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Chapter

Enhancing Water Use Efficiency by Using Potassium-Efficient Cotton Cultivars Based on Morphological and Biochemical Characteristic

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Abstract

Pakistan's agriculture sector faces a 50% water shortage, impacting crops like cotton and the textile industry, thus affecting the economy. K-efficient cotton cultivars, which withstand dry conditions through morphological and biochemical traits, can conserve moisture. K-efficient cotton cultivars can be used as donors of key K acquisition traits in breeding programs to develop promising cotton varieties with enhanced yields for the low K environments and can also be recommended for general cultivation to improve cotton production on a sustainable basis. This chapter aims to contribute to enhance water use efficiency (WUE) on the physiological basis to develop strategies for K-efficient cotton cultivars for improvement. Strategies involve regulating transcription factors to improve K-uptake efficiency, increasing root volume through lateral roots and root hairs, and enhancing K-uptake via channels and transporters, ultimately boosting WUE. Molecular breeding programs can leverage K⁺-associated QTLs to develop high K⁺ use efficiency cultivars. Physiological processes affecting WUE are discussed alongside factors influencing their contributions, acknowledging the complexity across crops, environments, and nutrients.

Keywords: K-efficient cultivars, gas exchange traits, morphological traits, water use efficiency, potassium use efficiency

1. Introduction

Cotton, which is a prominent commercial crop in over 30 nations, is produced mostly in warmer areas and has large shareholdings in China, India, the United States, and Pakistan [1]. In 2014–2015, the top five cotton-productive nations were China, India, Pakistan, and Brazil, with 6.5, 5.4, 3.5, 2.3, and 1.5 M, respectively [2]. As a glycophyte, cotton is more tolerant than other main crops to abiotic stressors. However, extreme conditions, such as drought, affect cotton growth, productivity, and fiber quality [3]. Cotton production is predicted to decrease owing to drought stress, according to a news release issued by the United States Department of Agriculture [4].

Similarly, cotton output decreased by 34% in Pakistan to only 9.68 million bales compared with 14.4 million bales in 2012, due to drought and high weather [5]. Other crops were harmed by drought in addition to cotton, as about 67% of crop losses in the United States were caused by drought stress in the last 50 years [6].

Water use efficiency (WUE) can be increased by reducing soil water evaporation and converting more moisture into biomass production through crop residue management, mulching, and target-based irrigation. Appropriate arrangement and improved water use is a possible measure for improving yield under water stress, and it assesses the way and depth of water application, and whether it was used at optimum level by the crop. Improved irrigation water use efficiency can be achieved by approving the best management practices of irrigation [7].

Potassium (K) is affianced in all the physiological developments of the plant, which need water. K supports water carrying and mineral translocation for the entire plant through the xylem. Under K-deficiency, the movement of minerals such as (NO_3^-), (PO_4^{3-}), (Ca^{2+}), (Mg^{2+}), and amino acid uptake is abridged. One option is to use the normal rate of K application can support the plant to alleviate the effect of the water-deficit through better water use efficiency (WUE), which was related to the lower leaf ET [8]. Secondly, the option is to use K-efficient crop cultivars that can reduce the effect of water shortage and improve WUE without compromising the yield [9]. This can be achieved by the K-efficient cultivar by special proteins present in the cell membrane. These are called transporters and channels. Based on their affinity for K^+ , K^+ transport components can be classified as high-affinity components (transporters), which are active at a low concentration of external K^+ , and low-affinity components (channels), which are active at a higher concentration, usually at more than 0.3 mM external K^+ [10]. During water shortage conditions, root regulate their water and ion uptake by modifying these proteins and channels to cope with the water shortage [6, 11–32]. It is, therefore, K-efficient cotton cultivars that could perform better for sustainably cotton production under arid climatic conditions.

1.1 Cotton is drought-sensitive crop

Millions of people worldwide are involved with cotton directly or indirectly. Cotton is a severely susceptible crop under water stress conditions that reduces productivity [33]. Earlier, water stress reduced cotton growth and cotton yield due to lowered flowering and retention of the boll. Cotton is classified as a low drought-sensitive crop, according to FAO data; however, drought stress is dreadful when cotton is at the flowering and bolls formation stages [34]. In Pakistan, the cotton crop is mainly grown in arid and semiarid climatic conditions where annual rainfall is less than 250 mm. In the future, therefore, cotton productivity is estimated to drop due to severe water shortages, irregular patterns of rainfall, and other environmental impacts [35].

Drought has broad and variable effects on cotton, such that exact financial figures are hard to calculate. In 2008 and 2009, world production of cotton was extremely low and in 2009 stocks declined significantly. As a result, in 2010 and 2011, cotton prices increased, causing a 10% drop in cotton consumption in 2011. From 2010 to 2013, the output of cotton was more than demand, but from 2011 production declined significantly from 2014 to 2015 by 6.5 percent, while consumption grew by over 6.5 million bales per year. We thus need to set cotton production and consumption strategies. Furthermore, because too unpredictable situations in the future, stressful cotton types must also be produced. The focus must, on the other hand, not only be placed on the diversity of stress-tolerant of cotton, although plant survival is highly essential

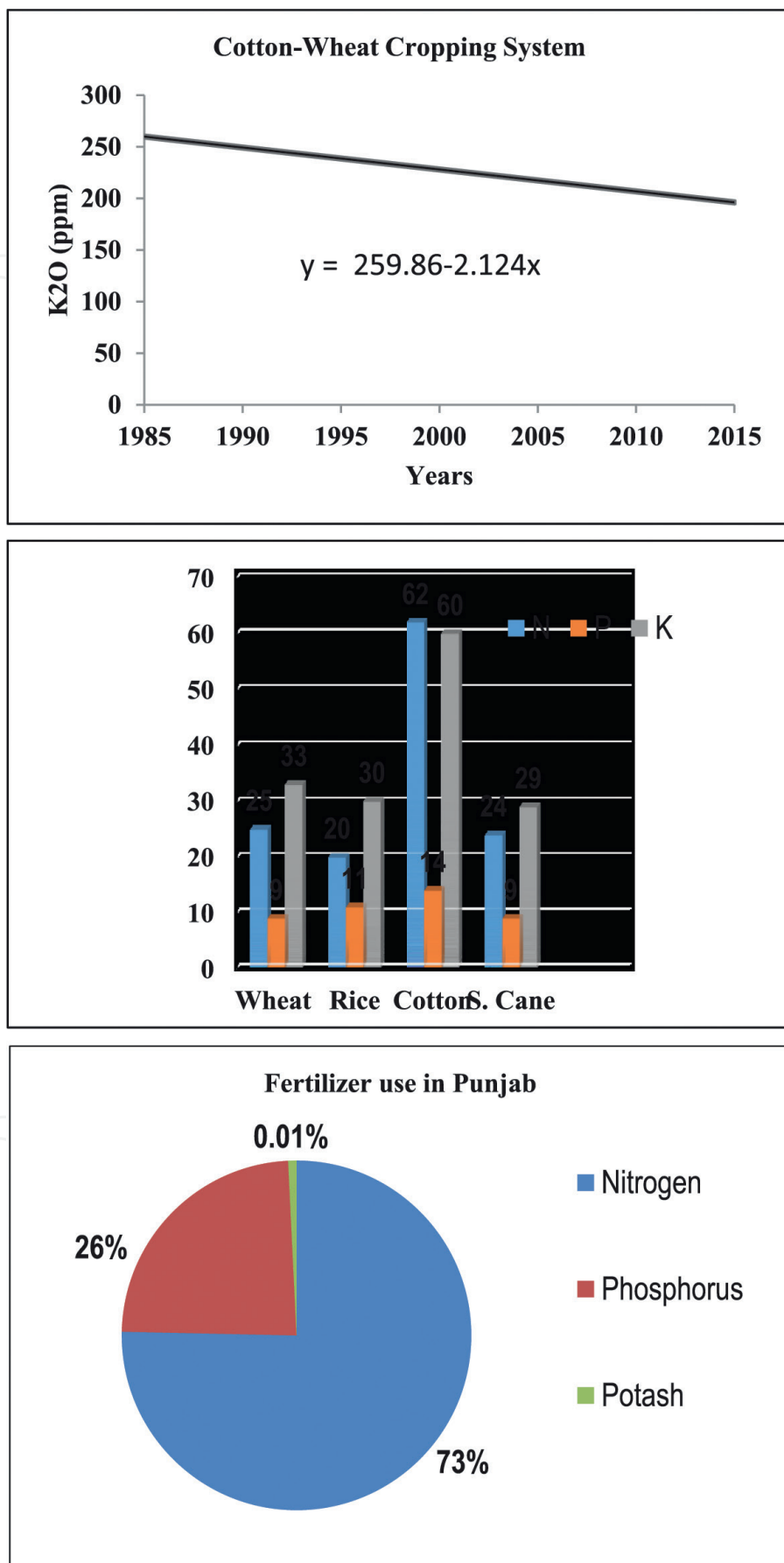


Figure 1.
K status and crop removal in Pakistani soils [11].

in the early stages of growth. It is widely recognized that improvements in yield and the stability in yields in cotton cultivations are vital for the expanding worldwide population under normal and drought conditions. Despite the complexities of the process of drought tolerance in cotton, the knowledge of the drought tolerance mechanism has been tremendously advanced. The drought-tolerant type of cotton might lead either to morpho-physiological, biochemical, and molecular modifications by nature or genetic engineering.

1.2 Current scenario of K-deficiency

The soil contains on average 2% K; however, soil K may be quite low in older or drained soils. Soil K is usually available in four pools: 0.1–0.2% of the soil solution, 1–2% of the exchangeable K, 1–10% of the nonexchangeable K, and 90–98% of the soil mineral solution [36]. Plant roots collect K from variable pools and dynamically adjusted K solution for soil [36, 37]. The soil K in a solution pool of soil is filled by potassium released from interchangeable areas [36]. The nonexchangeable K may be found in the range of 2: 1 and 2: 1: 1 type clay minerals [37]. Some plant species have been discovered to utilize K from an unchangeable pool, such as sugar beet (*Beta vulgaris* L.) with exudates, which results in a K-influx of 7–20% higher than that for wheat and barley roots [36].

The deficiency of K in Pakistani soils is about 35% [38], which is continuously increasing due to the low use of K ($<1.0 \text{ kg K}_2\text{O ha}^{-1}$) as compared to other countries of the world ($15 \text{ kg K}_2\text{O ha}^{-1}$). In the year 2007–2008, about 43% of Pakistani soils were deficient in K, as reported by Ref. [39], but currently, it reached up to 90% and needs K fertilization for better crop production. Cotton requires $\text{K}_2\text{O @}150 \text{ kg ha}^{-1}$ that almost equal to nitrogen from the soil, to get average crop yield [40] and is required $@ 4.5 \text{ kg ha}^{-1} \text{ day}^{-1}$ during peak bloom by cotton [41]. Despite high-K requirements, K-use in cotton production is very limited in Pakistan. The total content of K varies from 50 to 150 mg kg^{-1} in the soil across the Punjab province. Adequate K nutrition upgrades the proficiency of photosynthetic rate and development of plant roots, as investigated by Ref. [42]. However, most of the farmers of developing countries, including Pakistan, do not apply K-fertilizer to crops due to their high-prices. Under this situation, the identification of K-efficient crop cultivars can improve production and reduce the demand for K fertilizers in the country (**Figure 1**).

2. Biochemical modifications in cotton plant under water stress

In many plant activities, water is vital for the transport of nutrients, chemical and enzymatic reactions, cell growth, cell division, and transpiration [43]. Drought stress reduces plant development due to disruptions in the plant's main biochemical and physiological systems [44]. Drought stress affects root penetration, and stem elongation and increases water use efficiency. The leaf water potential, rate of transpiration, and leaf temperature are important traits that affect the growth of plants under water-deficit conditions. Although all stages of cotton development are affected by water stress, however, the reproductive phase, that is, flowering and boll development, are generally accepted as the most sensitive stages [45]. A very close relationship between nutrient uptake and water use efficiency has been observed in many crops. Therefore, nutrient uptake was reduced during drought stress, particularly N and K in cotton. Similarly, K contents in plant tissue also decrease due to drought stress and an overall reduction in nutrient uptake and there utilization [43].

Root growth is important for plant development as water and nutrients are mainly taken up via roots, whereas root elongation is affected by drought stress which ultimately limits crop yield [20]. Under severe drought stress, the elongation of plants may be inhibited by interrupted water flow from the xylem to the surrounding cells, which impairs mitosis and cell expansion, resulting in a reduction of root growth, nutrient uptake, plant height, and leaf area as well as plant growth [46]. In cotton, under water stress conditions chlorophyll contents decreased which reduced photosynthesis rate, sugar production, and pigments including chlorophyll *a*, chlorophyll *b*, and carotenoids [47].

There is a root-to-leaf transduction of chemical signals caused by water-deficit stress, through the production of abscisic acid (ABA), which results in the closure of stomata. Under drought stress, ABA promotes stomata closure to reduce the transpiration rate [48]. When water potential is low in plants, ABA also stimulates root growth and inhibits shoot growth. Once the soil water availability is reduced, the amount of ABA in the xylem increases, and consequently, ABA concentration in different parts of the leaf is increased. As ABA is directly associated with stomatal conductance, it reduces net CO₂ intake and decreased photosynthesis [48]. Existing cotton cultivars vary in tolerance to abiotic stresses, such as drought; therefore, maintenance of optimum plant cell turgor is an indication of the drought tolerance potential of a cultivar [49]. Similarly, a change in carbohydrate metabolism with an increase in glucose concentration in leaves and sucrose concentration in pistils of white flowers of cotton was observed under drought stress [50].

Ascorbate peroxidase activity is reported to increase whenever plants undergo in drought stress as reported in cotton grown under drought stress but glutathione metabolism levels were not changed [51]. However, the investigation of antioxidant activity in cotton plants exposed to drought stress is still controversial and is not well understood and superoxide radicals (SOD) or catalase (CAT) activities remained unchanged under drought stress [52]. It has been shown that CAT activity is not affected by drought stress, while, the Ascorbate peroxidase (APX) and SOD activity was increased [53]. In most plants, osmoregulation reduces the water potential of cells, thus increasing the gradient for water flow in the cell to maintain cell growth [54]. The maintenance of cell turgor contributes to ongoing physiological processes such as stomatal conductance and photosynthesis, as reported by Ref. [21, 55]; however, information on osmotic regulation in modern cotton varieties under drought stress is still lacking.

Yield is essentially the precise integration of the many systems of physiology. Drought stress negatively affects most of these physiological systems. The negative effects of shortage of water on yield depend mainly on the intensity of stress and the growth stage of plant life. In key crops, significant drought stress losses have been observed. The low moisture caused by parenthesis lowered the time to anthesis and reduced the time to fill the grain with cereal by anthesis [56]. Exposure of plants to drought stress can lead to total sterility of pearl millet (*Pennisetum glaucum* L.), typically owing to disrupted mobility in the assimilated ear [57]. The drought may be caused by many causes such as decreasing photosynthetic rate [58], disturbing assimilate partitioning [44], or inadequate growth of a prominent leaf [59]. Maize was significantly reduced in returns when exposed to drought conditions at the tasseling stage [14]. In the same way, the production and abortion of the developed bolls in cotton under drought circumstances were significantly reduced, which eventually affected the lint yield [60]. In drought environments, there was also a substantial drop in barley grain production (*Hordeum vulgare* L.), largely due to lower viable

grain tillers and grain with less than 1000 seeds [61]. Drought stress in the blooming stage produced more than a 50% decrease in the seed output by the exposition of pigeon peas (*Cajanus cajan* L.) [62].

Drought has a primary influence on the plants, namely poor germination and impaired planting. Several studies have demonstrated detrimental effects on germination and seedling development of drought stress [44, 63]. In major crops of fields, including pea (*Pisum sativum* L.), alfalfa (*Medicago sativa* L.), and rice (*Oryza sativa* L.) under drought stress, drought stress was observed to reduce germination, early sowing growth, root and shoot dry weight, hypocotyl length, and vegetative development [64–66]. Plant growth is achieved largely through the division of cells, expansion, and differentiation. Drought affects mitosis and cell elongation leading to poor growth [39]. Drought restricts the cell development process, largely owing to turgor loss [67]. Water limitation leads to cell elongation, largely because of the inadequate passage of water from the Xylem to the next cells [68]. Drought also reduces the number of leaves and the size of each leaf. The leaf growth usually depends on the turgor and the availability of assimilates. Reduced turgor and slower photosynthesis rate in circumstances of drought stress particularly restrict the growth of the leaf [59]. Fresh and dry weight in the water limitation conditions are likewise reduced significantly [69]. Plant height, leaf size, and, stem diameter were diminished significantly in maize under water-limiting conditions [70]. Ref. [71] found in another investigation that the bioaccumulation of maize has decreased considerably under dry conditions at different stages of growth.

Certain variables, such as the leaf water, leaf and canopy temperature, transpiration rates, and stomatal conductivity, impact water relations. Drought stress disrupts all of these processes in plants, but stomatal conductance is particularly impacted [44]. Drought conditions, which eventually raised the leaf and canopy temperature, showed a substantial decrease in the leaf water potential and transpiration rates [72]. The efficiency of the dry matter ratio accumulated with the water used is another essential characteristic of plant physiology control. Efficient wheat crops are more efficient at using water during drought conditions [73]. This improvement in the efficiency of water usage is large because the dry matter accumulates by absorbing less water due to the closure of the stomata and less transpiration. When subjected to an early season water scarcity, a decreased water efficiency in potatoes (*Solanum tuberosum* L.) was found, and eventually, biomass buildup and output were low [74].

3. Structural and physiological responses of the cotton plant under drought condition

Drought leads to a variety of changes in cotton plant growth and function. Drought, for example, seriously impedes many physiological processes regulating fiber quality and foliage output [45]. Mechanisms for drought resistance in plants consist of four groups, namely recovery, prevention, tolerance, and drought exhaust [75]. Water stress avoidance supports essential functions, such as stomatal control, in the event of moderate drought. The capacity of flora to undergo serious dehydration with osmotic adjustments and osmoprotectants is drought tolerance [76]. Plants have been developed to control the time of development to prevent moisture stress [77]. The capacity of plants to resume their development following drought damage is the recovery of drought. In the cotton area, biochemical, physiological, and molecular drought stress methods are examined in the preceding sections, as shown in **Figure 2**.

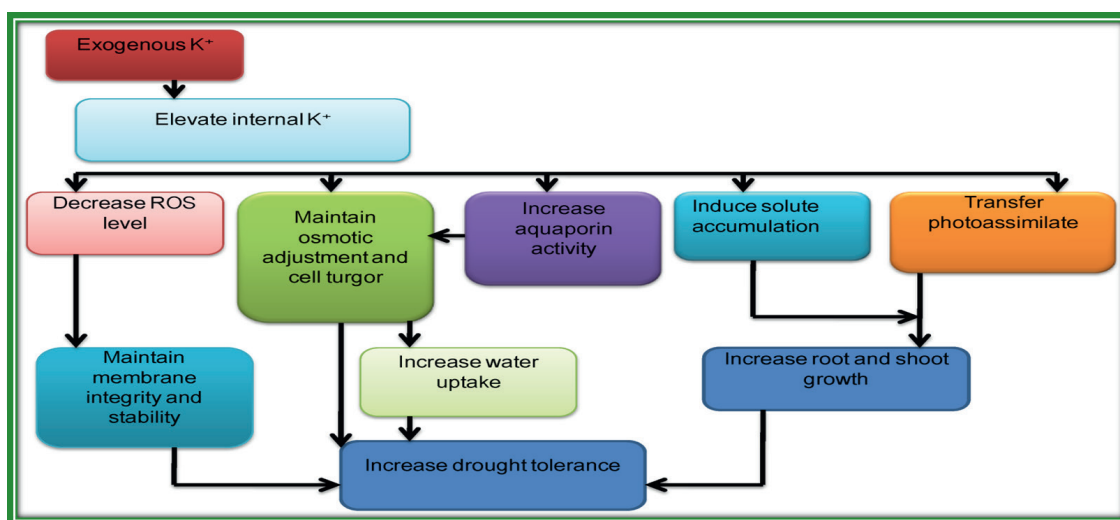


Figure 2.
 Drought tolerance mechanism of potassium [12].

Plant roots are important for sensing and responding in direct contact with soil water and nutrients to different external environmental stimulation systems. Because the root structure configuration of dry soils is difficult to gather, little data on change in root systems are available in drought, and most research on cereal crops is done. Plant roots respond to the surface moisture changes, that is, water shortage at the top of the ground leads to deeper root penetration, whereas the upper layer of surplus water lowers the root penetration [78] by up to 3 m.

The growth of root rates for predicting agricultural production losses in cotton crops is widely used. Inadequate soil humidity inhibits root growth and development and so affects the working of the aerial portions [78]. Water shortage in the topsoil results in deeper root penetration for a more extensive moisture and nutrient exploration, whereas excess water in the top floor produces a decreased root penetration [78]. Drought decreases the formation of over ground biomass via a decrease in the density of root, root mass, and root lengths [79]. However, characteristics such as hydraulic conductance and plant allometry are of significant interest to scientists in the process of drought resistance. The rooting system with many short and thin side roots enables the acquisition of oxygen and soil nutrients to a wide root surface area, compared to the dispersed root system [80]. The Fine Root System drives soil activities such as carbon cycling, sequestration, nutrient flows, structural stability, and soil microbial activity [81]. For adjusting to drought, increased length of root and soil proliferation are desired characteristics. The growth and penetration of roots depend on external partial oxygen pressure inside the root region [82]. Mild drought stress may increase root elongation during the early stage but root morphological and physiological activity is severely impeded by long-term water stress disruptions [79]. Finally, deeper root insertion makes it possible for the plant to explore deeper water and nutrients in the soil. Therefore, it is necessary to promote the dispersion of vertical roots to improve crop growth and dry stress development. All root characteristics may be relevant for drought stress, but researchers have been particularly interested in hydraulic conductance and plant allometry. Different researchers have examined the probable origins of drought stress [6]. More abundant (greater radicular density) and deeper soil root systems often serve as desired features to adapt to drought. For one case, [79] reported that mild and initial drought stress improves cotton root length, but a long-term water shortfall reduces root activity in comparison to control plants. Transgenic

cotton plants, with a stronger root structure than in the natural, were more resistant to drought stress in another trial [83]. Arabidopsis also harbored transgenic cotton plants that had a highly developed root gene, in addition to other characteristics tolerant to drought 1/homodomain glabrous 11 (AtEDT1/HDG11) [84].

3.1 Cotton lint yield

Lint yield is a complex integration of many physiological processes in cotton crops; most of them are severely affected by water stress. The development of new nodes in a cotton plant is dependent upon the availability of water because of the indefinite habit of growth. Duration and intensity of stress and plant development are linked to the detrimental effects of moisture stress on yield. Drought terminal significantly restricts the production of cotton by limiting carbon absorption and the buildup of biomass [85]. Inhibited synthesis of carbohydrates together with the depletion of the storage reserves (i.e., starch) owing to continuous breathing [86]. Ref. [87] reported that as a result of drought, reproductive structures and boll size decreases are induced [88]. Increased fruit and leaf abscissions might be linked to a final output loss for drought-stressed cotton crops [60]. In short, the loss of cotton production is closely linked to physiological and morphological plant stress processes.

3.2 Fiber quality

The cotton farmers are mostly focused on fiber quality, both as the fiber characteristics directly influence the fiber output and enhance the spinning processes [89]. The quality of the fibers is combined with the length of the fiber, fiber fineness of the wall, the strength of the fiber, the elasticity of the body fiber, naps (fiber nodules), short fiber index, uniformity index (fibers fitted in the spinning process), color grade and reflectiveness (fibers brightness) [19]. Fiber quality features are numerical and regulated by a variety of phenotypically significant and minor genes [90]. Lint quality is directly affected by water during fiber cell formation [91]. As a complex phenomenon with various morphological and physiological characteristics is connected with drought tolerance in the plant [92], the breeding of enhanced fiber quality characteristics under moisture stress is difficult [93]. The discovery for irrigated and water deficiency environments of stable quantitative traits loci (QTL) might therefore allow the molecular breeding of cotton genotypes with enhanced fiber quality and yield parameters. The use of abundant DNA markers for the cotton genome is necessary for the QTL, genetic diversity, and structural analysis [94].

Several QTLs have been highlighted in upland cotton on fiber yield features [95, 96]; however, there has been less emphasis given to identifying QTLs in terms of fiber quality under drought [97]. The inter-specific cotton plants F2 and F3 [98] are generated from a crossing between inbred lines *G. Siv'on* and *G. hirsutum* cv. CV F-177 barbecue. QTL (13 and 33) reported for the 16 QTLs, covering plant production, physiology, and fiber quality, under situations of well-watered and water deficiency. Ref. [28] discovered 79 QTLs combined with fiber quality features in the F2 and F3 generations which are derived from *Siv'on* and *G. hirsutum* cv. Barbados cv F-177 underwater conditions are irrigated and deficient. Seventeen of the 79 QTLs discovered were moisture-specific conditions whereas just two were well-watered. In the F2 population, the mapped physiological, yield, and plant structural characteristics in the cross between G were created [97]. *Hirsutum* cv. *Hirsutum* cv FH-901 (sensitive to drought) and *G. hirsutum* cv. *Hirsutum* cv RH-510 RH-510 (drought-tolerant). A

total of seven QTLs, three and two of which are water-limited and well-watered, were identified accordingly. These germplasm panel QTL analyses included a large range of relevant alleles that may be detected on *G. hirsutum* lines with various genetic information. In this work, 177 single SSR markers were utilized in a panel of 99 upland genotypes of cotton for the detection of significant quantitative trait loci (QTL) associated with 11 quality fibers and structural plant characteristics. The quality of fiber and the structural features of plants under water and water deficits were examined in another investigation. GLM analysis revealed that 74 and 70 QTLs were found under well-watered and limiting water situations, respectively. The MLM found 7 and 23 well water and water shortage QTLs, respectively [19].

For example, efforts have been undertaken to discover the particular fiber gene and its activities for improving fiber quality for characteristics of significant interest in cotton fiber. Cotton genomics promises to increase the understanding and systematic utilization of fundamental plant biology to improve cotton fiber quality, and cotton functional genomics. However, it is laborious to determine the activities of cotton genes that a quick pace has not been evaluated [15]. Actin cytoskeleton [99], polysaccharide biosynthesis, [2]), and the related genes are expressed in distinct routes for fiber formation. Of these, few are mostly present in the production of fiber [100], secondary biosynthesis cell wall [25], and fiber-extension [101]. A protodermal cotton gene 1 (GbPDF1) has now been expressed through the HDZIP2ATATHB2 core element at the fiber initiation stage [102]. In developing fibers, alpha expansion genes (GhExp1) encode a cell wall protein and govern the loosening of the cell wall [103]. Ref. [104] demonstrated the interruption of the fiber elongation and SuSy's role in osmosis control by the antisense removal of the sucrose synthase (SuSy) gene. On the other hand, GhPRP5 was a negative regulator in fiber formation, with proline-rich protein genes coding [105]. During secondary cell wall biosynthesis, cellulose synthesis is an important step in the formation of cells. Many types of research have been carried out to examine how cotton fiber controls and maintains the strong irreversible carbon sink that has a secondary synthesis of wall cellulose [25]. The subsequent discovery of a novel isoform Sus (SusC) during the secondary wall development of cellulose in fiber was followed [25]. Most of the expressed genes are associated with fiber maturity with cellular respiration [106]. Many transcription factors encode genes, that is, the fiber development phase included featured families from MYB, C2H2, bHLH, WRKY, and HD-ZIP. Past studies reveal that fiber formation in upland cotton has demonstrated significant expression in MYB-related genes [107]. Expression analyses from six MYB genes indicated that GhMYB6 was high in fiber, with R2R3 MYB gene encoding factor "GhMYB109" expressed in the fiber elongation and initiation [61]. The RAD-like GbRL1 is significantly expressed in cotton ovules at fiber commencement [108].

The identification of fiber-related loci markers can have useful impacts on genetic adaptation required under scarce water situations to create sufficient fiber. Many types of research into gene expression were conducted to understand the formation of cotton fibers, which offers problems. First, in comparison analysis, the bulk of the differentially expressed genes are connected to differences across species rather than to fiber-related features. Secondly, G protein-coding gene sequences are being used. *G* and *Ramondii*. *Arboreum* may not be precise enough for tetraploid cotton genetic analysis. Thirdly, it is unknown if any of the expressed genes found in previous research have changed the sequence between a mutant in cotton fiber and its natural type. In this context, the viable candidates for innovative cotton research are only differentially expressed genes with sequence variants and co-location with desired fiber properties.

3.3 Photosynthesis

Drought stress causes stomatal closure, reducing CO₂ absorption and consequently affecting photosynthesis rate [29]. In certain situations, however, stomata behavior is not necessarily linked to the photosynthetic rate, although this has to be clarified [109, 110]. As the water-deficit steadily rises in cotton, photosynthesis is strongly influenced along with growth. For example, photosynthesis and transpiration were shown to be altered in cotton in dry conditions [53, 106]. Incidentally, immature cotton leaves were shown to be photo-synthetically more resistant than mature leaves to drought and heat. There was no reduction in net photosynthesis when immature leaves were exposed to high temperatures (37°C). By comparison, the photosynthesis of mature leaf net decreased 66% under equal conditions [27]. A reduced lint production was reported when net photosynthesis deteriorated under water shortage conditions in the first growing season in another field trial of cotton in two consecutive growing seasons. However, there were no changes in the production of drought-treated fields in the next growing season due to heavy rainfall [28]. These researches have shown that drought stress decreases cotton photosynthesis, which in turn impacts growth and return.

Photosynthesis is the principal source of agricultural productivity, which is adversely affected by situations of water scarcity. When the stomata closures respond to wetness, the leaf photosynthetic capacity is reduced and the dehydration of chloroplast and CO₂ into the leaf is reduced (**Figure 3**). For example, moderate moisture stress induces stomata closure by controlling transpiration to prevent water loss. This decreases stomata behavior and limits the concentration of intercellular CO₂ [78]. In serious drought, decreased stomata conductance and (nonstomatal) metabolic damage, such as restricted carboxylation, become important photosynthetic constraints [87]. Likewise, stomata behavior is not continuously linked to photosynthesis, but investigation is needed [110]. Drought can impair both photosynthesis and seriously

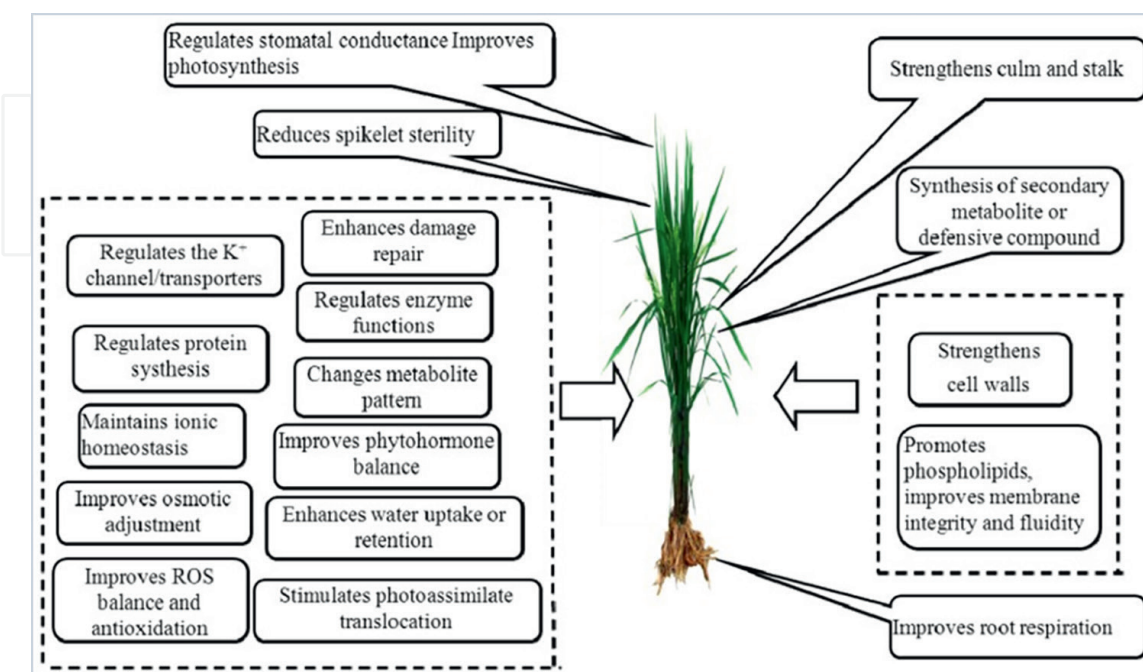


Figure 3. Physiological role of potassium in plant.

influence transpiration and depend on the degree of drought and plant growth [111]. Under mature cotton leaves up to 66 percent decrease has been reported in water shortage situations about smaller leaves [27]. Overall, using K-efficient cultivars under reduced irrigation condition along with $50 \text{ Kg ha}^{-1} \text{ K}_2\text{O}$ improve the net photosynthetic rate by about 30% as compared to potassium nonefficient cotton cultivars [11].

3.4 Stomatal regulation

The major purpose of stomata in plants is to control water loss through transpiration. In the event of a water-deficit-resistant plant, internal moisture preservation and fast stomata closure are critical. Water loss from cotton leaves is a major phenomenon in situations where water is in shortfall; however, the plants produce adaptations to survive under drought stress, that is, wilting and rolling leaves lead to less radiation interception and eventually lower water loss [75]. In general, a variety of xeromorphic characteristics increase drought tolerance, including a large cuticular epidermis, thicker and smaller leaves, smaller and denser stomata tissues, more epidermal trichomes in palisade, and a well-structured vascular bundle sheath [33]. In leaf gas exchanges between the leaf's internal cavity and its exterior surroundings, stomatal control plays an important function. The leaves of the plant disperse heat energy through three methods. Sensitive heat loss (radiation and convection) and transpiration are processes such as re-radiation. Transpiration is the essential mechanism for flowering plants, for energy collection, and maintenance of cellular processes. With 90 percent of plant water loss occurring by transpiration [112], stomatal regulation plays a major function in ensuring a supply of water and nutrients for the vital physiological process. The first approach to reduce water loss in cotton cultivation in drought conditions is to close the stomata under excessive transpiration [103], in the eight maize hybrids showed that the portion of transportable soil water that the stomata began to close throughout a drying cycle was statistically different. Therefore, a potential biomarker for induced drought tolerance is stomatal conductance; however, a negative association is found between drought resistance and cotton stomatal conductance.

A significant feature in cotton plants under drought stress is the reduction of water loss through leaves. Wilting and rolling of the ground lead to less radiation and hence less loss of water [75]. Plastic materials frequently exhibit various xeromorphic characteristics, and have structures that encourage drought tolerance, such as thicker and smaller leaves, thicker cuticle epidermis, thicker palisade tissues, more dense stomata, a high proportion of palisades to the spongy mesophyll thickness, and a vascular sheath developed [33, 113]. In a gas exchange between tissues and the atmosphere, Stomata control plays a crucial function. It is one of the primary processes for the generation of energy and cell activity in plants. 90% of plant water losses are due to stomata openings [114]. The closing of the stomata is the first step in cotton to decrease water loss when the transpiration rate is very high. Stomata activity could be a possible indication of drought tolerance for cotton as the relationship between drought tolerance and stomatal performance is negative.

3.5 Osmotic adjustment

Osmotic adjustment is an adaptation technique for the acclimation of increased cell turgor and water retention after stress. Osmotic leaf adjustment is significantly associated with drought tolerance in other crop species. The osmotic adjustment of compatible solutes in the cytosol is carried out in plant cells in response to

water stress. This lowers the cell's osmotic potential for cell turgor and cell growth. Compatible solutes such as proline, sorbitol, and glycine betaine are more soluble and do not interfere with metabolism in cells, even at high levels. Proline is a widely appropriate drought stress response in plants [24]. Proline accumulation in drought plants is, however, different and relies on cultivar and growing phase (e.g., proline accumulation in cotton ovaries was higher than in the leaves). Ref. [115] have suggested that during reproductive phases, the osmotic adjustment may be greater than in vegetative stages and may depend on tissue.

The water shortage affects the turgidity and osmotic balance of the cells at the cellular level. Osmotic adaptation is key to reducing the impacts of crop damage caused by drought. Mechanisms of plant protection also include osmoprotectants or osmolytes that control homeostasis after drought and cellular salinity stress. The effect of drought stress on osmotic balance is adverse and hence plants collect various organic and inorganic components to lower the osmotic potential of the dry weight [75]. Osmotic adjustment is involved in numerous organic compounds including amino acids (proline and glycine), sugar (trehalose and fructan), sugar alcohols (mannitol, sorbitol, D-mannitol and polyamine (polyamine and betaine), polyols, ectoin, alkaloids, and inorganic ions known as osmoprotectants/osmolytes [75, 116]. Such solutes help protect proteins and membranes from harm owing to high concentrations of inorganic ions and oxidative damage caused by drought stress [31]. The exogenous use of osmoprotective agents (proline and glycine betaine) has proven to be beneficial in decreasing the deleterious effects of cotton drought stress [117]. Transgenic cotton plants were more drought-tolerant than controlling plants and were more photosynthesized, had greater relative water content, improved osmotic adjustment, reduced lipid membrane peroxidation, and less ion leakage [76]. AnnBj1 ectopic annexin gene expression improved the content of the proline and sucrose, which increased the tolerance of drought in cotton [118]. In addition, the overexpression of the GhAnn1 cotton annexin gene improved dryness and salt tolerance by boosting the activity of superoxide dismutase (SOD) [119].

Compatible solutes protect the proteins and membranes from damage due to high levels of inorganic ions and water-deficit oxidant damage [31], and salinity [6]. Foliar application of glycine betaine and proline could be a useful approach for increasing tolerance in cotton cultivations [117]. More drought tolerance showed in cotton plants more glycine betaine in accumulation. The promotion of physiological processes, such as leaf photosynthesis, relative water, improved osmotic adjustment, and low lipid stability, might thus increase crop performance under drought by transgenic/nontransgenic method [42]. For example, a rise in proline and sucrose content of the AnnBj mustard annexin gene in cotton led to a higher tolerance of drought [118]. In addition, GhAnn1 overexpression, annexin cotton gene, drought, and salt tolerance have been enhanced by the enhancement of superoxide dismutase [119]. Further osmotic adjustment research in reproductive organs is needed to completely understand this process in drought cotton plants.

4. Biochemical and molecular mechanisms of drought tolerance

Plants via morphological adaptation avoid a range of environmental stressors. The drought tolerance mechanism is connected with several biochemical, morphological and molecular processes. The hormonal interaction inside the plant body controls these activities intensely.

4.1 Abscisic acid (ABA)

ABA is a natural plant stress hormone; stress response, growth, and reproductive behavior in cultivated plants. Osmotic stress in plants is linked to drought and the low available water induced by the synthesis of ABA and adaptation mechanisms [22]. The abscisic acid production is triggered after the reception of stress signals by the plasma membrane, excluding the xanthoxin transition into ABA. This usually happens in the cytoplasm [120]. ABA is typically rooted and transmitted by vascular tissues to higher regions of the plant [111]. In cotton, ABA is detected and transmitted using ABA-dependent or ABA-independent transmission, whereas the former are essential actors for stress-responsive gene expression under many stressors, including osmotic pressures. Many receptors in the plasma membrane, cytosol, the envelope of chloroplast, and nucleus have been identified. The plants display a low ABA concentration in the nonstress environment; sugar nonfermenting protein kinase 2 (SnRK2) is suppressed by protein phosphorylation of 2C (PP2C). ABA enhances drought tolerance in cotton plants through the modulation of stress-related genes. ABA-induced overexpression of cotton genes GhCBF3 in Arabidopsis led to drought tolerance in transgenic lines, with greater levels of relative water, chlorophyll, and proline than wild type [121]. The AREB1 and AREB2 are more expression-level compared to the wild transgenic line, while the stomata aperture is lower when ABA is treated. Suggesting that, through the ABA signaling route, GhCBF3 may increase drought resistance.

4.2 Jasmonic acid (JA)

Plant phytohormone and its active by-products known as jasmonate are considered Jasmonic acid (JA). In fighting many biotic and abiotic stressors, it plays a crucial function. In addition, JA is related to improving root structures, tendril coiling, pollen generation, and fruit maturation [122]. Exogenous application of jasmonate has been found to enhance plant performance in drought environments [18, 123]. The mechanism and production of jasmonic acid signaling were intensively researched. The repressor protein jasmonate-zim (JAZ) plays an important function in the JA signaling pathway as the JA signaling switch. Jasmonate/Jasmonate-Zim (JAI3/JAZ), proteins that are not under stress or lack of JA, are associated with and eliminate various elements of transcription, including myelocytomatosis (MYC2). Nonetheless, the degradation of JAZ proteins, as illustrated above, occurs under deficiency water, producing the effect of active transcription factors, that is, MYC2, which regulates stress tolerance-related genes [32]. Plant hormones usually do not work in one path, but depend partly on each other in different periods to control the environment and development paths. In plants, signal transduction occurs, and many changes may be organized to adapt in a challenging way to harsh conditions [123].

4.3 Reactive oxygen species (ROS)

The fractional reduction of ambient O₂ is responsible for the formation of reactive oxygen species (ROS). The cell ROS consists of four categories: radical hydroxyl (HO·), radical anion superoxide (O₂⁻), peroxide hydrogen (H₂O₂), and singlet oxygen (1O₂). HO· and 1O₂ are very reactive and may oxidize DNA and eventually causes cell death with RNA, lipids, and proteins [75]. The generation of ROS induces subcellular locations, namely the cell wall, chloroplast, nucleus, mitochondria, and plasma membrane [124]. Drought production increases such as a reduction in CO₂ fixation

leading to a decrease in NADP⁺ reconstruction during the Calvin cycle. This lowers the activity of the photosynthesis chain. Moreover, the Mehler reaction in electrodes may potentially increase the generation of ROS during photosynthesis by too many electrons leaking to O₂ [125]. By donating an electron in photosystem-I, the Mehler reaction decreases O₂ to O₂⁻. O₂⁻ via superoxide dismutase, which can be converted into water by ascorbate peroxidase, may be changed into hydrogen peroxide. It is difficult, however, to evaluate ROS levels of those created by photorespiration during the Mehler reaction. The photo-respiratory route also increases moisture stress, especially if RUBP oxygenation is strong because of the partial fixing of CO₂. Some 70 percent of overall humidity stress generation H₂O₂ takes occurs by photorespiration [125].

Plants have sophisticated systems to check the ROS redox homeostasis, to avoid extra ROS in cells. Changes in the metabolism of antioxidant enzymes may impact drought resistance in cotton plants. Plants have created antioxidant mechanisms to keep growing. This system consists of enzyme and nonenzyme additives. These enzymes include dismutase of superoxides, ascorbate peroxidase, and peroxides of guaiacol, reductase monodehydroascorbate, catala, reductase, and glutathione reductase of dehydroascorbate. Nonenzymatic components include reduced ascorbic acid (AA), flavonoids, carotenoids, proline, glutathione, and (GSH). Both components operate together to break ROS [126, 127]. The Halliwell Asada route detoxifies the H₂O₂ with the ascorbate peroxidase along with NADH MDAR, and GR [127]. In MDHAR, Ascorbate decreases MDHA. However, 2 MDHA molecules can be converted into MDHA and dehydroascorbate without being enzymatically reduced to ascorbate via the NADH and GR cycles [128]. The presence of NADPH reduces glutathione (GSH) via GR oxidation. Glutathione reductase activity rises with humidity stress, retaining oxidized and decreased levels of glutathione [129]. If oxidative signals and/or losses occur, the balancing of antioxidant activity and ROS generation determines whether [26]. The antioxidant capacity of various cotton cultivars affects the potential resilience to dry conditions. The moisture stress in cotton causes ROS formation; however, the ROS scraping process may also be improved and maintained by APX and GR activities [130].

The use of nutrients (Zn) was shown to reduce oxidative damage to cotton caused by polyethylene glycol (PEG). This raises the amount of CAT, APX, SOD, and enzyme-free antioxidants [52]. Increasing GR activities and better lump-sum levels have been reported in [130] drought-tolerant (CCRI-60). The CCRI-60 was capable of scavenging free radicals and protecting the plants against severe circumstances, in comparison to the sensitive (CCRI-27). This indicates better development and increased drought stress resistance. GbMYB5 down-control in *Gossypium barbadense* has resulted in decreased activity with antioxidants such as CTA, peroxidase (POD), SOD, and Glutathione S-transferase (GST) [30]. Further research is, however, necessary to discover genes in drought-resistant cotton cultivar pathways associated with the antioxidant enzyme. The use of Zn and K supplies can also help strengthen the cotton plant's antioxidant system [131].

5. Potassium as a drought stress ameliorating tool

Increases the leaf photosynthetic of crops, crop maturity, and high-quality fibers among all plant nutrients, K has a key role in increasing vigorous cotton development [23]. Due to its negative effects on cotton's surface of leaves of plants, photosynthesis, and production of biomass, K was shown to reduce yield and fiber quality [132], because K plays a major role in cotton growth, development, and quality fibers.

In addition, excess or insufficient K is vital to the normal function of the plants and also for the development of plants [9] in the growth medium to maintain the K level and its relation with other critical plant nourishment (particularly sodium (Na)). The management of K-fertilizer is, therefore, beneficial to enhance plant growth. Adequate K supplies influenced the overall growth of cotton substantially [133] because of their crucial function in the generation of biomass [134], an increase in its surface area, and the synthesis of photosynthesis [135].

Cotton is more vulnerable to low K and the most sensitive to K fertilization than other plants [81]. Ref. [133] He also found varied responses from conventional and Bt cotton cultivars to low K levels. In biomass output, four cotton cultivars are significantly different from K in a field test. Likewise, nutrient-efficient genotypes culture was proposed as a key strategy to enhance fertilizer efficiency [37]. By decreasing the usage of artificial fertilizers in agriculture, potassium intake and effective use of soil nutrients are anticipated to have good environmental benefits. The genotypes which are successful in K-uptake were proposed to have a broader root surface. This can lead to additional root-to-soil moves to maintain a broader root gradient. This might further enhance K translocation to different plant organs, which could maintain the optimum cytosolic K⁺ content. The enhanced selectivity from K to Na is the fundamental mechanism of better efficiency of use [37].

A sufficient supply of cotton K is not only necessary for water relations but also for improving the water use efficiency of (WUE) which can enable plants to live under drought stress [135]. Observed that WUE in cotton was enhanced by K but with cotton cultivars, this impact was different [136] shows that not all plants or K levels may have a favorable influence on every element of water in cotton stomach conductivity by fertilization with K under water-starved conditions.

Drought stress yields are a good tolerance to K applications, and they increased fiber yield and quality when compared with a well-watered control, under drought stress treatments [137]. Furthermore, it was observed that using K foliar spray, the micronaire, an indirect measure of fiber coarseness, was enhanced by 0.32. Drought stress saving the effects of drought stress and enhanced output was the use of foliar K. Although the reaction of cultivars was varied, the use of foliar K in the drought treatments increased fiber output and quality, to make it statistically comparable to well-watered control [138].

Both root development and the rates of K⁺ root diffusion were reduced during drought stress, reducing the uptake of K. Drought resistance as well as K absorption might be further depressed by the ensuing reduced levels of K. Consequently, maintenance of sufficient plant K is important for the dryness of plants. A strong relationship has been established between K's nutritional status and plant drought resistance. Adequate quantities of K can increase the overall dry mass accumulation under drought stress compared to lower K levels. The stomata control by K⁺ and the associated increased rates of photosynthesis may be related to this result. Furthermore, K is also crucial to the transfer of root development photo-assimilates. Root growth promotion was shown to enhance the root surface that was exposed to the soil as a consequence of improved absorption of root water by increasing adequate K supply under K-deficient soil. Lindhauer said that K nutrition not only enhanced the total dry mass of the plant and leaf area but also improved the retention of water in the drought of plant tissue. Drought stress has considerably decreased cell membrane stability [139]. Maize plants with a higher application of K were shown to respond more effectively to water stress in research [140]. These improvements were mostly due to K's function in enhancing stability and adjusting the capabilities of the cell membrane. A suitable supply of K is necessary to increase dryness by increasing root length and keeping the cell membrane stable.

Many studies have demonstrated that osmotic adjustment is positively linked to drought resistance in different plant types [141]. K^+ plays a crucial function in developing the capacity to adapt to drought environments as one of the most prominent inorganic osmotic in plants [142]. Increasing the K^+ , Cl^- , and Na^+ absorption by root cells regulated cell turgor restoration under osmotically-generated stress, partially mediated by K^+ transporters on the cellular plasma membrane [143]. Moreover, enough K promotes solvent accumulation, therefore decreasing the osmotic potential to sustain osmotic stress in plant cell turgor. In a word, an adequate K status can enable osmotic adjustments which maintain high turgor pressure, the relative water content, and reduced osmotic potential [144].

For seed adjustment to drought environments, rapid stoma closure and internal moisture conservation are critical. K plays a vital function during stomata activity in turgor control in guard cells [142]. Considering that stomata closure is preceded by the quick release of K^+ from the protective cells into the leaf apoplast, it is fair to believe that stomata could hardly be left open in K-deficient circumstances. Some studies show that K shortage in various agricultural plants might cause stomata closures and decrease photosynthesis rates [98, 145]. Rapid stomatal closure and internal humidity conservation are important for seed adaptability to drought conditions. K plays a key role in the turgor regulation activities in guard cells [142]. Since the closure of the stomata is before the rapid release of K^+ in leaf apoplast from the protecting cells, it is reasonable that under the K-deficiency situations, stomata could scarcely be left open. Some researchers have shown that K deficit may affect stomata closures and photosynthetic rates in different agricultural plants.

6. Selection and variation for K-uptake in cotton germplasm

In the area of genetic resource management, it is vital for sustainable cotton production to identify the genotypes of cotton for low K input. Production costs and management of K resources in agro environments would be reduced. Cultivation of nutrient-efficient crop genotypes is an effort to improve the efficiency of fertilizer usage [37] and decrease input costs and nutrient waste [17].

Categorization of cotton cultivars based on their growth performance under nutrient-deficient conditions is essential for the development of K-efficient cultivars in any crop. Soil worldwide is exhausting for the supply of adequate potassium (K) nutrition due to intensive crop cultivation systems. Exploiting genetic variability underlying an efficient K transport system is a viable, cost-effective strategy to increase cotton productivity in low-input production systems [12] stated during his experimentation to characterize 46 diverse cotton cultivars for enhanced K acquisition and utilization efficiency at low (0.26 mM K) and adequate (3.33 mM K) K levels in a sand culture experiment. There exists genetic variation in cotton cultivars for K acquisition and utilization. The Indicators such as DMYI and KUE, based on the mean and standard deviation, can be reliably used for the classification of indigenous cotton germplasm. The cotton cultivars including MNH-886, CYTO-124, FH-142, CIM-554, CIM-707, and IUB-2013 were found to be highly K-efficient and responsive. These cotton cultivars have a great potential for wider adaptation under both low and high-K input agriculture systems and, therefore, may be recommended for cultivation in soils.

Supply of adequate plant growth K improved significantly by 21–50% the growth characteristics of cotton and the yield of seed cotton from five cotton genotypes

being observed, including symposia branch number (21%), leaf number (34%), dry biomass with leaves (30%), dry biomass shoot (31%), boll number (50%) and cotton yield (92%) [161]. In four cotton cultivars for biomass production and partitioning between various organisms under the K fertilization impact, [133] observed significant differences [81] also reported the differential reaction of two K⁺ conventional cotton cultivars to two Bt and discovered that, because of decreased K⁺ absorption, the Bt-transgenic cotton cultivars were more vulnerable to the deficit than conventional cultivars. However, it is very preferable to select a wide variety of cotton genotypes to categorize their differential K absorption and use efficiency. Such grading might provide significant basic information to support cotton breeding efforts that achieve high efficiency of K-use.

The variations in the absorption and use of nitrogen [146] and potassium among cotton cultivars were also identified [147]. One of the major techniques for the sustainable strengthening of farming systems revealed by Ref. [148] is to use genotypic variations by selecting and identifying crop genotypes best adapted to unflavored soils using nutrients. In their growth response, K-uptake and efficiency associated substantially with shot dry weight were significantly different, indicating an essential function for the creation of biomass. Higher biomass accumulated in K levels in efficient cultivars in the absorption of K and efficiency. Because K is extremely mobile in plants, genotypic variations in K absorption were linked to alterations to K translocation across cells and the whole plant [37]. Bt-transgenic cotton cultivars tend to have an increasing interest in K fertilizers with the rising usage of transgenic cotton as documented by Ref. [149] as a result of a more sensitive contemporary K shortage than traditional cultivars [149]. Reported that high-yielding, early maturing, and determinant cotton cultivars are more sensitive to drought stress compared with indeterminate cultivars that mature later with small boll numbers and weight.

K-uptake efficient genotypes have special physiological mechanisms to achieve enough K-uptake and efficient genotypes can have a larger area for contact between the root and the earth with a greater root surface absorptive capacity to maintain the soil and root spread gradient according to [37] K-uptake efficient genotypes. In eight cotton cultivars under controlled conditions both in growing chamber and field environments, the genetic diversity in K absorption and application was investigated, that [69]. K-efficient cultivars outperformed the K-inefficient cultivars by 29 and 234%, respectively, for K (dry mass supplied by unit K fixation) productivity (dry mass per unit K accumulates) and K. Under field circumstances with soil-compatible K-deficiency, the K-efficient cultivars generated a 59% greater potential yield (dry weight for each regenerative organ). During blooming, boll development, and seed production stage, however, signs of K insufficiency appeared.

More efficient cultivars are expected to have a favorable influence on the environment in their use and use of soil nutrients because farmers may decrease their chemical use in agriculture and demand significant yields, where fertilizer efficiency can be constrained by chemical and biological responses, drying of topsoil, subsurface limitations, and/or the involvement of disease [37].

7. K-efficient cotton cultivars' relation with water use efficiency

Only limited research work has been done on water use efficiency by using K-efficient cultivars. Our findings suggest that the selection of K-efficient cotton cultivars with adequate K application has the potential to improve nitrogen-use

efficiency and save considerable quantities of fertilizer and irrigation water, up to 35% in cotton, without yield loss under arid climatic conditions [11]. The authors [135], in their experiment, describe the degree of association between K levels and physiological processes implying that a high supply of K must be aimed at under dry land conditions for improvement in drought tolerance or WUE should be explored genetically despite adopting optimum mineral nutrition and water management strategies. The normal dose of potassium fertilizer reduces the impact of stress and improves water use efficiency by up to 30% by reducing leaf evapotranspiration and preventing water losses, and maintaining leaf water potential [11].

8. Conclusion

The world population will increase up to 9 billion in the year 2050. The biotic and abiotic factors are the main cause of the reduction of yield as well as quality. Therefore, it is necessary to reduce the massive application of fertilizers; however, overuse of N fertilization and K deficiency become a source of poor yield and quality. Recently, more attention has been focused on the effects of morpho-physiological traits that ultimately determine yield. Although all stages of cotton development are affected by drought stress, however, the reproductive phase of flowering and boll development is generally accepted as the most sensitive stages. Therefore, it is necessary to develop nutrient-efficient cultivars to fulfill the yield gap in many regions. According to our knowledge, little information is available for the characterization of cotton cultivars for potassium uptake under drought stress. The knowledge of drought tolerance of K-efficient cotton cultivars during drought stress is crucial for maintaining yield production in regions where water supply is limited or annual rainfall is less.

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