. Cai *et al.*, 2013 [3] reported 50- 70% of lint yield losses due to drought.

Being a crop of indeterminate growth habit, production of new nodes in a cotton plant depends on water availability (Khan *et al.,* 2018) [9]. The drought tolerance is a oligogenic trait and depends up on various environmental and genetic, physiological factors. Thus a sound understanding of phenological, morpho– physiological and biochemical mechanisms of crop is needed for sustainable crop improvement.

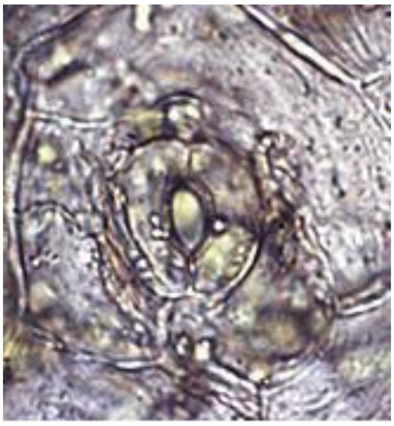
Structural and physiological responses to drought

Drought resistance mechanisms in plants are composed of four categories: recovery, avoidance, tolerance and drought escape. Stress avoidance strategies of crop include stomatal regulation. Drought tolerance is ability of plant to withstand the negative impact of stress by osmo regulation and accumulating osmo protectants. And some plants complete their life cycle before possible onset of water stress, come under drought escapers. Being glycophyte, cotton could tolerate slight concentrations of salt in soils and also moderately drought tolerant.

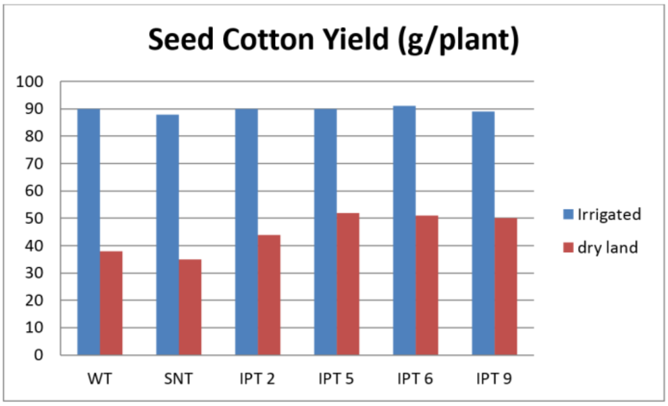
Stomata regulation

Stomatal regulation plays a significant role in leaf gas exchange between the intracellular cavity of the leaf and external environment (Khan *et al.,* 2018) [9]. Stomata occur on the epidermal layer of plants. Stomatal pore surrounded by two guard cells along with surrounding subsidiary cells form the stomatal complex. Wilting is the earliest visible symptom for drought. The leaf rolling and wilting leads to less radiation interception and ultimately lower water loss. In general the plants xerophytic adaptations include thick cuticle, wax coating, thick and tiny leaves with low leaf area ratio, smaller and denser stomata, sunken stomata and more trichomes with a well structured vascular and mechanical tissues.

The plants dissipate excess heat energy through re- radiation, heat loss (through conduction and convection) and transpiration. Among such most significant is transpiration. Almost 80 to 90% of water loss occurs from the plant through stomatal transpiration. Often lenticular and cuticular transpiration also plays a minor role under particular conditions.



Stomatal apparatus on the cotton leaf



Seed cotton yield of cotton lines under full irrigation and dry land conditions. (Adapted from Zhu *et al.,* 2008) [19]. WT, wild-type cotton (Coker 312); SNT, segregated non-transgenic cotton; IPT2 to IPT9, four independent *IPT*-transgenic cotton lines. Black bar, full irrigation condition; grey bar, dry land condition. *Statistically significant at the<0.05 level; **statistically significant at the < 0.01 level.

A. Salt stress and cotton

In cases of low moisture availability and high salt concentration outside the root environment makes it difficult for plants to absorb water. To mitigate this plants produce and accumulate osmolites in cells. They help in increasing the osmatic concentration in the root which in turn creates water

potential gradient between soil and root. And this gradient acts a force for absorption of water into the root cells from soil.
Compatible solutes like proline, sorbitol, and glycinebetaine, and are more soluble and do not interfere with cell metabolism even at higher concentration (Bray *et al*., 2002) [1].

B. Temperature and cotton
Cotton being a tropical crop, requires uniform high temperatures approximately 21 to 30 ^{0}C. There are also reports of reduced growth rate under conditions of temperature below 20 ^{0}C. The plant is also physiologically sensitive to freezing. It needs a minimum of 210 frost free days in a year for proper anthesis and yield.
Cotton itself a perennial shrub and has semi xerophytic origin. But there are also studies shown negative correlation between temperature and cotton yield. Leaf expansion is optimal under a 30/22 °C day/night temperature regime for Upland cotton and declines at temperatures in excess of this growth temperature regime (Reddy *et al.*, 1992c) [16]. The *gossyopium* is moderately tolerant to chilling and salt stress. High temperatures at tropical areas particularly for upland cotton has both desirable and undesirable influences on plant functions. For instance high evoparative demand at high temperatures could cause intense water stress (Hall, 2001) [8], which speeds up the metabolic activities and end up with more losses of water.
When high temperatures exposure is coupled with water deficit, the plants may be resulted in photooxidation. Through photo oxidation chlorophyll molecules or any thermo sensitive compounds will be oxidized and damaged. In such conditions, plants produce anti oxidants SOD, APOX, CAT, GR. Temperature also influences the solubility of gasses, like CO_2, O_2. Low or adaptive temperatures facilitate better solubility of gasses, and high amounts of gases can be held in cell sap. Thus low temperature favours high production of carbohydrates and inturn reduces the low temperature stress. High temperatures increase the time for transition of phenological stages. Boll retention and number of fruiting branches are also negatively influenced by high temperature. Heat stress is reported to inhibit the pollination by limiting the anther dehiscence in rice (Matsui and Omasa, 2002).
From 1979 to 2003, an increase of 0.35 and 1.13 °C have already documented in the annual mean maximum and minimum temperatures respectively, at the International Rice Research Institute, Manila, Philippines (Khan *et al.,* 2018) [9]. These climate particularly temperature changes and scanty rainfall have exposed the crops to drought induced stress. Drought severity is unpredictable as it depends on several factors, for instance rainfall amount and distribution, evaporative demands and moisture storing ability of soils. Over the las 50 years, drought stress alone was responsible for approximately 67% of the cotton lint yield losses in USA, one of the top cotton producing countries in the world (Comas *et al.,* 2013) [4].

C. Light and cotton
Among a lot of electromagnetic radiation spectrum (ERS) that reaches earth's atmosphere, human eye can only detect small portion of this spectrum. And that portion is closely corresponds to photosynthetcically active radiation (PAR), which ranges from 400-700 approximately. This PAR radiation is responsible for photosynthetic energy and electron transport reactions in plants. But the radiations beyond this range also have a role in physiology of plant. Far –red and red light radiations can be detected by phytochrome, a blue colored pigment. Photomorphogenesis, the light altered growth is directed in plants by phytochrome, cryptochrome and phototropins.
UV light has a negative effect on plant growth. Light at insufficient intensities can lower the rate of photosynthesis and electron release from water breakage during light reactions. Too much of light intensity can also cause photoinhibition, which is a potential photo destructive reaction.
Alteration of light intensities affected growth of cotton plant Transpiration rate and SPAD readings are highly sensitive to light intensities. Low light intensity has negative effect to growth of cotton and lead to slow growing owing to lack of light.

Conclusion
The need for development of desired machinery and location specific varieties for cotton is need of the hour.

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