PHYSIOLOGICAL EVALUATION OF COTTON GENOTYPES FOR MOISTURE STRESS

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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By

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the thesis entitled **"PHYSIOLOGICAL EVALUATION OF COTTON GENOTYPES FOR MOISTURE STRESS"** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis / publication of any University or scientific organization. The sources of material used and all assistance received during the course of investigation have been duly acknowledged.

Place : Akola. **(Sonone Madhavi Prakash)**

Date : / /2019 Enrolment No. : LL-1027

CERTIFICATE

This is to certify that, the thesis entitled **"PHYSIOLOGICAL EVALUATION OF COTTON GENOTYPES FOR MOISTURE STRESS"** submitted in partial fulfilment of the requirement for the degree of **"Master of Science in Agriculture (Agricultural Botany) Plant Physiology"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **Sonone Madhavi Prakash** under my guidance and supervision.

The subject of thesis has been approved by the Student's Advisory Committee.

Place : Akola
Date : / /2019

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(C) Abbreviations

%	-	Per cent
/	-	Per
µg g fresh wt^{-1}	-	microgram per gram fresh weight
µg	-	microgram
Agri.	-	Agriculture
Agril.	-	Agricultural
C.D.	-	Critical difference
cm	-	Centimeter
cm^2	-	Centimeter square
CSI	-	Chlorophyll Stability Index
d.f.	-	Degree of freedom
DAS	-	Days After Sowing
Dev.	-	Development
Dr. PDKV	-	Dr. Panjabrao Deshmukh Krishi Vidyapeeth
et al.	-	et alia (and others)
Fig.	-	Figure
fr.	-	Fresh
g/ gm	-	Gram
G.	-	*Gossypium*
ha.	-	Hectare
i.e.	-	id est (that is)
J.	-	Journal
mg	-	milligram
MS	-	Maharashtra state
N.S.	-	Non significant
No.	-	Number
PGI	-	Post Graduate Institute

PHST	-	Plant Height Stress Index
PKV	-	Panjabrao Krishi Vidyapeeth
Prof.	-	Professor
Publ.	-	Publication
RBD	-	Randomized Block Design
Res.	-	Research
RWC	-	Relative water content
Sci.	-	Science
SCY	-	Seed Cotton Yield
SE(m±)	-	Standard error of mean
Sr.No.	-	Serial number
TCC	-	Total Chlorophyll Content
TDM	-	Total Dry Matter
USA	-	United State of America
Viz.,	-	Videlicet (Namely)
Wt.	-	Weight
YSI	-	Yield Stability Index

(D) THESIS ABSTRACT

a)	**Title of the thesis**	**:**	**"PHYSIOLOGICAL EVALUATION OF COTTON GENOTYPES FOR MOISTURE STRESS."**
b)	**Full name of the student**	**:**	**Sonone Madhavi Prakash**
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ABSTRACT

The present investigation entitled "Physiological evaluation of cotton genotypes for moisture stress" was conducted during *kharif* season

of 2018-19 in RBD on the experimental field of Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (M.S.) under non stress and water stress condition.

The seeds of ten cotton *(Gossipium hirsutum)* genotypes i.e. AKH-09-5, AKH-2012-8, AKH-1301, AKH-1302, NH-545, P-688, AKH-9916, AKH-8828, PKV Rajat and NH-615 were sown in three replications. One set of three replications grown in field condition and another set of genotypes replicated thrice was sown in earthen pots under rainout shelter.

Present investigation indicates, significant superiority of the cotton genotypes tolerant towards water stress on the basis of morpho-physiological, biochemical, stress indices, seed cotton yield and its attributes.

Leaf area (cm^2/ plant) was remained significantly higher in AKH-9916 under both stress (1030.04 cm^2/ plant) and non stress condition (1965.44 cm^2/ plant) at 120 DAS. Genotype AKH-9916 also recorded significantly higher total dry matter production at harvest under both non stress (58.2 gm/plant) and water stress condition (33.53 gm/plant).

Relative water content percentage was recorded significantly higher in genotype AKH-1301 (79.36 %) under non stress condition where in stress condition, it was found lower as compared to genotypes under non stress condition. AKH-9916 (70.86 %) was recorded higher in respect of relative water content percentage in water stress condition at 120 DAS. Significantly more proline content was observed in AKH-09-5 (65.03 µg/g fresh weight) under non stress condition and AKH-1301 (81.8 µg/g fresh weight) in stress condition at 120 DAS.

On the basis of stress indices higher yield stability index (0.72) and higher drought tolerant efficiency (73.1 %) was observed in PKV Rajat followed by AKH-9916 and AKH-8828, the released genotype.

Under non stress condition AKH-9916 (50.53 g/ plant) was recorded significantly more seed cotton yield followed by NH-615 (49.80 g/plant), AKH-1302 (49.23 g/plant) and AKH-8828 (48.66 g/plant). Under

water stress condition, AKH-9916 (36.36 g/plant) was remained significantly higher followed by AKH-8828 (34.86 g/plant) and AKH-1301 (31.63 g/plant) for seed cotton yield.

The genotype AKH-1302 (49.23 g/plant) produce statistically more seed cotton yield than the released variety PKV Rajat (40.84 g/plant) followed by AKH-1301 (47.13 g/plant) under non stress condition. Under water stress condition none of the new genotypes recorded statistically more seed cotton yield than the released varieties i.e. AKH-9916, AKH-8828, PKV Rajat and NH-615.

The present study projected the significant superiority of cotton genotypes AKH-9916, AKH-8828 and AKH-1301 tolerant towards water stress when sown under stress and non stress condition. However, the present findings needs further confirmation on multilocation basis.

CHAPTER I

INTRODUCTION

1.1 Background Information

Cotton is soft, fluffy, staple fibre that grows in boll, or protective capsule around the seeds of cotton plants of genus *Gossypium*.The plant is a shrub native to subtropical region around the world including America, Africa, India and Pakistan.The fibre most often in spun into yarn or thread and used to make a soft, breathable textile, which is most widely used natural fibre cloth in clothing.

Cotton was first cultivated in the old world 7000 years ago by the inhabitants of indus valley civilization, which covered a huge swath of north western part of the Indian subcontinent. In India, there are ten major cotton growing states which are divided into three zones, *viz*., north zone, central zone and south zone. North zone consists of Punjab, Haryana, and Rajasthan. Central zone includes Madhya Pradesh, Maharashtra and Gujarat. South zone comprises Andhra Pradesh, Telangana, Karnataka and Tamil Nadu. Besides these ten States, cotton cultivation has gained momentum in the Eastern State of Orissa. Cotton is also cultivated in small areas of non-traditional States such as Uttar Pradesh, West Bengal & Tripura.

There are four cultivated species of cotton *viz*., *Gossypium arboreum, G. herbaceum, G. hirsutum and G. barbadense*. The first two species are diploid (2n=26) and are native to old world. They are also known as Asiatic cottons because they are grown in Asia. The last two species are tetraploid (2n=52) and are also referred to as New World Cottons. *G. hirsutum* is also known as American cotton or upland cotton and *G. barbadense* as Egyptian cotton or Sea Island cotton or Peruvian Cotton or Tanguish Cotton or quality cotton. *G. hirsutum* is the predominant species which alone contributes about 90% to the global production. Perhaps, India is the only country in the world where all the four cultivated species are grown on commercial scale.

Cotton, a semi-xerophyte, is grown in tropical & sub tropical conditions. A minimum temperature of 15^{o}C is required for better germination at field conditions. The optimum temperature for vegetative growth is 21-27^{o}C and it can tolerate temperature to the extent of 43^{o}C but temperature below 21^{o}C is detrimental to the crop. Warm days of cool nights with large diurnal variations during the period of fruiting are conducive to good boll and fibre development. Cotton is grown on a variety of soils ranging from well drained deep alluvial soils in the north to black clayey soils of varying depth in central region and in black and mixed black and red soils in south zone. Cotton is semi-tolerant to salinity and sensitive to water logging and thus prefers well drained soils.

Cotton is the backbone of textile industry, which consumes 59 % of the country's total fibre production. It accounts for 34% of the country's export and fetches about Rs. 50,000 crores annually to the exchequer. Along with the industry, which it sustains, it touches the country's economy at several points including employment and export earnings. India annually cultivates more than twenty million hectares, the largest in the world. In fact, one out of every four hectares of land under cotton in the world is in India. Around 6 to 6.5 million farmers grow the crop in about 10 States (Punjab, Haryana, Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Andhra Pradesh, Telangana, Karnataka and Tamil Nadu). Around 80 million people are estimated to depend on it one way or the other to make out their living.

1.2 Importance of Study

It is estimated that one third of world population has been in area where the water sources are poor. About 95 to 97 percent area is under rainfed cultivation. Most of the times erratic rainfall with uneven distribution occurs. Therefore, cotton crop has to face the water stress at flowering and boll development stage. Plant responses to drought are complex and different mechanisms are adopted by plants when they encounter drought (Jones, 2004) which include; i) drought escape by rapid development and finish life cycle before sever water stress. ii) drought

avoidonce by increasing water uptake and reducing transpiration rate by reduction of stomatal conductance. iii) drought tolerance by maintaining tissue turgour during water stress via osmotic adjustment. iv) resisting severe stress through survival mechanisms (Izanloo *et al.* 2008). Plant response to drought is in two ways *viz*., susceptibility and tolerance, which depends on the species, genotypes and development age of the plant. A strategy that tolerant plant often uses to overcome water deficit is the accumulation of solutes (osmotic adjustment) in the cell to help or maintain plant water status, particularly under drought. Drought tolerance is the struggle of plants to survive in the drought condition with little or no injury. Drought tolerance is either acquired by mitigating drought or by showing high degree of drought tolerance.

Plant scientists are making concerted effort in identifying genotypes with higher yield coupled with relatively better drought tolerance. The progress in developing crop cultivars for tolerance to abiotic stress particularly drought has been slow, because of lack of knowledge of inheritance of tolerance, low heritability and lack of efficient techniques for screening germplasm (Kush, 1998).

Therefore, the efforts were undertaken to investigate physiological components causing performance difference in deficit of stress condition and evaluated different genotypes of cotton which are more productive and tolerant to stress condition with utilizing minimum water resources on the basis of physiological / biochemical parameters. Considering above facts, the investigation was carried out for selection of drought tolerant genotypes amongst the release/ pre-release/ parents of *G. hirsutum* of cotton on the basis of physiological parameters with following objectives.

1.3 Objectives

1. To determine the physiological response of diverse cotton genotypes under different levels of moisture stress.
2. To identify the cotton genotype suitable for moisture stress condition.

1.4 Hypothesis

Determination of physiological basis for moisture stress genotypes with desirable methods for detecting the minimum losses due to water stress. In this ideology, plant must have the genetic and physiological capabilities to tolerate the water stress. A significant effort had been taken to identify these characters, their expression and genetic control had been undertaken so that the drought tolerance of cotton may further be improved. High level of relative water content, chlorophyll content, proline content are some important physiological parameters which are related with the drought tolerance.

The present study will be helpful for selecting drought tolerant genotypes against abiotic (drought) stress and also be useful to the plant breeders for further genetic improvement of cotton.

1.5 Scope and Limitations

Drought tolerance is developmental and physiological programme of adopting to changing climate particularly water stress. Several types of drought resistant/tolerant mechanism must be considered. The systematic characterization, differences in physiological response of plant to drought stress which leads to better understanding of mechanism of drought resistance.

It is a matter of great concerned that agriculture industry received several set back every year, particularly received several situations due to uncertain and uneven distribution of rainfall. The study of drought tolerant genotypes would be helpful for detecting physiological, biochemical parameters converting with drought tolerance in cotton.

This study will also be useful for investigating impacts of different traits associated with drought tolerance in cotton genotypes for improving their drought tolerance capacity.

CHAPTER II

REVIEW OF LITERATURE

The most cotton physiological drought stress researches has been conducted in arid production regions, growth chambers or green houses. With the objective to document the effects of moisture stress on the physiology of cotton grown (Pettigrew, 2004a), in pots (Basal *et al*. 2005).

Water was the cheapest input earlier and has becoming costly day by day. This scarcity of water decreases Agricultural production. Hence, its utilization on scientific basis with modern concept is highly desirable. A harmful effect of water stress result in low productivity depends on degree of stress and stage of crop growth.

Among the abiotic stresses, water stress is perhaps the most yield limiting factor in cultivated crops including cotton. A number of studies showed that drought tolerance is complex multi-genic agronomic trait. Previous researchers proposed modifying root systems (robust root), water use efficiency, stomatal conductance, photosynthetic rate, leaf water content, carbon isotope discrimination, canopy temperature (T^{o}C), initial water content, the rate of excised leaf water loss, and compatible solutes (osmoprotectants) as a selection criterion for drought tolerant cotton improvement program. (Huseyin and Ayedin, 2006)

Considering above facts for drought tolerance in promising genotypes of cotton in research program on ‘Physiological evaluation of cotton genotypes for moisture stress’ was undertaken and the following review is presented to highlight the salient features related for research under different subheads.

2.1 Effect of Water Stress on Morpho-physiological Parameters

Krieg (1997) indicated that, the crop growth rate was reduced by water stress through a reduction in size and number of leaves produced and in reduction of photosynthesis. He also indicated that the period from square initiation to first flower represents the most critical development period in terms of water supply affecting yield components. The peak flowering period was the most sensitive to drought and at this time water stress led to the greatest decrease in yield.

Nonami (1998) stated that, under severe water deficit, cell elongation of higher plants can be inhibited by disruption of water flow from the xylem to the surrounding elongating cells.

Harris *et al*. (2002) stated that, the first effect of drought is reduced germination and poor stand establishment.

Young *et al.* (2004) reported that, as water stress increases, older leave senescence to various degrees this reduces leaf area of plants. also reported loss of leaf function and premature onset of senescence of older leaves. They suggested that ethylene may serves to regulate leaf performance throughout its lifespan as well as to determine the onset of natural senescence and mediate drought induced senescence.

Pettigrew (2004a) in a related study, found that the primary effect of drought on above-ground, vegetative growth was reduced by 35% which decreases leaf area index. Under water stress, decrease in seed cotton yield is primarily due to the reduction in number of bolls.

Kaya *et al.* (2006) found that, drought stress has been reported to reduce germination and seedling stand.

Zeid and Shaheed, (2006) studied on alfalfa (*Medicago sativa*), germination potential, hypocotyls length and shoot and root fresh and dry weights were lowered by polyethylene glycol induced water shortage, while the root length was increased.

Tripathy *et al.* (2000) and Manikavelu *et al.* (2006) studied in rice, during the vegetative growth stage, drought stress reduced the plant growth and development to a great extent. Growth is accomplished through

cell division, cell enlargement and differentiation and involves genetic, physiological, ecological and morphological incidents and their complex interactions.

Taiz and Zeiger (2006) reported, the quality and quantity of plant growth depend on these events which are influenced by water deficit. Cell growth is one of the most drought responsive physiological processes due to decrease in turgour pressure.

Ratnakumari and Subbarammama (2006) studied 21 genotypes regarding drought tolerant parameters, a genotype BShv-971612 recorded highest mean value for dry matter production. RWC, chlorophyll ‘a’, total chlorophyll content in leaves were high in CPD-446. The genotypes SCS-37, GBhv-139 and L-762 recorded the highest mean value for SLA, SLW and chlorophyll stability index (CSI) respectively.

Bedse *et al.* (2007) conducted pot culture experiment with three genotypes Shatak, Ganga-11, and YMH-9805 to study effective soil moisture stress on physiological and biochemical parameters and conclude that moisture stress significantly reduced the leaf area, dry weight of plant, chlorophyll and nitrogen content.

Nagarajan and Nagrajan (2010) and Malik *et al.* (1979) studied that, plant growth rates are generally reduced when soil water supply is limited, shoot growth is often more inhibited than root growth and in some cases; the absolute root biomass of plants in drying soil may increase water use efficiency related to well watered controls. Almost every plant process is affected directly or indirectly by water content is accompanied by other changes such as increase in salt concentration and increase in mechanical impedance.

Patil (2011) studied the effect of water stress on performance of the cotton genotypes, the study revealed that, water stress reduced plant height, number of leaves, leaf area, total dry matter, stomatal conductance, transpiration, NAR and leaf area duration in all the genotypes under water stressed condition compared with well watered control. He also reported

significant decrease in total dry matter content in genotypes grown under well watered condition both in field as well as in rain out shelter compared to rainfed condition.

According to Loka *et al.* (2011), drought stress severely restricts cotton growth and development, such as affecting plant height, leaf dry weight, stem dry weight, leaf area index, node number, fibre quality, canopy and root development.

Fang and Xiong (2015) stated that, drought stress causes a wide range of adverse effects on physiological traits as well as productivity of cotton crop. Under drought conditions specifically in cotton leaves, net photosynthetic rate, transpiration rate, stomatal conductance, carboxylation efficiency and water potential decreased significantly.

Wang *et al.* (2016) and Lv *et al.* (2017) studied that, increased ABA content under drought stress leads to adjustments in the pore size, the protection of the structure and function of cell membrane, the inhibition of plant growth, and a reduction in the metabolic rate, thereby improving the drought resistance of plants.

2.2 Effect of Water Stress on Photosynthesis

Hoekstra *et al.* (2001) stated that, dehydration results in cell shrinkage, a decline in cellular volume. This makes cellular contents more viscous. Increased concentration of solutes leading to increased viscosity of cytoplasm may become toxic and may be harmful to the functioning of enzymes, including those of the photosynthetic machinery.

Lawlor and Cornic (2002) explained, photosynthesis plays a major role in determining crop productivity in all species and is directly affected by water stress. Photosynthetic rates of the leaves decrease as the relative water content and leaf water potential decrease.

Pandey *et al.* (2002) conducted studies to determine the effect of water-deficit stress on the photosynthetic metabolites on cotton during the reproductive stage. They reported that water-stress resulted in a decrease in leaf ATP content while, nicotinamide adenine dinucleotide

phosphate (NADP) content was increased. Leaf 3-phosphoglyceric acid (3-PGA) and pyruvate content remained unaffected by the water stress treatments.

Bota *et al.* (2004) stated that, stomatal closure in response to a water deficit stress primary results in decline in the rate of photosynthesis. Very severe drought condition results in limited photosynthesis due to decline in rubisco activity.

According to Chaves and Oliveira (2004) and Flexas *et al.* (2004), decreased CO2 diffusion from outside the plant to the site of carboxylation is the main cause for reduced photosynthetic rates under most water-stress conditions.

Pettigrew (2004b) speculated that the higher photosynthetic rates and increased PSII quantum efficiency (ΦPSII) with rehydrated plants could be attributed to the higher chlorophyll content per unit leaf area that was observed.

According to Said and Hugh (2005), reduced photosynthetic carbon assimilation and therefore reduced crop dry matter accumulation is a principal effect of soil water deficit in cotton and other crops.

Enahli and Earl (2005), observed that, quantum efficiency of PSII decreases under conditions of water stress. Additionally, they observed, where water stress levels varied from moderate to severe, that even though photosynthetic rates remained unaffected under moderate stress rates, significant decreases were observed in the velocity of carboxylation of Rubisco and at the CO2 concentration at the site of carboxylation.

Flexas *et al.* (2006) observed that, photosynthetic rates are mostly limited by decreased stomatal conductance as well as reduced mesophyll conductance that ultimately result in a general metabolic impairment due to lower carbon substrate concentrations.

Massacci *et al.* (2008) who observed that photosynthetic electron transport was enhanced under conditions of water stress due to an

increased efficiency in the open PSII reaction centers. They also observed that photorespiration increased at the onset of water stress in order to prevent an inhibition of the photosynthetic apparatus and over-production of damaging reactive oxygen species. He attributed this to an increase in photorespiration rates in order to prevent an inhibition of the photosynthetic apparatus and over-production of damaging reactive oxygen species.

Chaves *et al.* (2009) stated, drought stress causes stomata closure, which leads to the decreased CO_2 intake, affecting the rate of photosynthesis and consequently reduces growth and yield.

Deeba *et al.* (2012) and Li *et al.* (2011) reported photosynthesis is severely affected along with growth as the water deficit increases gradually in the field of cotton. For example, it was found that photosynthesis as well as transpiration was affected under drought conditions in cotton. It has been reported that young leaves of cotton are photosynthetically more tolerant to drought and heat as compared to mature leaves.

Basu *et al.* (2016) studied during drought stress, limited intercellular CO_2 concentration leads to the accumulation of reduced photosynthetic electron transport components that can potentially reduce the molecular oxygen, resulting in the production of ROS, which are deleterious to photosynthetic apparatus.

Zhang *et al.* (2017) stated that, stomata closing in response to moisture stress results in a reduction in leaf photosynthetic capacity resulting in chloroplast dehydration and decreased CO_2 diffusion into the leaf. For instance, mild moisture stress stimulates stomata closure to reduce water loss by regulating transpiration. This reduces stomatal conductance and limits intercellular CO2 concentration.

2.3 Effect of Water Stress on Respiration

Lambers *et al.* (1996) reported that, the root is a major consumer of carbon fixed in photosynthesis and uses it for growth and maintenance, as well as dry matter production.

Davidson *et al.* (2000) reported that, drought tolerance is a cost-intensive phenomenon, as a substantial quantity of energy is spent to deal with it. The fraction of carbohydrate that is vanished through respiration determines the overall metabolic efficiency of the plant. However, according to Huang and Fu (2000) the rate of photosynthesis limits the plant growth when soil water availability is reduced.

Flexas *et al.* (2005) stated that, the complicated interactions that take place with other environmental factors, as well as the existence of a stress threshold under which changes in respiration rates occur have been proposed as the causes of these discrepancies in plant respiration under water stress conditions.

Atkin *et al.* (2007) affirmed that, Of the CO2 fixed each day by net photosynthesis, about 30-70% is released back to the atmosphere through dark respiration with 50-70% of whole plant respiration occurring in leaves.

According to Atkin and Macherel (2009) the responses of respiration rates to water deficit are variable and with no clear pattern depending on the type and the age of tissue (mature or still actively growing), the duration and severity of stress, changes in activity of respiratory enzymes, changes in hormonal and osmolyte accumulation, substrate availability and ATP demand.

Lawlor and Tezara (2009) speculated that drought stress might also result in an increased ATP content through the respiratory pathway in order to compensate for reduced rates of chloroplast ATP synthesis.

According to Farooq *et al.* (2009), water suppression leads to reduction in photosynthesis and respiration rates, delay in nutrients absorption and assimilation, losses in turgidity and stomatal conductance, senescence and leaf shedding, among others.

Sanhueza *et al.* (2013) reported that respiration rate increases in plants in the drought tolerant *Nothofagus* species.

Dahal and Vanlerberghe (2017) stated that, in response to a rapid onset of water deficit stress, the severity of which increased continually over time, the AOX amount in *Nicotiana tabacum* leaf was a strong determinant of the rate of respiration in the light (RL).

2.4 Drought Tolerance Mechanisms under Moisture Stress

Blum (1997) observed that, Stomatal tool has been investigated as a tool determing drough tolerance in sorghum. Stomatal aperture acts plant protecting mechanism by decreasing water loss through closure it's during period of plant water stress as well as influencing the rate of photosynthesis and respiration. Water saving species reduces transpiration mostly by closure of their stomata in response to water deficit well before wilting. Stomata may remain open during the early morning hours and close as solar radiation increases. There is desirable genetic diversity within the species and among the species in sensitivity of stomata to drought stress.

Saxena *et al.* (1996) reported that, stomatal frequency has also been considered as one of the indices of drought resistance. Low stomatal frequency may be associated with drought tolerance. High rate of stomatal resistance and lower rate of transpiration can be used for screening germplasm for drought resistance.

According to Borrell *et al.* (2000) size, shape, surface characteristics, angle and arrangement of leaves play important role in determining drought tolerance in crop plants. Leaf pubescence generally increases leaf reflectance and reduces net radiation resulting in lower leaf temperature under high radiation. Green leaf area at physiological maturity is a good indicator of drought tolerance. Thickness of leaf cuticle, epidermis, hypodermis and number of stomata generally increases under water stress, while the number of hairs and stomatal length decreased.

Singh *et al.* (2006) studied that, the bound water in living tissue is more likely to play a major role in tolerance to abiotic stresses in cotton by maintaining the structural integrity and/or cell wall extensibility of

the leaves, whilst an increased amount of free water might be able to enhance solute accumulation, leading to better osmotic adjustment and tolerance to water stress and maintenance of the volumes of sub-cellular compartments for expansive leaf growth.

Jones (2004) reported that, plant responses to drought are complex, and different mechanisms are adopted by plants when they encounter drought. These mechanisms can include: (i) drought escape by rapid development, which allows plants to finish their cycle before severe water stress; (ii) drought avoidance by, for instance, increasing water uptake and reducing transpiration rate by the reduction of stomatal conductance and leaf area; (iii) drought tolerance by maintaining tissue turgor during water stress via osmotic adjustment, which allows plants to maintain growth under water stress; and (iv) resisting severe stress through survival mechanisms (Izanloo *et al.* 2008).

Manavalan *et al.* (2009) studied that, drought escape is the ability of plants to adjust their growth period or lifecycle, such as the cotton variety with a short life cycle, to avoid the seasonal drought stress.

According to Luo (2010), drought tolerance is the capability of plants to withstand severe dehydration through specific physiological activities, such as osmotic adjustment via osmoprotectants.

Monneveux and Ribaut (2011) reported that, genotypic selection for adaptation to different water regimes is an important strategy in breeding programmes to develop drought tolerant varieties.

Sun (2015) found that, the tolerance to water deficit depends on the plant growth stage; when water deficit occurred at critical stages, such as reproduction, growth and development of the plant may be affected.

Fang and Xiong (2015) explained that, plant drought tolerance mechanisms can be divided into four strategies: drought avoidance, drought escape, drought tolerance and drought recovery.

Maqbool *et al.* (2017) reported that, integration of conventional, molecular and omic-based techniques can successfully be employed to develop tolerant plant genotypes. In general, breeding strategies have been employed to manipulate the genetic makeup of crops for enhancing their tolerance against drought.

2.5 Osmotic adjustment (OA)

Delauney and Verma (1993) evaluated that, proline is a compatible solute; its accumulation has been demonstrated to be associated with abiotic stresses. Proline is accumulated to higher concentration during stress condition and declines upon rehydration. It serves as a cytoplasmic osmotic balance for potassium accumulation as the main osmoticum in the vacuole. Proline serves as a protectant of various enzymes and biological membranes subjected desiccation and heat stress.

Turner (1997) studied that, osmotic adjustment is referred as net increase in solute concentration, may be perceived as an important mechanism to drought stress. In addition, it is being frequently correlated with yield stability in dry environment. This process has been considered as an important physiological adaptation characteristic associated with drought tolerance and it has drawn much attention during last years.

According to Lawlor and Cornic (2002), production of osmolytes is a general method in plants to maintain osmotic potential and cell turgor, however, they also have secondary roles such as stabilization of membranes and maintenance of proper protein conformation at low leaf water potentials, protection of cells by scavenging for ROS as well as regulation and integration in the metabolism of stressed photosynthetic tissues.

Kusaka *et al.* (2005) stated that, osmotic adjustment can be defined as a decrease in the cell sap osmotic potential, resulting from a net increase in intracellular solutes rather than from a loss of cell water.

Hessine *et al.* (2005), compatible solutes *viz*., sugars, glycerol, proline or Glycine betine can also contribute to osmatic adjustment.

According to Martinez *et al.* (2005) as water is being removed from the plant cells, its osmotic potential is reduced due to the simple effect of solute concentration. However, during the process of cellular water loss, solutes are actively accumulated and lead reduction in osmotic potential. This reduces the outflow of water from cell, thereby reducing the loss of turgor and allows stomatal opening and expansion growth to continue progressively at lower water potentials.

Silva *et al.* (2010) studied that, it is a cellular adaptive mechanism vital for stress-tolerant plants; allow plants to continue growing in the case of drought.

Sujata and Awant (2013) reported that, ABA also helps in regulating other hormones like ethylene, which cause senescence. Under higher ABA levels, ethylene production is inhibited leading to a reduction in the development of plant.

Hanci and Cebeci (2014) reported that, proline works as a signaling molecule to regulate mitochondria, cell production, and cell death. Moreover, it also plays a key role in buffering cellular redox potential.

Fang and Xiong (2015) studied that, reduction of water loss through leaves is a crucial phenomenon in cotton plants under drought stress. Wilting and rolling of leaves result in less radiation and thus reduced water loss. Drought stress has negative effects on osmotic balance, and therefore, plants accumulate different organic and inorganic substances to reduce the osmotic potential in response to drought stress.

Fang and Xiong (2015) and Singh *et al.* (2015) reported that, numerous organic compounds, including amino acids (proline, glycine), sugars (trehalose, fructan), sugar alcohols (mannitol, sorbitol, D-ononitol), amines and polyamines (polyamine, betaines), polyols, ectoine, alkaloids

and inorganic ions, known as osmoprotectants/osmolytes, are involved in osmotic adjustment.

Ghaderi and Siosemardeh (2011) and Boudjabi *et al.* (2015) stated that, compared to any other amino acid present in plants, proline is the one that is accumulated at far higher levels under water deficit conditions.

Iqbal *et al.* (2016) have reported that the accumulation of proline in drought-tolerant and drought-sensitive cultivars has revealed the significance of this osmolyte.

Anjum *et al.* (2017) have studied the drought-induced changes in growth, osmolytes accumulation, and antioxidant metabolisms of maize hybrids.

Wang *et al.* (2008) and Hasanuzzaman *et al.* (2017) reported that, drought induces osmotic stress, oxidative damage, stomatal closure, damage to cellular structures, as well as a decrease in gas exchange rates.

2.6 Effect of Moisture Stress on Biochemical Processes

Agastian *et al.* (2000) studied that, polyphenols are increased in all cotton genotypes under waters stress conditions. Increase in polyphenols contents in different tissues under stress has been reported in a number of plants.

Hoekstra *et al.* (2001) affirmed that, compounds including proline, glutamate, glycine betaine, carnitine, mannitol, sorbitol, fructans, polyols, trehalose, sucrose, oligosaccharides and inorganics ions like K+ helps to maintain their hydrated state and therefore function to provide resistance against drought and cellular dehydration.

Showler (2002) explained that, water deficit stress resulted in increased free proline levels (49.9 fold) that were correlated with diffusive resistance (second per cm).

Ratnakumari and Subbaramamma (2006) has reviewed high level of activities *viz*., Nitrate reductase, glutamine synthetase, glutamine

tolerance genotype point to their possible role in overcoming moisture stress.

Parida *et al.* (2007) reported that, cotton leaves under water stress exhibited large reductions in starch concentrations, variable effects on sucrose accumulation and increased hexose sugars.

Levi *et al.* (2009) stated that, many compatible solutes (i.e. proline, trehalose and glycine betaine) not only aid in osmotic adjustment but also protect against water deficit stress by buffering redox reactions by scavenging free radicals, preventing protein degradation, maintain membrane stability and aiding in signal transduction. Similarly, decreased osmotic potential was recorded under moisture stress.

Kuromori *et al.* (2010) reported that, ABA synthesis occurs in the roots, it is then transported via vascular tissues, and it shows stomatal closure responses in a variety of cells, such as guard cells.

Wang *et al.* (2012) reported that, glutathione, carotene, and ascorbate are the main antioxidants that are produced in greater amounts under drought stress.

Bahari *et al.* (2015) reported that, drought treated seedlings showed elevated levels of oxidative stress, and simultaneous increase in the activities of the enzymes catalase (CAT), ascorbate peroxidase (APX), glutathione reductase (GR), peroxidase (POD), and polyphenol oxidase (PPO) when compared to control plants.

According to Riemann *et al.* (2015), plant hormones do not function in discrete pathways but rather depend on each other at different stages to control environmental as well as developmental pathways. This results in signal transduction that can assimilate various processes and respond to the stress in a complex way.

Ullah *et al.* (2017) stated that, drought stress induces the expression of stress-related transcription factors and genes, such as reactive oxygen species (ROS), scavenging, abscisic acid (ABA) or

mitogen-activated protein kinase signaling genes that activate various drought-related pathways to induce tolerance in the plant.

2.7 Chlorophyll content

Drought stress produced changes in photosynthetic pigments and components (Anjum *et al.* 2003), damaged photosynthetic apparatus and reduced activities of calvin cycle enzymes, which are important causes of reduced crop yield (Monakhova and Chernyadev, 2002).

Chetti *et al.* (2002) reported that, the property of chlorophyll stability was found to be correlated with drought resistance and hence it is criteria for measuring drought tolerance. Chlorophyll stability index decreased with increased water stress in most of the genotypes. Tolerant genotypes showed lower leaf temperature under stress than susceptible ones, but transpiration rate was comparatively high in tolerance ones.

Astorga and Melendez (2010) reported that, under drought conditions, a decline in chlorophyll pigments have been reported, making plant vulnerable to die.

Farooq *et al.* (2009) and Li *et al.* (2011) studied drought stress reduces the plant growth by influencing various physiological as well as biochemical functions such as photosynthesis, chlorophyll synthesis, nutrient metabolism, ion uptake and translocation, respiration, and carbohydrates metabolism

Sampathkumar *et al*. (2014) stated that, a higher CSI helps the plants to withstand moisture stress through better availability of chlorophyll. The sufficient moisture level in the plant root zone might be the reason for higher CSI.

According to Bahari (2014) and Bolat *et al.* (2014) crops facing water stress often undergo changes in the relative water content, chlorophyll index, and stomatal conductance.

2.8 Effect of Moisture Stress on Root Development

Ball *et al.* (1994) reported that, root growth of 55 days old seedlings of cotton reduced after withholding water.

Mehdi *et al.* (2001) stated that, dry root weight was increased under water stress conditions The root/shoot ratios also increased as the water content increased due to an absolute increase in root weight with shoot weight not being affected. Changes in water distribution as a result of irrigation practices can also impact the growth of cotton roots.

Basal *et al.* (2005) reported a considerable genetic variation for root length, lateral root number, root fresh weight, lateral root dry weight and total root dry weight of 68 cultivated cotton race stocks during late vegetative stage.

Leport *et al.* (2006) studied the drought stress frequently enhances allocation of dry matter to the roots, which can enhance water uptake.

McMichael and Lascano (2010) demonstrated the occurrence of “hydraulic lift” in cotton roots where water is transmitted to the roots in the drier upper soil layers through the root system. The water moves from the wetter lower layers to the upper layers to maintain the viability of the roots in the drier layers to reduce overall root stress. McMichael (unpublished data) showed that rooting densities of cotton increased significantly at lower depths and decreased in upper soil layers in several commercial cotton cultivars when the upper soil profile dried.

Waseem *et al.* (2011) reported that, plant responses against drought stress not only involve the physical adaptation of roots and leaves to enhance water absorption and minimize water loss respectively, but they are also accompanied by a series of gene encoding regulatory proteins that are involved in signaling and enhancing the expression of a number of certain other genes.

Couso and Fernandez, (2012) studied that, in water deficient soil, roots of plant become clumped and hence the ability of water uptake is reduced making plant vulnerable to severe structural problems.

Akhtar and Nazir, (2013) reported that, plants that are adaptive develop adventitious roots to gain maximum air trapped within the pores of soil. Hormones like ethylene and auxin facilitate the formation of adventitious roots making plants resistant to such conditions.

According to Luo H. *et al.* (2015), drought reduces aboveground biomass accumulation by decreasing root volume density, root mass density and root length density.

Luo *et al.* (2016) reported that, mild and initial-stage drought stress enhanced root length in cotton, but long-time water deficit reduced the root activity as compared to control plants.

Zhang *et al.* (2017) stated that, root growth rates are commonly employed for estimating crop yield losses in cotton crop. Insufficient soil moisture restricts root growth and development and consequently impairs functioning of the aerial parts.

2.9 Evaluation of Genotypes for Moisture Stress Tolerance

Ullah *et al.* (2006) evaluated 32 upland cotton (*Gossypium hirsutum* L.) for drought tolerance traits, he found large genotypic variation among genotypes for cotton productivity traits like drought susceptibility index with seed cotton yield, boll number and certain physiological attributes like net assimilation rate, stomatal conductance and transpiration rate.

Singh *et al.* (2006) evaluated fifteen cotton genotypes developed at Nagpur and Sirsa for their drought tolerance to behavior alongwith LRA-5166 and H-777 under irrigated and simulated drought conditions in the field. SSI for biomass and yield was relatively low in genotypes DCI-774, CNH-30, CNH-40, DTS-2, LRA-5166, TOM16xBN and HAF-277x BN,. Based on the SSI for yield and biomass and RWC, genotype DCI-274, CNH-36, CNH-36, CNH-40, DTS-2.

Longenberger *et al.* (2006) developed a design to evaluate a screening method for drought tolerance in cotton seedlings. 21 converted race stocks (CRS) and two cultivars were evaluated for seedling drought

tolerance (SDT) on an individual plant basis. Genotypes were evaluated under greenhouse conditions. Seedlings were subjected to three sequential cycles of drought at 15 days after planting (DAP). Drought cycles consisted of withholding water until the moisture content of indicator 'Deltapine 491' (DP 491) plants, had an average volumetric water content of 0.07. Genotypes differed in their percent survival following three consecutive drought cycles. Drought cycles 2 and 3 did not contributed to the separation of genotypes. DP 491 was the most tolerant genotype evaluated. They observed CRS did not differ in drought tolerance with 'Acala 1517-99'. CRS M-9044-0165 was the most stable genotype across the two experiments.

Mahmood *et al.* (2006) evaluated eight cotton varieties (BH-118, CIM-446, FH-900, FH-901, MNH93, MNH-552, MNH-554 and NIAB Krishma) for drought tolerance using various growth and productivity traits. These varieties were subjected to two and four water deficit cycles. The varieties showed distinct responses with respect to moisture deficit conditions. Certain growth and productivity traits provided some manifestation of drought resistance in these varieties. The MNH-93 and BH-118 appeared to be more drought tolerant for both growth and yield parameters as compared to other varieties under evaluation. MNH-552, MNH-554, CIM-446, FH-900 and NIAB-Krishma exhibited some potential to withstand drought intensities, although an affirmative relationship for growth and yield attributes cannot be established in these varieties.

At CICR, Nagpur, Anonymous (2007) studied eleven genotypes *viz.,* LRA-5166, NHH-44, CAT-3845, CAT-3874, CAT-1911, CAT-3791, CAT-379 (*G*. *hirsutum),* AC-7602, AC-6577, AKA-8401,(*G*. *arborium*) were grown in pots and water stress were induced at flowering during main season. Morpho-physiological parameters and biochemical traits indicated that leaf water potential was maintained significantly higher in (*G*. *hirsutum),* genotypes both in control and stressed plants compared to *G. arborium* genotypes. Among the genotypes CAT-3640 recorded relatively higher leaf water potential under water stress condition. It

remained relatively higher in AC-6755 (*G*. *arborium)* stomatal resistance relatively increased due to water stress condition. Higher leaf solute potential was noticed in *G. arborium* genotypes indicating a trend towards higher osmotic adjustment during water stress condition. It remained relatively higher in AC-6755 (*G*. *arborium).* Stomatal resistance significantly increased due to water stress particularly in *G*. *hirsutum* genotypes which may facilitate dehydration avoidance of leaf water status during stress period. Transpiration rate decreased due to water stress and it remained relatively higher in control plants *G*. *hirsutum* genotypes. NRase activity was maintained higher in CAT-3791, CAT-379 (*G. hirsutum),* AC-7602 (*G*. *arborium)* during water stress. Total biomass production however decreased and root-shoot ratio increased under drought stress. Water stress induced during flowering decreased seed cotton yield and it was more prominent in diploid cotton genotypes whereas *G*. *hirsutum* genotypes mostly showed yield stability. Biochemical studied on abiotic stresses with particularly reference to heat and drought in cotton. NR activity was estimated at 90 DAS in leaf samples of cotton genotypes (11 *G*. *hirsutum)* and 5 *G*. *arborium* lines) under control and moisture stress conditions. NR activity has been found to increase during stress in only four genotypes.

Ullah *et al.* (2008) assessed genotypic variability for drought tolerance in cotton using physiological attributes with productivity traits under well watered and water stress regimes in field experiment and reported that seed cotton yield was markedly affected under water stress conditions in all cultivars studied. Substantial genotypic variations were found for physiological traits like gas exchange.

Anonymous (2008) studied fifty advanced culture lines of cotton (*G*. *hirsutum)* as raised in field and evaluated for drought tolerance during peak flowering stage. Biochemical parameters *viz*., reducing sugars, amino acids, phenol and physiological parameters like chlorophyll content and membrane stability were analyzed in both control and stressed plants. The yield per plant and fibre quality was also quantified. Finally, the lines

have been separated based on the differential expression of each biochemical factors in control and stress plants. The differences are expressed as per cent increase/decrease over the control. The genotype was rated as tolerant if there was a positive chlorophyll value, negative membrane stability value, higher reducing sugars and amino acid content and less of phenols. These are rated with LRA-5166 which is known as moderately tolerant to moisture stress as a standard. Based on these values the lines DTS-39-08, DTS-44-08, DTS-62-08, DTS-67-08 were found to be tolerant lines.

Yildiz-Aktas *et al.* (2009) tolerant and sensitive cotton genotypes were grown at normal (field capacity) and limited (1/3 field capacity) water supply, chlorogenic acid isomers and flavonoids were identified in high performance liquid chromatography (HPLC) patterns of polyphenols. At normal water supply, the tolerant genotypes were distinguished by higher content of all polyphenols types, high proline, carotenoids and antiradicles (AR) capacity was observed. However this response was less pronounced in the tolerant than in the sensitive genotypes that are despite the stress condition imposed the tolerant plants maintained a more effective defense system and gives support to weaker structure membrane damage in drought exposed tolerant varieties.

Khalid *et al.* (2011) evaluated the responses of 80 genotypes/lines of *Gossypium hirsutum* at seedling stage under water stressed and non-stressed conditions in glasshouse. Plant growth was measured as longest root and shoot after 45 days. They found genotypic differences for indices of drought tolerance were statistically significant. Based upon the differences and similarities, four tolerant i.e., 149F, B-557, DPL-26, BOU 1724-3 and 4 susceptible namely FH-1000, NF-801-2, CIM-446 and H-499 genotypes/lines were crossed in all possible combinations. The responses of 64 families were examined under water stress and non-stressed conditions at seedling stage. They found the genotypes B-557 and DPL-26 had the greatest tolerance index and appeared to be tolerant to water stress. In addition, BOU- 1724, 149F, VH-57, CIM-497 and BH-124

also seem to be the tolerant genotypes/lines. The genotypes/lines NF 801-2, FH- 1000, Dixi-king and H499-3 were found susceptible.

Vladimir and Cothren (2011) evaluated the effects of 1-Methylcyclopropene on gas exchange, plant growth and yield components of cotton under drought during the reproductive phase in cotton. Their study revealed that drought started to impact gas exchange at a moderate water stress, 5 DAT (days after 1-MCP treatment) (-1.4 MPa). The 1-MCP increased water use efficiency (WUE) in well watered plants at 1 DAT. Many of the yield components, plant mapping, and biomass parameters investigated were adversely affected by drought.

Muhammad *et al*. (2011) evaluated 31 cotton genotypes/cultivars under two irrigation regimes i.e., seven irrigations (Control) and two irrigations (Stress), using split plot design with four replications. Chlorophyll content, plant height, transpiration rate, stomatal conductance was significantly decreased in the cotton under water stressed condition compared to well watered condition.

Ullah *et al.* (2017) studied physiological traits linked with drought tolerance in cotton have strong relationship with yield parameters such as, photosynthetic rate; which significantly decreases with the imposition of water stress, can be effectively used for germplasm screening under drought conditions.

Lu *et al.* (2017) and Ullah *et al.* (2017) stated that, there are several studies on genome, epigenome and transcriptome level to identify drought tolerance associated quantitative trait loci (QTLs), genes and transcripts in cotton.

2.10 Effect of Water Stress on Crop Growth and Yield

According to Earl and Davis (2003) three main mechanisms lessen crop yield by soil water deficit (i) reduced canopy absorption of photosynthetically active radiation, (ii) decreased radiation-use efficiency and (iii) reduced harvest index.

Stiller *et al.* (2004) in the mid-1990s found that dryland cotton in Australia produced only 48% of the yield of irrigated cotton. Furthermore, the cotton fiber of the dryland crop was 4% shorter than the irrigated crop. Pettigrew (2004b) in Mississippi found that drought reduced cotton yields by 25% mainly as a consequence of reducing boll number by 19%.

Pettigrew (2004a) reported that moisture deficit lowered cotton (G*ossypium hirsutum*) lint yield, although the timing, severity, duration had roles in determining, how the plant reacted to moisture deficit. Lint yield was generally reduced due to reduced boll production because of fewer flowers and greater boll abortions when the stress intensity was greater during reproductive growth. He further reported that higher productivity of high yielding cotton genotypes has largely controlled by low leaf area index (LAI), low leaf area duration (LAD), higher boll number and increased boll weight.

Farooq *et al.* (2009) noted that, physiologically, water suppression leads to changes in cell division and expansion. Consequently, other processes are triggered such as reduction in photosynthesis and respiration rates, delay in nutrients absorption and assimilation, losses in turgidity and stomatal conductance, senescence and leaf shedding, among others.

Karademir *et al*. (2011) evaluated the effect of water stress and non-stress conditions on cotton yield and fiber quality properties. By evaluating twelve cotton genotypes for yield and fiber quality properties they found significant differences among genotypes and water treatments for seed cotton yield, fiber yield, ginning percentage and all fiber quality properties except fiber uniformity.

Patil (2011) reported that, there was significantly more boll numbers per plant and boll weight were recorded well watered irrigated condition cotton genotypes both in field as well as in rain out shelter compared to water stressed rainfed condition.

Wen (2013) affirmed that, water deficit in cotton causes boll shedding and thus lower productivity.

Sapeta, (2013) observed that, drought symptoms are mostly found in the leaves of plants showing loss of turgor, drooping, wilting, etiolation, yellowing, and premature downfall.

Tsuchihashi and Goto (2004) and Ghaffaripour and Samson (2015) stated that, drought induced inhibition of physiological and biochemical processes negatively affects concentration of biomolecules and growth, which ultimately causes a reduction in biomass of plants.

Hejnak *et al*. (2015) studied the detrimental effects of drought stress on cotton. According to their results, 50% dry matter accumulation of *Gossypium barbadense* (*G. barbadense*) was limited under drought stress. Moreover, the stomata conductance, photosynthetic rate and transpiration rate were also decreased under water deficit.

Zheng *et al.* (2016) studied that, drought stress has also been reported to reduce plant height, leaf area, stem diameter, and plant biomass in different field crops.

Tadayyon *et al.* (2017) reported that, drought stress causes a significant increase (5% probability level) in Na+ and K+ concentrations and a decrease in Zn and Cu concentrations. In addition, increasing concentrations of Ca, Mn, and Fe were observed in the shoots.

Baboev *et al.* (2017) studied that, drought is the most significant because it limits flora diversification and agricultural productivity. Drought reduces crop yield more than 50% worldwide.

2.11 Effect of Water relation

Siddique *et al.* (2001) studied that, relative water content, leaf water potential, leaf temperature, stomatal resistance, rate of transpiration and canopy temperature are important traits that influence plant water relation. Relative water content of wheat leaves was higher primarily during leaf development and decreased at the dry matter accumulation and leaf

matured. Apparently, water-stress wheat and rice plants had lesser relative water content than non-stressed ones.

Siddique *et al.* (2001) observed that, exposure of the plants to drought stress decreased leaf water potential, relative water content and transpiration rate, with a rise in leaf temperature.

According to Egilla *et al.* (2005), in study under drought stress, relative water content, transpiration, stomatal conductance, turger potential and water use efficiency were decreased. Infact, although components of plant water relations are affected by lowered availability of water, stomatal opening and closing is more strongly influenced. Moreover, under water stress, change in leaf temperature may be an important factor in controlling leaf water status. Drought tolerant species maintain water use efficiency by reducing the water loss. However, the lower plant growth leads to lower water use efficiency.

Hussain (2009) reported additive type of gene action for leaf temperature and relative water content.

According to Brito (2011), the reproductive phases coincide with stages where crop water requirements increased, with water consumption varying between 2.5 and 6 mm day^{-1}.

Loka and Oosterhuis (2012) affirm that, the reproductive phase of the cotton plant is the most sensitive one to water deficit.

Ananthi *et al.* (2013) reported that, significant decrease in RLWC under moisture stressed condition is due to reduced absorption of water from the soil and inability to control water loss through the stomata.

Conaty *et al.* (2015) stated that, during moisture stress, reduced transpiration rate activated cooling system of leaf water potential and maintain higher canopy temperature.

According to Cordao (2015), although cotton is a species adapted to water deficit, at least 400 to 500 mm of water are required during the growing season to achieve good yields.

CHAPTER III

MATERIAL AND METHODS

An experiment was conducted on “Physiological evaluation of cotton genotypes for moisture stress”, Details of materials used and methods adopted during the course of investigations are explained hereunder.

3.1 Experimental Details and Technical Programme

3.1.1 Seed material

The experimental material consisted of ten diverse genotypes of *G. hirsutum* cotton which was procured from Senior Research Scientist (Cotton), Cotton Research Unit and planted at experimental field of Cotton Reaserch Unit, Dr. PDKV, Akola (M.S.).

3.1.2 Location

The experiment was carried out on the experimental field of Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola located at 304.415 meter altitude, 20^{o}30’ N latitude and 72^{o}02’ l^{o}ngitude during *Kharif* season of during *Kharif* season of 2018-19.

EXPERIMENTAL DETAILS

A] water stress condition

1) Pot culture with desired quantity irrigation upto initiation of bolls was given.

2) Water stress was imposed at initiation of bolls for 12 days for every genotype and replication wise.

3) Second stress was imposed 12 days after first stress.

This situation was maintained in water stress condition / control condition.

Number of pots : 90 pots for water stress condition (Three replications)

(3 pots per genotypes per replications)

120 polybags containing soil was sown as separate set for root parameter and dry matter production studies.

Pot size : Earthen pot size was as under –

Height : 18 inch

Upper diameter : 17 inch

Lower diameter : 10 inch

Genotypes under water stress condition was sown in earthen pots. Five holes of 2.5 cm deep around the peripheri was made in each pots and two seeds was sown per hill. After germination seedlings was thinned and maintained one plant per hill, thus there was three seedlings per pot was maintained.

B] Non stress condition

Genotype in field condition with suppliment of irrigation at different growth stages upto harvest.

Before sowing of seeds the field capacity (moisture content %) was measured by gravimetric method in both the condition.

Design : Randomized Block Design

Replications : Three

Date of sowing : July 7th 2018

Spacing : 60 cm×30 cm

Plot size : Gross - 3.0 × 6.0 mt^2

Net - 2.40 × 5.40 mt^2

Date of harvesting : 3 pickings as per maturity of genotypes and undertaken replication wise separately.

TRETMENTS DETAILS (10 Genotypes) : *G. hirsutum*

1) AKH-09-5
2) AKH-2012-8
3) AKH-1301

4) AKH-1302

5) NH-545

6) P-688

7) AKH-9916

8) AKH-8828

9) PKV Rajat

10) NH-615

3.2 Observations Recorded

3.2.1 Morphological observations

3.2.1.1 Plant height (cm)

Observations on plant height were recorded (cm) at 30, 60, 90, 120 and at harvest. The height of the three observational plants from each treatment and replication were recorded with scale from the base of a plant to top most developing node. From these plants of each treatment, mean height was calculated and recorded.

3.2.1.2 Number of leaves /plant

Number of functional leaves were recorded at 30, 60, 90, 120 DAS from three randomly selected observational plants from experimental plot and pots also. From these three plants of each treatment, mean number of leaves was calculated and recorded.

3.2.1.3 Leaf area (cm^2/plant)

Leaf area (cm^2/ plant) was recorded at 30, 60, 90, 120 DAS. All leaves from observational plant were detached and scanned with the help of instrument “CI - 202 Automatic Leaf Area meter, CID (INC), USA.” The summation of the values for each treatment and each replication were done and recorded.

3.2.1.4 Dry matter production studies

For dry matter study, single plant from each treatment and replication was uprooted periodically at 60, 90, 120 DAS and at harvest.

The plant samples were washed with tap water carefully in order to remove soil and dust particles adhered to it. The samples were allowed to dry at room temperature separately for 48 hrs. The plant samples were then placed in the big size brown paper perforated bags. After drying the sample on open air basis, the plant sample was finally dried in hot air oven at 70^{o}C upto achieving the constant weight. The average total dry matter was recorded (g/plant) genotype and replication wise.

3.2.1.5 Relative Water Content (RWC) (%)

Relative water content was recorded at 60, 90 and 120 DAS of plant growth. RWC of leaves gives an idea of water retaining ability of plant in leaf. Third leaf from top was selected from each treatment and replication wise. Their fresh weight was immediately taken, labelled and were placed in polythene bags separately to avoid water loss. Leaves were weighted on electronic balance, and then transferred to petridish containing water. The leaves were kept floating on water for 4 hrs and after that their turgid weight was measured. The dried weight of leaves was recorded after keeping it in hot air oven at 70^{o}C.Relative water content was calculated with the equation given by Barrs and Weatherley, (1962).

$$RWC(\%) = \frac{\text{Fresh weight} - \text{oven dry weight}}{\text{Turgid weight} - \text{oven dry weight}} \times 100$$

3.2.1.6 Number of monopodia per plant

The monopodial branches bearing at least one functional sympodial branch were counted separately on each plant and the average value was recorded at the time of harvest.

3.2.1.7. Number of sympodia per plant

Fruiting branches arising from the main stem were counted separately on each plant at harvest and average value was recorded.

3.2.1.8 Root length

Observations on root length were recorded in centimeter at 60 DAS and at harvest. The root length of the single plant from each replication and treatments were recorded with scale from the base of a plant near to root to the tip of root.

3.2.1.9 Root: Shoot ratio

For root : shoot ratio, single plant from each treatment and replication was uprooted periodically at 60 DAS and at harvest. The plant samples were washed with the tap water carefully in order to remove soil and dust particles adhered to it. The samples were allowed to dry at room temperature separately for 48 hrs. The plant samples were then placed in the big size brown paper perforated bags. After drying the sample on open air basis, the plant sample was finally dried in hot air oven at 70^{o}C upto achieving the constant weight. Roots were separated from the top (cut at soil line). Root and shoot were separately weighed and recorded for each plant treatment (genotype) and replication wise. The root : shoot ratio was calculated using formula :

$$\text{Root : shoot ratio} = \frac{\text{Dry weight for roots}}{\text{Dry weight for shoot}}$$

3.2.2 Laboratory and Biochemical observations

3.2.2.1 Leaf Proline content (µg g fresh wt^{-1})

Proline content from the leaf tissues of each treatment and each replication were estimated at 90 and 120 DAS. Adopted the procedure as suggested by Bates *et al*. (1973). The leaf sample of 0.5 g was homogenized in 10 ml of 3 percent sulphosalicylic acid. The homogenate was filtered through a double layered filter paper. A 2 ml of the filtrate was taken in a test tube to which 2 ml of acid ninhydrin reagent (2.5 g of ninhydrin was dissolved in 40 ml of 6M orthophosphoric acid and 60 ml of glacial acetic acid), 2 ml of glacial acetic acid was added. The test tubes containing the mixture were placed in boiling water bath for one hour. The test tubes were then cooled by keeping in an ice bath. The contents were

transferred to a separating funnel and 4 ml of toluene was added and mixed vigorously. The coloured toluene fraction was separated and measured at 520 nm in a spectrophotometer. A blank was maintained with all the reactants except the leaf extract. Proline content in leaf tissue was calculated by using the equation:

$$\text{Proline (µg/ g fresh wt)} = \frac{34.11 \times OD520 \times V}{2 \times f}$$

Where,

V = Total volume of extract

f = grams of fresh leaf

2 = Volume of extract taken

3.2.2.2 Estimation of chlorophyll content (mg/g fresh wt.)

Leaf chlorophyll content was estimated at 60, 90 and 120 DAS by following Hiscox and Israelston (1979). In this method, 100 mg of fresh leaf tissue was weighed and incubated in 7.0 ml dimethyl sulfoxide (DMSO) at 65°C for 2 hr. At the end of the incubation period, supernatant was decanted and the volume was made up to 10.0 ml with DMSO. The absorbance of the extract was read at 645, 652 and 663 nm in a spectrophotometer using DMSO as blank.

The chlorophyll content was calculated by the equation as given below:

$$\text{Chlorophyll (a) (mg/g fresh wt.)} = 12.7\,(A663) - 2.69\,(A645) \times \frac{v}{1000 \times W}$$

$$\text{Toal Chlorophyll (mg/g fresh wt.)} = 20.2\,(A645) + 8.02\,(A663) \times \frac{v}{1000 \times W}$$

Where,

A = absorbance at specific wavelengths,

v = final volume of chlorophyll extract,

W = fresh weight of sample.

3.2.2.3 Chlorophyll stability index

Chlorophyll stability index was recorded at 60, 90, and 120 DAS of plant growth. This method is based on pigment changes induced by heating. The chlorophyll destruction commences rapidly at critical temperature of 55-56°C. For measuring Chlorophyll Stability Index (CSI), third fully expanded leaf from the top was used.

Leaf samples of 0.2 g were collected in two sets. One set was placed in the test tubes, kept in hot water bath, maintained at 56°C for 30 minutes. Another set was kept at room temperature to serve as control. Chlorophyll content was estimated from heated and unheated leaf sample (Dhopte and Livera, 1989). The absorbance of the extract was read at 645 and 663nm in a spectrophotometer using DMSO as blank. The chlorophyll content was calculated by using the following formula and expressed in mg/g fr.wt.

The difference in two readings Total chlorophyll content without heating and total chlorophyll content after heating is defined as CSI. and it is inversely related with drought tolerance efficiency (DTE).

CSI was calculated by the formula as given below,

$$\text{CSI} = \frac{\text{CS}}{\text{CC}} x100$$

Where,

CS = Total chlorophyll content of stressed plant (mg/g fresh wt.)

CC = Total chlorophyll content of control plant (mg/g fresh wt.)

3.2.3 Yield and yield attributes

3.2.3.1 Number of bolls per plant

From the initiation of first picking the number of bolls per plant was counted and recorded upto last picking and the summation of number of bolls at each picking gave number of bolls per plant.

3.2.3.2 Seed cotton yield per plant (g)

The seed cotton obtained from all three observational plants from each treatment and replications were weighted separately and mean seed cotton yield (g) was calculated and recorded.

3.2.3.3 Test weight (g)

The test weights were recorded by weighing 1000 seeds from each treatment and each replication wise.

3.2.4 Stress indices

3.2.4.1 Drought intensity

It was estimated as per the formula suggested by Dhopte and M. Livera (1989) and given by Fisher and Wood, (1979).

$$\text{Drought Intensity (DI)} = 1 - \frac{\text{Yield under stress}}{\text{Yield under non-stress}}$$

3.2.4.2 Drought tolerance efficiency

Drought tolerance efficiency was worked out by multiplying drought index with 100. It was calculated using the equation by Dhopte and M. Livera (1989),

$$\text{Drought Tolerance Efficiency (DTE)} = \frac{\text{Yield under stress}}{\text{Yield under non-stress}} \times 100$$

3.2.4.3 Yield stability index

It is relative to the ratio of the mean yield of all genotypes under stress to non-stress (Fisher and Wood, 1979) to assess the

response of genotype to drought. It is also termed as yield stability index and estimated as per Dhopte and M. Livera (1989).

$$\text{Yield Stability Index (YSI)} = \frac{\text{Yield under stress}}{\text{Yield under non-stress}}$$

3.2.4.4 Plant height stress index

Plant height stress index is the ratio of plant height of stressed plants to plant height of non-stress (control plant). Plant height stress index was determined by the equation given by Fisher and Wood (1979),

$$\text{Plant Height Stress Index (PHSI)} = \frac{\text{Plant height under stress}}{\text{Plant height under non-stress}} \times 100$$

3.2.5 Analysis of variance :

The analysis of variance was performed to get the significance of differences between the treatments for all the characters as per the methodology suggested by Panse and Sukhatme (1967). The 'F' test whenever revealed significant, the critical differences were worked out at 5% level of significance for comparisons.

Table 3.1. ANOVA table

Sources of variations	d.f.	Sum of squares	Expected mean sum of squares	F cal.	F table
Replication(s)	(r-1)	RSS	M1	M1/M2	
Treatment(s)	(t-1)	TSS	M2	M2/M3	
Error	(t-1) (r-1)	ESS	M3		

1) S.E. (m±) = standard error of treatment means

$$= \sqrt{\frac{EMS}{r}}$$

2) C.D. = critical difference = S.E. (M) x $\sqrt{2}$ x table ‘t’ at 5%

3) C.V.% = $\frac{\sqrt{EMS}}{G.M.} \times 100$

CHAPTER IV

RESULTS AND DISCUSSION

The experimental findings on “Physiological evaluation of cotton genotypes for moisture stress.” carried out at the experimental field of Cotton Research Unit, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif* season of 2018-2019. The result obtained are discussed in this chapter to have a clear understanding about the relationship of different factors *viz*., non moisture stress and moisture stress condition on morphological and physiological characters of cotton genotypes. The results are discussed briefly in this chapter supported with sound reasoning and appropriate evidence.

4.1 Morphological Characters

4.1.1 Plant height (cm)

The plant height (cm) was recorded at 30, 60, 90,120 DAS and at harvest and data presented in Table 4.1 and depicted by Figure 4.1. Data pertaining to genotypes revealed that genotype AKH-1301 showed significantly higher (16.45 cm) plant height at 30 DAS in non stress condition and other remained at par to each other where in moisture stress condition genotype AKH-9916 (16.66 cm) showed significantly higher plant height over mean value (13.89 cm) and other remained at par to mean value of all genotypes.

At 60 DAS under non stress condition genotype AKH-8828 showed significantly higher plant height (56.54 cm) over mean value (51.01 cm) followed by AKH-9916 (54.36 cm). Under water stress condition genotype AKH-9916 (55.66 cm) showed significantly higher plant height over mean value (49.02 cm) followed by AKH-8828 (54.66 cm).

At 90 DAS genotype AKH-8828 was recorded significantly highest plant height (76.36 cm) followed by AKH-9916 (74.97 cm), and AKH-1302 (73.29 cm) under non stress condition.

Table 4.1. Effect of water stress and non stress condition on plant height (cm) in different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	30 DAS		60 DAS		90 DAS		120 DAS		At harvest	
		Non Stress	Stress	Non stress	stress	Non stress	Stress	Non stress	stress	Non stress	stress
1	AKH-09-5	14.31	13.87	52.24	49.31	69.54	60.29	78.91	67.65	81.07	68.78
2	AKH-2012-8	12.57	12.81	51.63	46.47	66.73	56.59	74.12	61.65	76.49	62.00
3	AKH-1301	16.45	15.91	48.82	46.96	70.79	61.21	80.49	67.81	83.35	69.21
4	AKH-1302	13.91	13.73	50.27	51.85	73.29	62.48	86.37	70.83	88.07	73.40
5	NH-545	12.4	12.39	51.25	48.13	65.02	58.01	74.59	63.03	76.53	64.39
6	P-688	12.47	11.91	44.45	43.12	59.74	49.91	67.99	55.64	70.76	57.54
7	AKH-9916	15.03	16.66	54.36	55.66	74.97	68.51	85.45	75.83	87.6	77.88
8	AKH-8828	14.01	15.56	56.54	54.66	76.36	65.35	83.16	71.14	84.61	73.79
9	PKV Rajat	15.43	12.51	50.85	47.66	67.27	60.62	77.19	68.70	78.43	69.80
10	NH-615	11.97	13.56	49.70	46.38	65.13	55.35	73.41	60.31	74.78	61.15
	GM	13.85	13.89	51.01	49.02	68.88	59.83	78.17	66.26	80.17	67.79
	SE(m±)	0.87	0.72	0.67	1.36	1.21	0.80	1.15	1.27	1.30	1.86
	CD@5%	2.60	2.16	1.99	4.06	3.60	2.38	3.42	3.78	3.87	5.54

Under moisture stress condition, the range of plant height was found between 68.51 to 49.91 cm. Genotype AKH-9916 (68.51 cm) recorded significantly higher plant height over mean value (59.83 cm) followed by AKH-8828 (65.35 cm) and AKH-1302 (62.48 cm).

At 120 DAS genotype AKH-1302 (86.37 cm) was recorded significantly higher plant height followed by AKH-9916 (85.45 cm) and AKH-8828 (83.16 cm) under non stress condition. Genotype AKH-9916 (75.83 cm) was recorded significantly higher plant height over mean value of all genotypes (66.26 cm) followed by AKH-8828 (71.14 cm) and AKH-1302 (70.83 cm) under water stress condition.

At harvest range of plant height was recorded between 88.07-70.76 cm under non stress condition. Genotype AKH-1302 found significantly higher under non stress (88.07 cm) followed by AKH-9916 (87.6 cm) and AKH-8828 (84.61 cm) and under water stress condition AKH-9916 found significantly higher (77.88 cm) over mean value followed by AKH-8828(73.79 cm) and AKH-1302 (73.4 cm). Genotype P-688 (57.54 cm) was recorded lowest plant height under water stress condition.

Genotype AKH-1302 (88.07 cm) showed superior mean performance with respect to plant height (cm) and AKH-1301 (83.35 cm) remained at par over the released genotype PKV Rajat (78.43 cm) among all four released genotypes *viz*., AKH-9916, AKH-8828, PKV Rajat and NH-615 under non water stress condition. Genotype AKH-1302 (73.4 cm) recorded superior plant height over the released genotype NH-615 (61.15 cm) and remained at par with AKH-1301 (69.21 cm) and AKH-09-5 (68.78 cm) under water stress condition at the time of harvest.

This observation was in association with the results noted by Kaya *et al*. (2006); Hussain *et al.* (2008). According to Nonami (1998), water stress reduced cell elongation of higher plants due to disruption of water flow from the xylem to the surrounding elongating cells. Drought stress has also been reported to reduce plant height, leaf area, stem diameter, and plant biomass in different field crops (Zheng *et al.* 2016).

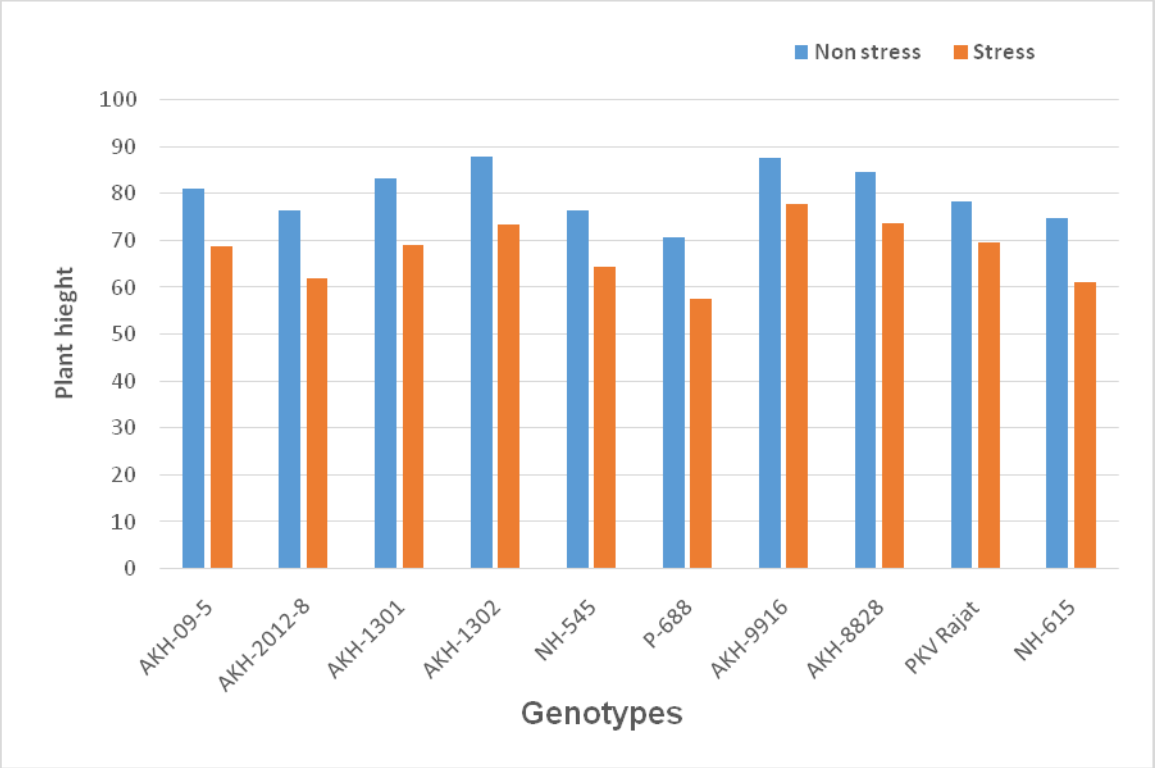

Fig 4.1. Effect of water stress and non stress condition on plant height (cm) in different cotton genotypes at harvest

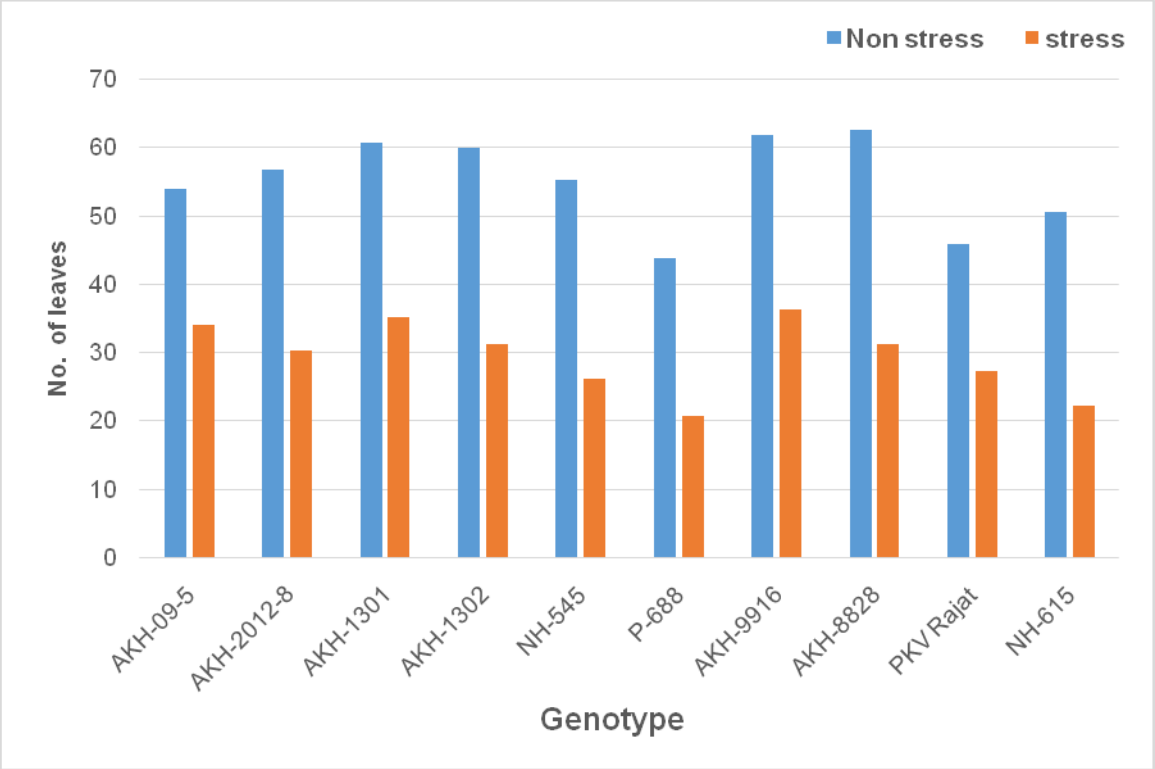

Fig. 4.2. Effect of water stress and non stress condition on number of leaves in different cotton genotypes at 120 DAS

4.1.2 Number of leaves per plant

Number of leaves per plant was recorded at 30, 60, 90 and 120 DAS and data presented in table 4.2. Data regarding number of leaves showed significant differences among mean performance of genotypes in all growth stages under both stress and non stress condition.

Data at 30 DAS under non stress condition showed significant differences among all genotypes. Genotype PKV Rajat (9.73) showed highest number of leaves followed by AKH-9916 (9.26) and AKH-1302 (9.03). Under water stress condition a single genotype AKH-1302 (8.26) found significantly highest number of leaves over mean value of all genotypes (6.46).

At 60 DAS genotype AKH-1301 (45.76) was recorded significantly higher number of leaves under non stress condition followed by AKH-9916 (43.66) and AKH-8828 (42.23). Under water stress condition AKH-1301 (41.13) was recorded significantly higher number of leaves over mean value followed by AKH-9916 (40.66), AKH-1302 (39.20) and AKH-8828 (38.63).

At 90 DAS, the genotype AKH-1301 (81.9) was significantly highest among all genotypes over mean value (68.80) followed by genotype AKH-9916 (81.46) and AKH-8828 (78.60) under non stress condition. Genotype P-688 (54.63) showed lowest number of leaves per plant followed by PKV Rajat (56.66). Under stress condition genotype AKH-9916 (62.73) was significantly higher followed by AKH-1301 (62.3), AKH-1302 (58.76), AKH-8828 (54.9) over mean value.

At 120 DAS under non stress condition AKH-8828 (62.43) was significantly recorded highest number of leaves per plant followed by AKH-9916 (61.83), AKH-1301 (60.6) and AKH-1302 (59.83) over mean value of all genotypes. P-688 was noted for lowest number of leaves per plant (43.76) among all genotypes. Under water stress condition AKH-9916 (36.13) was significantly superior over mean value of all genotypes followed by AKH-1301 (35.16) and AKH-09-5 (33.96). Under stress

conditions genotype P-688 (20.66) was noted lowest number of leaves followed by NH-615 (22.09).

Data recorded at 120 DAS showed that, genotype AKH-1301 (60.6) found superior over the released genotype NH-615 (50.53) followed by AKH-1302 (59.83), AKH-2012-8 (56.60) and NH-545 (55.10) in non stress condition. Also, under stress, the genotype AKH-1301 (35.16) was significantly superior over released genotype AKH-8828 (31.23) followed by AKH-09-5 (33.96).

It revealed that, during water stress condition plant reduced leaf growth and increased rate of leaf aging and senescence of older leaves. Young *et al*. (2004) also reported loss of leaf function and pre-mature onset of senescence of older leaves. They suggested that ethylene may serve to regulate leaf performance throughout its lifespan as well as to determine the onset of natural senescence and mediate drought induced senescence. Present findings on number of leaves per plant are in accordance with the findings of Kreig (1997) who indicated that, the crop growth rate was reduced by water stress through a reduction in size and number of leaves per plant.

Table 4.2. Effect of water stress and non stress condition on number of leaves in different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	30 DAS		60 DAS		90 DAS		120 DAS	
		Non Stress	Stress	Non stress	stress	Non stress	Stress	Non stress	stress
1	AKH-09-5	6.63	5.70	38.23	34.86	65.53	50.30	53.83	33.96
2	AKH-2012-8	8.43	7.20	39.66	33.56	64.46	48.76	56.60	30.26
3	AKH-1301	8.26	6.36	45.76	41.13	81.90	62.30	60.60	35.16
4	AKH-1302	9.03	8.26	41.20	39.20	72.40	58.76	59.83	31.16
5	NH-545	7.03	5.13	35.50	32.80	73.70	50.13	55.10	26.03
6	P-688	6.46	5.43	26.63	21.00	54.63	35.66	43.76	20.66
7	AKH-9916	9.26	7.20	43.66	40.66	81.46	62.73	61.83	36.13
8	AKH-8828	8.13	7.33	42.23	38.63	78.60	54.90	62.43	31.23
9	PKV Rajat	9.73	6.46	30.03	30.73	56.66	46.16	45.73	27.23
10	NH-615	7.96	5.50	28.76	24.84	58.70	36.80	50.53	22.09
	GM	8.09	6.46	37.17	33.74	68.80	50.65	55.02	29.47
	SE(m±)	0.21	0.45	1.64	1.06	2.12	1.35	1.42	0.84
	CD@5%	0.63	1.35	4.88	3.17	6.31	4.02	4.23	2.50

4.1.3 Leaf area (cm²/ plant)

The leaf area (cm²/plant) was recorded at 30, 60, 90 and 120 DAS and data presented in Table 4.3 and Figure 4.3. The data on leaf area/plant showed significant differences of all genotypes during all growth stages under both water stress and non stress conditions.

Data obtained at 30 DAS under non stress condition showed significant differences among genotypes when compared with mean value (128.73 cm²/plant). Genotype PKV Rajat (141.17 cm^2 /plant) was noted significantly higher leaf area followed by AKH-2012-8 (136.85 cm^2 /plant) over mean value. Genotype P-688 (108.37 cm^2 /plant) was noted lowest leaf area followed by NH-615 (119.67 cm^2 /plant). Under water stress condition genotype AKH-09-5 (120.61 cm^2 /plant) was found significantly highest over mean value and followed by AKH-1302 (120.37 cm^2 /plant) and AKH-2012-8 (117.91 cm^2 /plant). The genotype P-688 (98.31 cm^2 /plant) was recorded lowest followed by NH-615 (102.73 cm^2 /plant).

At 60 DAS under non stress condition AKH-1301 (1125.5 cm^2 /plant) showed significantly higher leaf area per plant over mean value of all genotypes followed by AKH-1302 (1047.08 cm^2 /plant) and AKH-9916 (1042.1 cm^2 /plant). Under water stress condition AKH-1302 (973.58 cm^2 /plant) was recorded significantly higher followed by AKH-9916 (949.97 cm^2 /plant), AKH-8828 (931.09 cm^2 /plant) and AKH-1301 (926.67 cm^2 /plant).

At 90 DAS, the genotype AKH-1301 (2451.97 cm^2 /plant) was significantly showed highest leaf area under non stress condition followed by AKH-9916 (2382.41 cm^2 /plant) and AKH-8828 (2280.29 cm^2 /plant). Under water stress condition, the genotype AKH-9916 (1690.55 cm^2 /plant) showed significantly highest leaf area followed by AKH-1301 (1674.33 cm^2/plant), AKH-1302 (1566.18 cm^2/plant) and AKH-8828 (1458.91 cm^2 /plant).

Table 4.3. Effect of water stress and non stress condition on leaf area (cm^2/pl.) in different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	30 DAS		60 DAS		90 DAS		120 DAS	
		Non Stress	Stress	Non stress	stress	Non stress	Stress	Non stress	stress
1	AKH-09-5	128.56	120.61	954.22	846.00	1941.10	1350.24	1687.56	952.02
2	AKH-2012-8	136.85	117.91	974.69	838.33	1892.08	1296.46	1798.69	744.41
3	AKH-1301	127.86	107.07	1125.50	926.67	2451.97	1674.33	1930.50	980.60
4	AKH-1302	130.61	120.37	1047.08	973.58	2172.33	1566.18	1892.41	887.31
5	NH-545	126.21	110.42	857.64	819.04	2183.66	1371.63	1764.31	745.77
6	P-688	108.37	98.31	646.73	538.27	1686.43	945.43	1382.40	590.73
7	AKH-9916	133.09	110.22	1042.10	949.97	2382.41	1690.55	1965.44	1030.04
8	AKH-8828	134.88	114.41	1018.86	931.09	2280.29	1458.91	1917.19	864.91
9	PKV Rajat	141.17	112.14	782.53	674.52	1669.27	1243.35	1459.27	754.81
10	NH-615	119.67	102.73	796.03	598.35	1781.56	972.06	1656.03	632.99
	GM	128.73	111.42	924.53	809.58	2044.11	1356.91	1745.38	818.36
	SE(m±)	2.24	1.83	33.68	15.00	52.59	30.82	38.72	28.88
	CD@5%	6.68	5.45	100.07	44.58	156.27	91.58	115.05	85.83

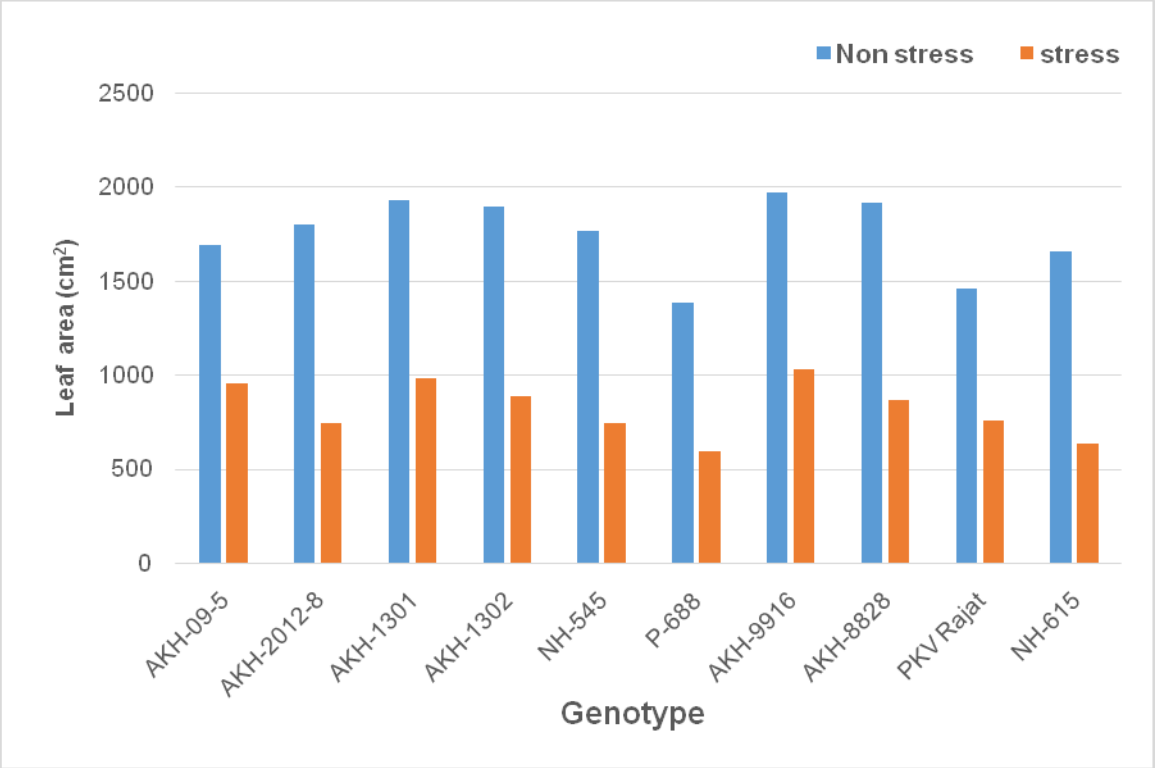

Fig. 4.3. Effect of water stress and non stress condition on leaf area (cm^2) in different cotton genotypes at 120 DAS

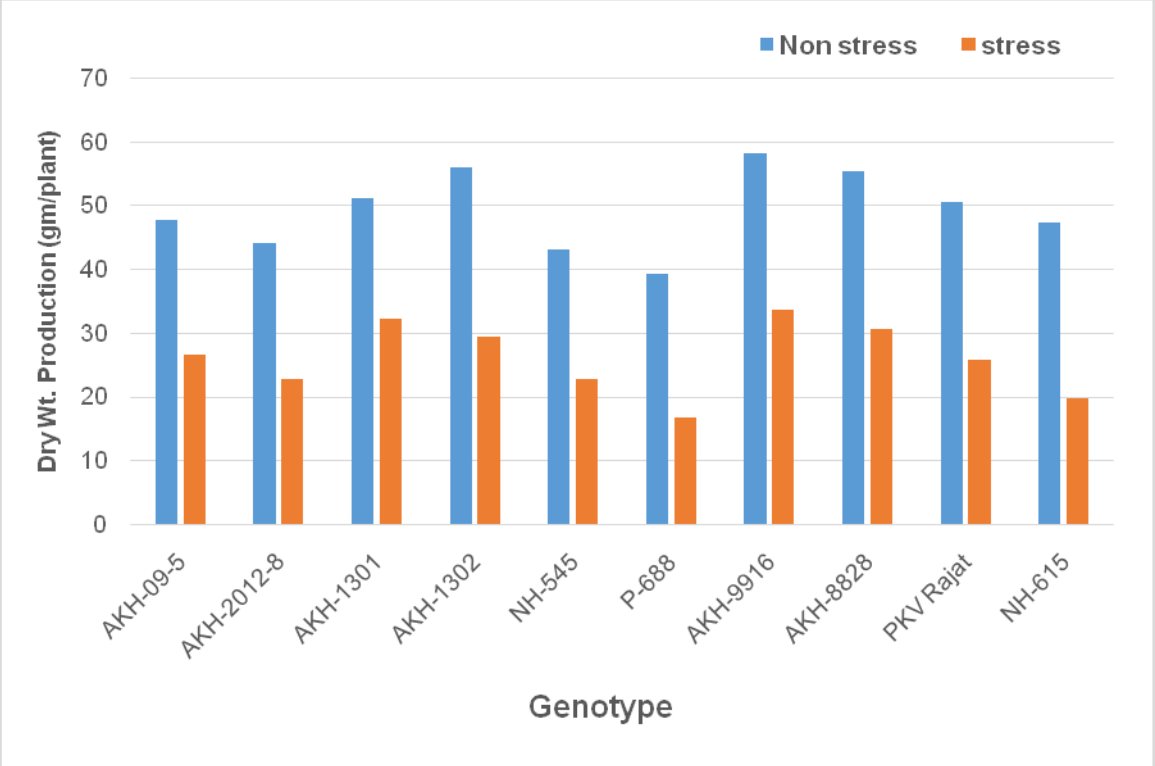

Fig. 4.4. Effect of water stress and non stress condition on total dry matter production (gm/ plant) in different cotton genotypes at harvest

At 120 DAS genotype AKH-9916 (1965.44 cm^2 /plant) was remained significantly higher followed by AKH-1301 (1930.5 cm^2 /plant), AKH-8828 (1917.19 cm^2 /plant) and AKH-1302 (1892.41 cm^2 /plant) under non stress. Under stress condition AKH-9916 (1030.04 cm^2/plant) was observed significantly highest followed by AKH-1301 (980.60 cm^2 /plant) and AKH-09-5 (952.02 cm^2 /plant) over mean value (818.36 cm^2 /plant). P-688 was observed lowest under both non stress and stress condition among all the genotypes studied.

Under non stress condition, genotype AKH-1301 (1930.5 cm^2 /plant) was recorded superior in respect of leaf area and remained at par with AKH-1302 (1892.41 cm^2 /plant) and AKH-2012-8 (1798.69 cm^2 /plant) over released genotype NH-615 (1656.03 cm^2 /plant). AKH-1301 (980.60 cm^2 /plant) was found superior over AKH-8828 (864.91 cm^2 /plant) and remained at par with AKH-09-5 (952.02 cm^2 /plant) under water stress condition at 120 DAS.

The reduced leaf area, leaf growth and response to water stress may conserve water. These findings are in accordance with the findings of Patil (2011). The effect of water stress on performance of the cotton genotypes, revealed that, water stress reduced plant height, number of leaves, leaf area, total dry matter, stomatal conductance, transpiration, NAR and leaf area duration in all the genotypes under water stressed condition compared with well watered control. He also reported significant decrease in total dry matter content in genotypes grown under well watered condition both in field as well as in rain out shelter.

4.1.4 Total dry matter production (TDM, g/plant)

Total dry matter production (g/plant) as influence due to water stress and non stress condition of different genotypes of cotton are presented in Table 4.4 and depicted in Figure 4.4. Data on total dry matter/plant was significantly influenced at all growth stages under both water stress and non stress condition.

At 60 DAS under non stress condition, genotype AKH-1301 (15.9 gm/ plant) synthesized significantly highest dry matter production and followed by AKH-9916 (14.5 gm/ plant). Genotype P-688 (8.83 gm/ plant) was observed lowest total dry matter production. Under water stress condition only single genotype AKH-1301 (13.7 gm/ plant) produced significantly higher over mean value (10.68 gm/ plant) of all genotype. Genotype NH-615 (6.73 gm/ plant) was observed lowest for total dry matter production.

At 90 DAS, range of dry matter production was observed between 40.05 to 29.66 gm/plant under non stress condition. Genotype AKH-9916 (40.05 gm/ plant) was found significantly higher in total dry matter production followed by AKH-8828 (39.89 gm/ plant) and AKH-1301(37.83 gm/ plant) under non stress condition. Under stress condition AKH-9916 (24.10 gm/ plant) was recorded significantly higher total dry matter production followed by AKH-1301 (24.03 gm/ plant).

At 120 DAS under non stress condition AKH-8828 (67.66 gm/ plant) was recorded significantly higher over mean value of all genotypes (58.59 gm/ plant) followed by AKH-1302 (65.3 gm/ plant), AKH-9916 (64.20 gm/ plant) and AKH-1301(60.73 gm/plant). Under stress condition genotype AKH-1301 (45.9 gm/ plant) was significantly higher over mean value (38.83 gm/ plant) of all genotypes followed by AKH-9916 (44.86 gm/ plant) and AKH-8828 (43.3 gm/ plant). However, genotype P-688 (30.30 gm/ plant) and NH-615 (34.33 gm/ plant) was recorded lowest dry matter production among all genotypes under stress condition at this stage.

At harvest genotype AKH-9916 (58.20 gm/ plant) was significantly produce highest total dry matter production over mean value (49.22 gm/ plant) of all genotypes under non stress condition followed by AKH-1302 (55.96 gm/ plant) and AKH-8828 (55.33 gm/ plant). Lowest dry matter production was recorded in P-688 (39.2 gm/ plant), NH-545 (43 gm/ plant) and AKH-2012-8 (44.03 gm/ plant). Under stress condition AKH-9916 (33.53 gm/ plant) was recorded significantly highest total dry matter production over mean value (25.99 gm/ plant) of all genotypes followed by AKH-1301 (32.23 gm/ plant), AKH-8828 (30.63 gm/ plant) and AKH-1302

Table 4.4. Effect of water stress and non stress condition on total dry matter production (gm/ plant) in different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	60 DAS		90 DAS		120 DAS		At harvest	
		Non Stress	Stress	Non stress	stress	Non stress	Stress	Non stress	stress
1	AKH-09-5	12.46	11.46	32.19	20.76	58.00	40.16	47.66	26.50
2	AKH-2012-8	12.95	10.03	34.30	18.63	54.03	34.40	44.03	22.73
3	AKH-1301	15.90	13.70	37.83	24.03	60.73	45.90	51.06	32.23
4	AKH-1302	13.76	12.33	36.10	22.36	65.30	41.23	55.96	29.30
5	NH-545	10.90	11.53	31.76	19.26	52.33	35.13	43.00	22.80
6	P-688	8.83	6.76	29.66	13.23	50.86	30.30	39.20	16.76
7	AKH-9916	14.50	12.23	40.05	24.10	64.20	44.86	58.20	33.53
8	AKH-8828	13.93	12.96	39.89	22.60	67.66	43.30	55.33	30.63
9	PKV Rajat	10.16	9.10	30.82	17.96	57.16	38.66	50.50	25.73
10	NH-615	9.06	6.73	31.36	14.73	55.63	34.33	47.30	19.66
	GM	12.24	10.68	34.39	19.77	58.59	38.83	49.22	25.99
	SE(m±)	0.72	0.79	0.66	1.07	0.71	0.93	1.51	0.51
	CD@5%	2.16	2.35	1.97	3.20	2.12	2.78	4.49	1.54

(29.3 gm/ plant). P-688 (16.76 gm/ plant) and PKV Rajat (19.66 gm/ plant) was recorded lowest total dry matter production.

Genotype AKH-1302 (55.96 gm/ plant) noted superior over the released genotype PKV Rajat (50.5 gm/ plant) under non stress condition and under water stress condition genotype AKH-1301 (32.23 gm/ plant) was recorded superior over released genotype AKH-8828 (30.63 gm/ plant) at the time of harvest.

Moisture deficit reduced the morphological growth of crop results in decreased dry matter production of investigated genotypes. The present findings were in association with Krieg (1997) noted that the crop growth rate was reduced by water stress through reduction in size and number of leaves produced and in reduction of photosynthesis. Reduced photosynthetic C assimilation (and therefore reduced crop dry matter accumulation) is a principal effect of soil water deficit in cotton and other crops (Said and Hugh, 2005).

4.1.5 Relative water content (RWC %)

The relative leaf water content (RLWC) was recorded at 60, 90 and 120 DAS and presented in Table 4.5. The data regarding leaf RWC showed significant differences among different genotype at 60, 90 and 120 under non stress and water stress condition.

At 60 DAS, range of relative water content was recorded between 83.46-68.06 % under non stress condition. Genotype AKH-09-5 (83.46 %) showed significantly higher RWC percentage among all genotypes followed by AKH-9916 (82.50 %) and AKH-8828 (81.94 %). Under water stress condition AKH-9916 (82.06%) was recorded significantly highest RWC over mean value of all genotypes (76.88 %) followed by AKH-09-5 (80.85 %).

At 90 DAS genotype AKH-1301 (81.66%) was significantly higher over mean value (75.53 %) of all genotype and followed by AKH-9916 (80.44 %) and AKH-09-5 (80.8 %) under non stress condition. Under stress condition significantly highest RWC% was recorded in AKH-9916

(76.13 %) over mean value of all genotypes followed by AKH-8828 (74.76 %). Lowest relative content was recorded in P-688 among all genotypes under both stress and non stress condition.

At 120 DAS range of RWC percentage was observed between 79.36-59.96 % and genotype AKH-1301 (79.36 %) was recorded significantly highest RWC % followed by AKH-9916 (78.5 %) and AKH-1302 (76.76 %) under non stress condition. P-688 (59.96 %) was found lowest among all genotypes. Under stress condition range of RWC % was 70.86 to 53 % and significantly higher genotype was AKH-9916 (70.86 %) followed by AKH-1302 (68.96%) and AKH-8828 (68.56%). It was recorded that at 120 DAS under non stress condition genotype AKH-1301(79.36 %) was recorded superior over released genotype PKV Rajat (72.53%) followed by AKH-1302 (76.76%) with respect to RWC %. Where in stress condition, genotype AKH-1302 (68.96%) recorded superior over the released genotype PKV Rajat (60.4%) and found at par with AKH-09-5 (67.2%), AKH-1301 (66.16%) and AKH-2012-8 (65.13%) respectively.

Table 4.5. Effect of water stress and non stress condition on relative leaf water content (%) in different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	60 DAS		90 DAS		120 DAS	
		Non Stress	Stress	Non stress	stress	Non stress	Stress
1	AKH-09-5	83.46	80.85	80.80	73.23	76.13	67.20
2	AKH-2012-8	76.53	78.38	72.53	69.86	70.80	65.13
3	AKH-1301	79.33	78.94	81.66	70.80	79.36	66.16
4	AKH-1302	80.33	77.49	78.66	71.76	76.76	68.96
5	NH-545	78.00	75.66	74.40	68.83	70.86	63.03
6	P-688	68.06	66.17	63.00	60.86	59.96	53.00
7	AKH-9916	82.50	82.06	80.84	76.13	78.50	70.86
8	AKH-8828	81.94	79.02	78.93	74.76	75.83	68.56
9	PKV Rajat	80.53	78.72	75.53	67.23	72.53	60.40
10	NH-615	73.96	71.52	68.96	62.06	65.26	56.93
	GM	78.46	76.88	75.53	69.55	72.60	64.02
	SE(m±)	0.84	1.21	1.37	1.36	1.29	1.48
	CD@5%	2.49	3.60	4.09	4.06	3.84	4.41

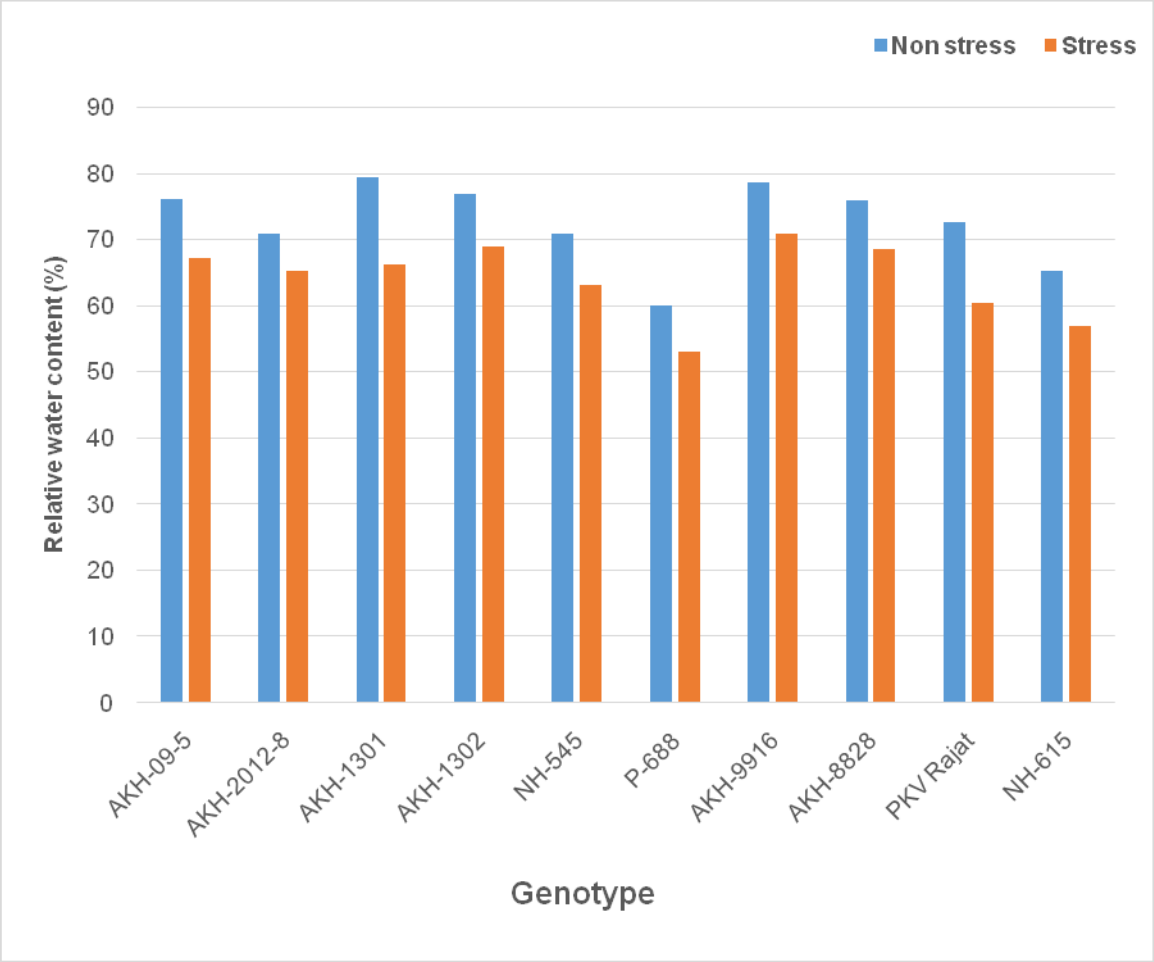

Fig. 4.5. Effect of water stress and non stress condition on relative leaf water content (%) in different cotton genotypes at 120 DAS

Exposure of these plants under drought stress decreased leaf water potential, RWC and transpiration rate, with a rise in leaf temperature. Hussain (2009) reported additive type of gene action for leaf temperature and relative water content. Under water stress, change in leaf temperature may be an important factor in controlling leaf water status. Drought tolerant species maintain water use efficiency by reducing the water loss. The present study is in agreement with the findings of Egilla *et al*. (2005). Significant decrease in RLWC under moisture stressed condition is due to reduced absorption of water from the soil and inability to control water loss through the stomata as noted by Ananthi *et al.* (2013).

4.1.6 Number of Monopodia per plant

Number of monopodia per plant as influenced due to water stress and non stress condition of different genotypes presented in Table 4.6.

Data on number of monopodial branches per plant at harvest under both water stress and non stress condition showed significant differences among all genotypes. Under non stress condition, at harvest data depicted that among 10 genotypes AKH-09-5 (1.81) recorded more number of monopodia followed by AKH-1301 (1.79), AKH-9916 (1.72) and NH-615 (1.71). Under stress condition, among ten genotypes, PKV Rajat (1.79) recorded significantly more number of monopodial branches per plant followed by AKH-8828 (1.72) and AKH-1302 (1.67). Genotype NH-545 (1.21) was recorded for lowest number of monopodial branches.

Under non stress condition at harvest genotype AKH-09-5 (1.81) was significanty superior over released variety AKH-8828 (1.65) and found at par with AKH-1301 (1.79). AKH-1302 was recorded superior for number of monopodia (1.67) over the released genotype NH-615 (1.55) under water stress condition.

4.1.7 Number of sympodial branches per plant

Number of sympodial branches per plant as influenced due to water stress and non stress condition is presented in table 4.6. Data at

harvest on number of sympodial branches per plant showed significant differences under both water stress and non stress condition in all genotypes.

Under non stress condition, sympodial branches were ranged between 10.23 to 7.06. Among all 10 genotypes, AKH-8828 (10.23) recorded significantly more number of sympodial branches followed by AKH-9916 (10.13), AKH-1301 (9.9) and AKH-615 (9.4). Under water stress condition, range of sympodia found between 10.46 to 7.3. Genotype AKH-9916 (10.46) recorded significantly more sympodial branches per plant over mean value (8.92) followed by AKH-1301 (9.96), AKH-8828 (9.83) and AKH-09-5 (9.73).

Genotype AKH-1301 (stress: 9.96 and non stress: 9.9) found superior over released genotype NH-615 under both stress (9.13) and non stress (9.4) condtions with respect to number of sympodia.

Table 4.6. Effect of water stress and non stress condition on number of monopodia and sympodia of different cotton genotypes at harvest

Sr. No.	Cotton Genotypes	Number of monopodia		Number of sympodia	
		Non Stress	Stress	Non stress	Stress
1	**AKH-09-5**	1.81	1.46	8.53	9.73
2	**AKH-2012-8**	1.30	1.53	8.50	8.10
3	**AKH-1301**	1.79	1.45	9.90	9.96
4	**AKH-1302**	1.15	1.67	9.00	9.03
5	**NH-545**	1.68	1.21	8.13	8.33
6	**P-688**	1.59	1.53	7.06	7.30
7	**AKH-9916**	1.72	1.62	10.13	10.46
8	**AKH-8828**	1.65	1.72	10.23	9.83
9	**PKV Rajat**	1.20	1.79	8.56	7.36
10	**NH-615**	1.71	1.55	9.40	9.13
	GM	1.56	1.55	8.94	8.92
	SE(m±)	0.04	0.04	0.07	0.14
	CD@5%	0.12	0.12	0.21	0.42

4.1.8. Root Parameters Study

4.1.8.1 Root length (cm) per plant

Root length (cm) per plant as influenced due to water stress and non stress condition on different cotton genotypes presented in Table 4.7. Data under water stress and non stress condition was found to be significantly differed in root length at both stages (60 DAS and at harvest).

At 60 DAS, under non stress condition AKH-9916 (42.1 cm) was noted significantly higher root length followed by AKH-1302 (40.34 cm) over mean value (34.46cm). Under water stress condition only genotype AKH-9916 was recorded significantly highest root length of 37.56 cm over mean value of all genotypes (30.42 cm).

Table 4.7. Effect of water stress and non stress condition on root length (cm) of different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	60 DAS		At harvest	
		Non Stress	Stress	Non stress	stress
1	AKH-09-5	36.46	29.40	53.13	40.73
2	AKH-2012-8	38.36	30.53	55.03	43.86
3	AKH-1301	35.43	33.86	56.43	49.53
4	AKH-1302	40.34	29.13	57.66	42.46
5	NH-545	34.63	31.03	51.90	43.70
6	P-688	28.23	26.66	47.96	37.66
7	AKH-9916	42.1	37.56	55.43	47.56
8	AKH-8828	30.06	33.16	53.40	51.83
9	PKV Rajat	29.10	28.26	49.43	40.93
10	NH-615	29.90	24.56	48.23	38.56
	GM	34.46	30.42	52.86	43.68
	SE(m±)	1.37	1.36	1.44	1.66
	CD@5%	4.09	4.06	4.30	4.96

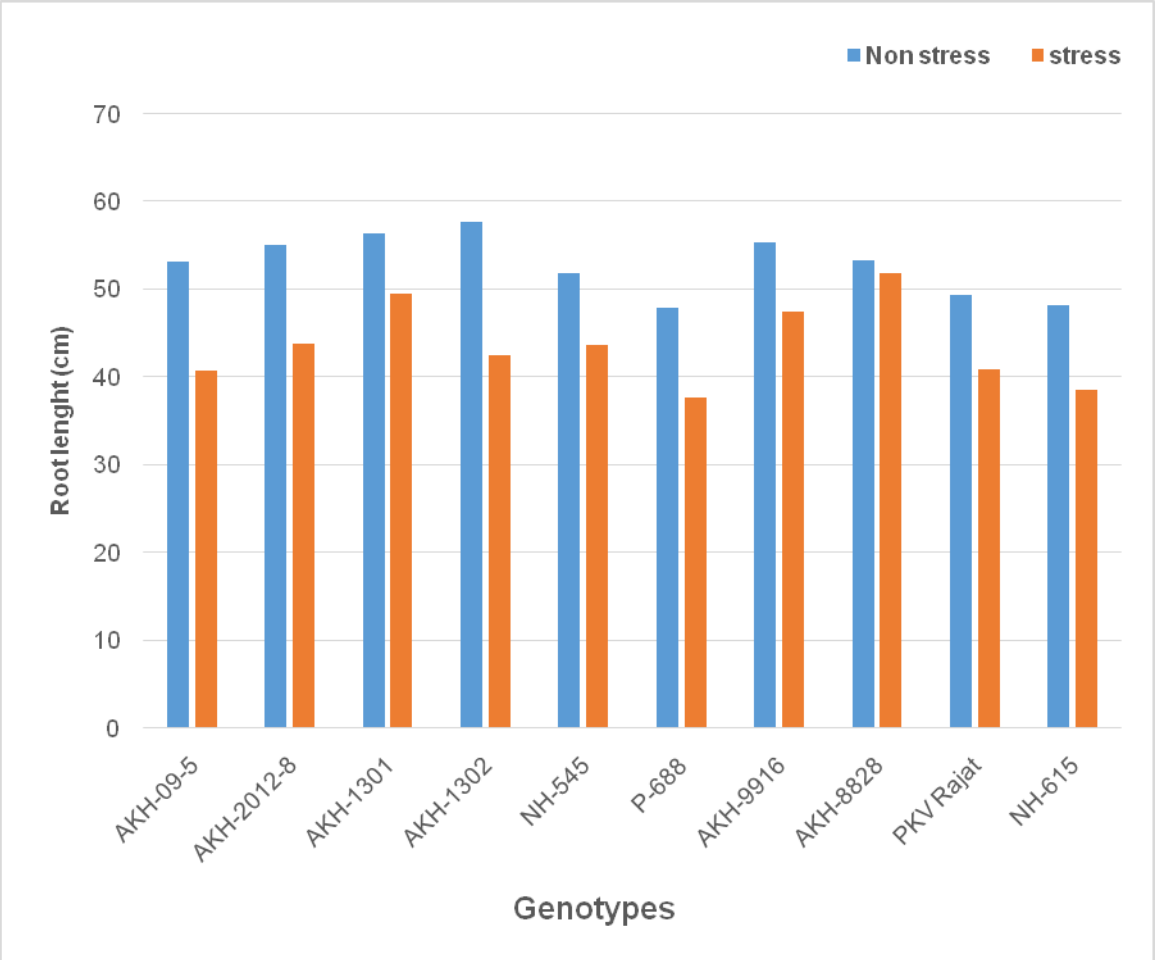

Fig. 4.6. Effect of water stress and non stress condition on root length (cm) of different cotton genotypes at harvest

At harvest, range of root length was obtained between 57.66-47.96 cm however, only single genotype AKH-1302 (57.66 cm) was found significantly higher under non water stress condition over mean value of all genotype (52.86 cm). Under stress condition range recorded for root length was between 51.83 to 37.66 cm. Genotype AKH-8828 (51.83 cm) was found significantly higher root length over mean value (43.68 cm) followed by AKH-1301 (49.53 cm) under water stress condition.

Genotype AKH-1302 (57.66 cm) noted superior when compared with released genotype PKV Rajat (49.43 cm) followed by AKH-1301 (56.43 cm) and AKH-2012-8 (55.03 cm) under non stress condition and under stress condition, AKH-1301 (49.53 cm) recorded superior over released variety PKV Rajat (40.93 cm) at harvest.

Under moisture stress root length of genotypes observed restricted than the genotypes of non stress condition. Root growth rates are commonly employed for estimating crop yield losses in cotton crop. Insufficient soil moisture restricts root growth and development and consequently impairs functioning of the aerial parts (Zhang *et al.* 2017).

4.1.8.2 Root : shoot dry weight ratio

Root: shoot dry weight ratio per plant as influenced by stress and non stress condition in different cotton genotype are presented in table 4.8. Data under water stress and non stress condition was significantly differed in root: shoot dry wt. ratio at both the stages (60 DAS and at harvest).

At 60 DAS, no one genotype was significantly higher over mean value (0.27) for root: shoot dry wt. ratio under non stress condition. Under water stress condition significantly higher ratio was observed in AKH-9916 (0.24) followed by NH-545 (0.23).

At harvest AKH-1302 (0.34) was significantly higher under non stress condition followed by AKH-9916 (0.33). PKV Rajat (0.22) was observed for lowest root: shoot ratio among all genotypes. Under water stress only AKH-1301 (0.25) was recorded significantly higher root:shoot

ratio over mean value of all genotype (0.19). Genotype AKH-1302 (0.34) was recorded significantly superior over released variety AKH-8828 (0.27) under non stress condition. However, under stress AKH-1301 (0.25) obtained superior over AKH-8828 (0.18) at harvest.

Table 4.8. Effect of water stress and non stress condition on root : shoot dry weight ratio of different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	60 DAS		At harvest	
		Non Stress	Stress	Non stress	stress
1	**AKH-09-5**	0.196	0.116	0.263	0.140
2	**AKH-2012-8**	0.253	0.203	0.273	0.196
3	**AKH-1301**	0.316	0.156	0.303	0.250
4	**AKH-1302**	0.323	0.126	0.343	0.233
5	**NH-545**	0.280	0.233	0.280	0.213
6	**P-688**	0.246	0.176	0.253	0.163
7	**AKH-9916**	0.323	0.240	0.330	0.230
8	**AKH-8828**	0.310	0.206	0.270	0.183
9	**PKV Rajat**	0.196	0.140	0.226	0.173
10	**NH-615**	0.286	0.113	0.240	0.143
	GM	0.273	0.171	0.278	0.193
	SE(m±)	0.022	0.015	0.021	0.017
	CD@5%	0.068	0.046	0.065	0.052

Moisture stress reduced the both root and shoot dry weight. The findings of present observation were in association with Luo H. *et al* (2015). Drought reduces aboveground biomass accumulation by decreasing root volume density, root mass density and root length density.

4.2 Biochemical Characters

4.2.1 Leaf Proline Content (µg/g fresh weight)

Leaf proline content as influenced due to water stress condition in different genotypes of cotton species are presented in table

4.9. Data on leaf proline content as influenced due to water stress and non stress condition at 90 and 120 DAS revealed significant differences.

At 90 DAS under non stress condition, the genotype PKV Rajat (58.8 µg/g fresh weight) was recorded significantly higher proline content followed by AKH-1302 (56.33 µg/g fresh weight), AKH-1301 (54.1 µg/g fresh weight), AKH-2012-8 (52.16 µg/g fresh weight) over mean value. Under water stress condition genotype AKH-9916 (72.7 µg/g fresh weight) was significantly higher among all genotypes over mean value and found at par with AKH-1302 (72 µg/g fresh weight). Lowest proline content was recorded in the genotype P-688 (57.13 µg/g fresh weight) and AKH-1301 (62.9 µg/g fresh weight).

Table 4.9 Effect of water stress and non stress condition on proline content (µg/g fresh weight) of different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	90 DAS		120 DAS	
		Non Stress	Stress	Non stress	stress
1	**AKH-09-5**	42.56	69.56	65.03	71.16
2	**AKH-2012-8**	52.16	63.50	62.56	74.13
3	**AKH-1301**	54.10	62.90	50.43	81.80
4	**AKH-1302**	56.33	72.00	58.26	79.33
5	**NH-545**	35.63	69.33	59.63	75.76
6	**P-688**	48.66	57.13	42.90	69.16
7	**AKH-9916**	50.86	72.70	63.83	81.46
8	**AKH-8828**	46.60	64.13	60.60	77.26
9	**PKV Rajat**	58.80	66.60	51.63	70.50
10	**NH-615**	41.33	68.4	52.20	68.93
	GM	48.71	66.62	56.71	74.95
	SE(m±)	0.97	1.40	1.09	1.22
	CD@5%	2.89	4.16	3.26	3.64

At 120 DAS under non stress condition, AKH-09-5 (65.03 µg/g fresh weight) was significantly higher over mean value followed by AKH-9916 (63.83 µg/g fresh weight), AKH-2012-8 (62.56 µg/g fresh weight)

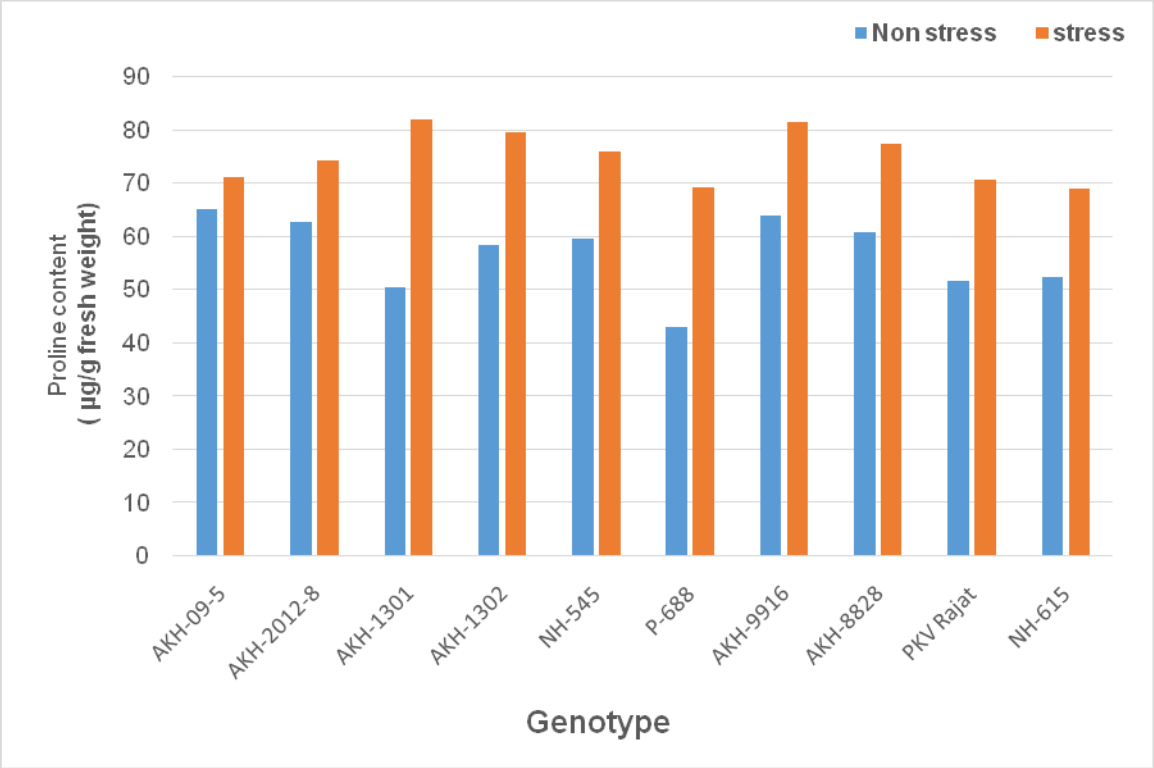

Fig. 4.7 Effect of water stress and non stress condition on proline content (µg/g fresh weight)of different cotton genotypes at 120 DAS

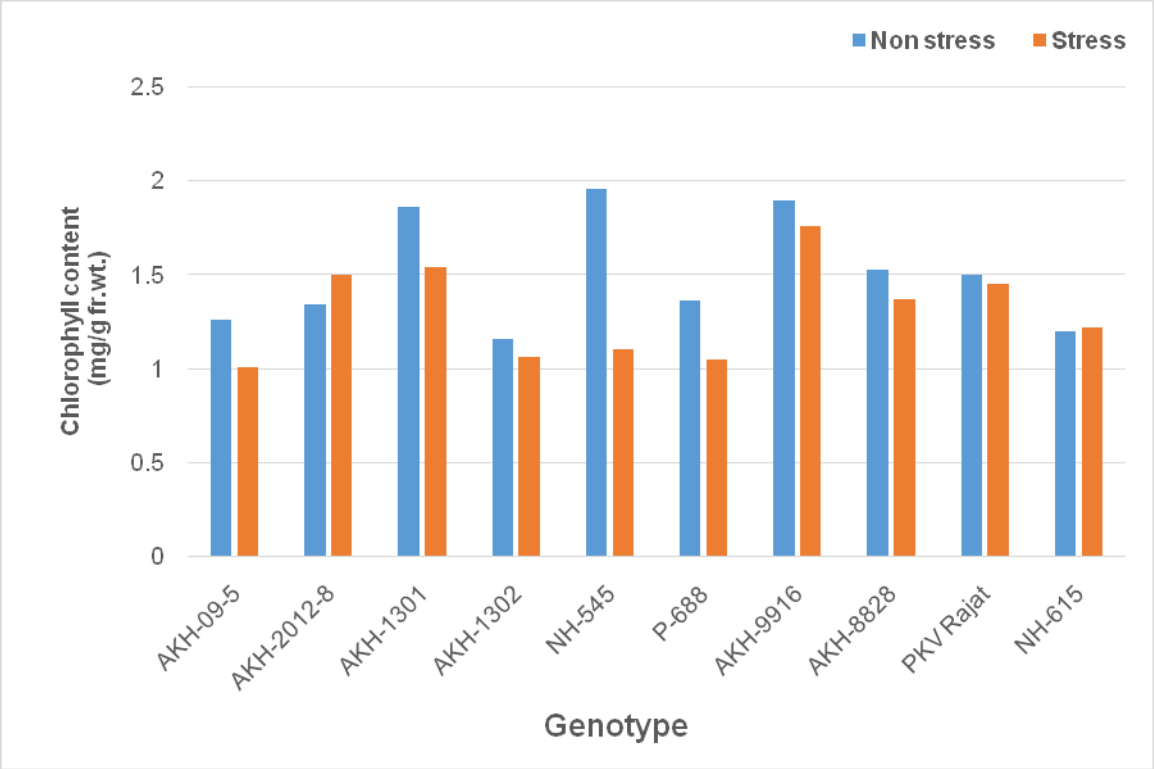

Fig. 4.8. Effect of water stress and non stress condition on total chlorophyll content (mg/g fr.wt.)of different cotton genotypes at 120 DAS

and AKH-8828 (60.6 µg/g fresh weight). Under stress condition genotype AKH-1301 (81.8 µg/g fresh weight) was significantly higher and found at par with AKH-9916 (81.46 µg/g fresh weight) and AKH-1302 (79.33 µg/g fresh weight). In both stress (69.16 µg/g fresh weight) and non stress condition (42.9 µg/g fresh weight) genotype P-688 was recorded lowest proline content.

Under non stress condition genotype AKH-09-5 (65.03 µg/g fresh weight) was recorded significantly superior over released genotype AKH-8828 (60.6 µg/g fresh weight) whereas, under water stress condition the genotype AKH-1301(81.8 µg/g fresh weight) was superior over AKH-8828 (77.26 µg/g fresh weight).

Proline is a compatible solute and its accumulation is associated with abiotic stresses. It is accumulated to higher concentration during water stress condition and declines upon rehydration. It serves as a cytoplasmic osmotic balance for potassium accumulation as the main osmoticum in the vacuole. Proline serves as a protectant of various enzymes and biological membranes subjected to desiccation and heat stress. The present findings are in accordance with the findings Iqbal *et al*. (2016), who reported that, the accumulation of proline in drought-tolerant and drought-sensitive cultivars has revealed the significance of this osmolyte.

4.2.2 Total Chlorophyll content (mg/g fr.wt.)

Total leaf chlorophyll content as influenced due to water stress and non water stress condition showed statistically significant differences among different cotton genotypes (Table 4.10).

At 60 DAS genotype AKH-2012-8 (2.14 mg/g fr.wt.) was significantly noted higher for total chlorophyll content among all genotypes followed by AKH-9916 (2.1 mg/g fr.wt.) and AKH-1301 (1.93 mg/g fr.wt.) under non stress condition. Under stress AKH-8828 (2.4 mg/g fr.wt.) was significantly highest followed by AKH-9916 and PKV Rajat (2.16 mg/g fr.wt.) over mean value of all genotypes (1.82 mg/g fr.wt.).

At 90 DAS, NH-545 and AKH-9916 (2.26 mg/g fr.wt.) were noted significantly higher total chlorophyll content over mean value

followed by AKH-2012-8 (2.23 mg/g fr.wt.) under non stress condition. Under stress condition, AKH-9916 (2 mg/g fr.wt.) recorded significantly higher and remained at par with AKH-8828 (1.86 mg/g fr.wt.) and PKV Rajat (1.73 mg/g fr.wt.).

At 120 DAS under non stress condition, NH-545 was significantly (1.96 mg/g fr.wt.) highest among all genotypes followed by AKH-9916 (1.9 mg/g fr.wt.). Under water stress, genotype AKH-9916 (1.76 mg/g fr.wt.) was significantly higher and at par with AKH-1301 (1.54 mg/g fr.wt.). Among all 10 genotypes lowest chlorophyll content was found in AKH-09-5 (1.01 mg/g fr.wt.) under water stress at this stage.

Total chlorophyll content was recorded significantly superior in NH-545 (1.96 mg/g fr.wt.) over released genotype AKH-8828 (1.53 mg/g fr.wt.) under non stress condition. AKH-1301 (1.54 mg/g fr.wt.) was superior over released genotype NH-615 (1.22 mg/g fr.wt.) followed by AKH-2012-8 (1.5 mg/g fr.wt.) under water stress condition.

Table 4.10. Effect of water stress and non stress condition on total chlorophyll content (mg/g fr.wt.) of different cotton genotypes at different growth stages

Sr. No.	Cotton Genotype	60 DAS		90 DAS		120 DAS	
		Non Stress	Stress	Non stress	Stress	Non stress	Stress
1	AKH-09-5	1.33	1.96	1.36	1.66	1.26	1.01
2	AKH-2012-8	2.14	1.40	2.23	1.27	1.34	1.50
3	AKH-1301	1.93	2.00	2.03	1.44	1.86	1.54
4	AKH-1302	1.23	1.66	1.43	1.20	1.16	1.06
5	NH-545	1.70	1.50	2.26	1.48	1.96	1.10
6	P-688	1.23	1.60	2.00	1.04	1.36	1.05
7	AKH-9916	2.10	2.16	2.26	2.00	1.90	1.76
8	AKH-8828	1.83	2.40	2.13	1.86	1.53	1.37
9	PKV Rajat	1.80	2.16	1.96	1.73	1.50	1.45
10	NH-615	1.73	1.36	1.86	1.20	1.20	1.22
	GM	1.70	1.82	1.95	1.49	1.51	1.30
	SE(m±)	0.05	0.08	0.07	0.07	0.12	0.07
	CD@5%	0.15	0.26	0.21	0.21	0.36	0.23

Total chlorophyll content determines the photosynthetic capacity of the cotton genotypes and influences the rate of photosynthesis, dry matter production and the yield. The variation in the chlorophyll content may be due to availability of water whether due to stress or non stress condition and partly due to varietal performance. Under drought conditions, a decline in chlorophyll pigments have been reported, making plant vulnerable to die (Astorga and Melendez, 2010).

4.2.3 Chlorophyll stability index (CSI %)

Chlorophyll stability index (%) as influenced due to non stress and stress condition in different genotypes of cotton are presented in table 4.11. CSI under water stress and non stress condition at 60,90 and 120 DAS showed significant differences.

Table 4.11. Effect of water stress and non stress condition on chlorophyll stability index (%) of different cotton genotypes at different growth stages

Sr. No.	Cotton Genotypes	60 DAS		90 DAS		120 DAS	
		Non Stress	Stress	Non stress	stress	Non stress	Stress
1	AKH-09-5	20.73	17.84	30.02	23.99	29.82	20.41
2	AKH-2012-8	17.44	15.34	31.13	22.19	29.07	18.89
3	AKH-1301	19.76	18.18	33.31	29.25	32.65	24.89
4	AKH-1302	18.77	18.90	35.95	28.93	31.88	21.56
5	NH-545	19.54	17.74	29.27	23.10	26.25	19.32
6	P-688	17.70	15.06	26.07	23.34	23.51	18.72
7	AKH-9916	26.94	25.69	37.21	33.13	34.92	28.67
8	AKH-8828	24.15	24.41	34.14	29.77	32.96	22.48
9	PKV Rajat	20.70	19.02	28.10	23.18	24.24	16.42
10	NH-615	15.57	15.82	24.63	21.71	20.80	15.20
	GM	20.13	18.80	30.98	25.86	28.61	20.65
	SE(m±)	0.59	0.66	0.53	0.36	1.58	0.71
	CD@5%	1.78	1.96	1.57	1.08	4.71	2.12

At 60 DAS, under non stress condition AKH-9916 (26.94%) was remained significantly highest over mean value (20.13 %) followed by AKH-8828 (24.15%). Under stress condition, AKH-9916 (25.69 %) itself was noted for more CSI followed by AKH-8828 (24.41 %) over mean value of all genotypes (18.80 %).

At 90 DAS under non stress, genotype AKH-9916 (37.21 %) was significantly highest over mean value followed by AKH-1302 (35.95 %), AKH-8828 (34.14 %) and AKH-1301 (33.31 %). Under stress condition, AKH-9916 (33.13 %) was noted significantly highest over mean value of all genotypes (25.86%) and followed by AKH-8828 (29.77%), AKH-1301(29.25%) and AKH-1302 (28.93 %).

At 120 DAS, AKH-9916 was significantly higher in both non stress (34.92%) and stress (28.67%) condition over mean value. Under stress it was followed by AKH-1301 (24.89%). Under both stress and non stress condition genotype NH-615 was recorded lowest CSI.

AKH-1301 (32.65%) recorded superior CSI followed by AKH-1302 (31.88%), AKH-09-5 (29.82%) and AKH-2012-8 (29.07%) over released genotype PKV Rajat (24.24%) under non stress condition. Under water stress condition, genotype AKH-1301 (24.89%) was noted significantly superior over released variety AKH-8828 (22.48%).

It is seen from the recorded data for CSI that, higher chlorophyll stability index was found in genotypes of water stress condition. The above findings support that higher CSI helps the plants to withstand moisture stress through better availability of chlorophyll. The sufficient moisture level in the plant root zone might be the reason for higher CSI (Sampathkumar *et al.* 2014).

4.3 Yield and Yield Attributes

4.3.1 Number of bolls per plant

Data on number of bolls/plant as influenced due to water stress and non stress condition is presented are in table 4.12.

Under water non stress condition, significantly higher number of bolls was recorded in AKH-9916 (17.1) followed by AKH-8828 (16.4) over mean value of all 10 genotypes (14.16). Lowest number of bolls was recorded in P-688 (10.73) and NH-615 (12.83). Under stress condition AKH-9916 (10.46) was observed significantly higher number of bolls per plant over mean value of all genotypes.

Genotype AKH-1301 (15.26) was found superior over the released genotype NH-615 (12.83) under non stress condition whereas under water stress also the genotype AKH-1301(10.4) was superior followed by AKH-1302 (10.16) over the released variety NH-615 (8.66).

The increase in boll number was due to reduction in the abscission of intact buds and bolls per plant under non stress. However, reduced in number of bolls may be due to abscission of floral buds/ squares due to hormonal and C:N ratio imbalance, formation of more abscissic acid under water stress in susceptible genotypes. Wen (2013), affirmed that, water deficit in cotton causes boll shedding and thus lower productivity.

4.3.2 Seed cotton yield (SCYg/plant)

Data on seed cotton yield plant^{-1} (g) showed significant differences under both stress and non water stress condition in different cotton genotypes. Under non stress condition genotype AKH-9916 (50.53 gm/plant)) was recorded significantly higher seed cotton yield followed by NH-615 (49.8 gm/plant), AKH-1302 (49.23 gm/plant), AKH-8828 (48.66 gm/plant) and AKH-1301 (47.13 gm/plant). Under stress condition similarly, AKH-9916 (36.36 gm/plant) was significantly higher followed by AKH-8828 (34.86 gm/plant) and AKH-1301 (31.63 gm/plant). P-688 was found lowest in both stress (19.43 gm/plant) and non stress condition (32.03 gm/ plant).

Genotype AKH-1302 (49.23 gm/plant) was significantly superior over released variety PKV Rajat (40.84 gm/plant) followed by AKH-1301 (47.13 gm/ plant) and NH-545 (43.4 gm/plant) under non stress condition. Under stress condition, not a single genotype was recorded for

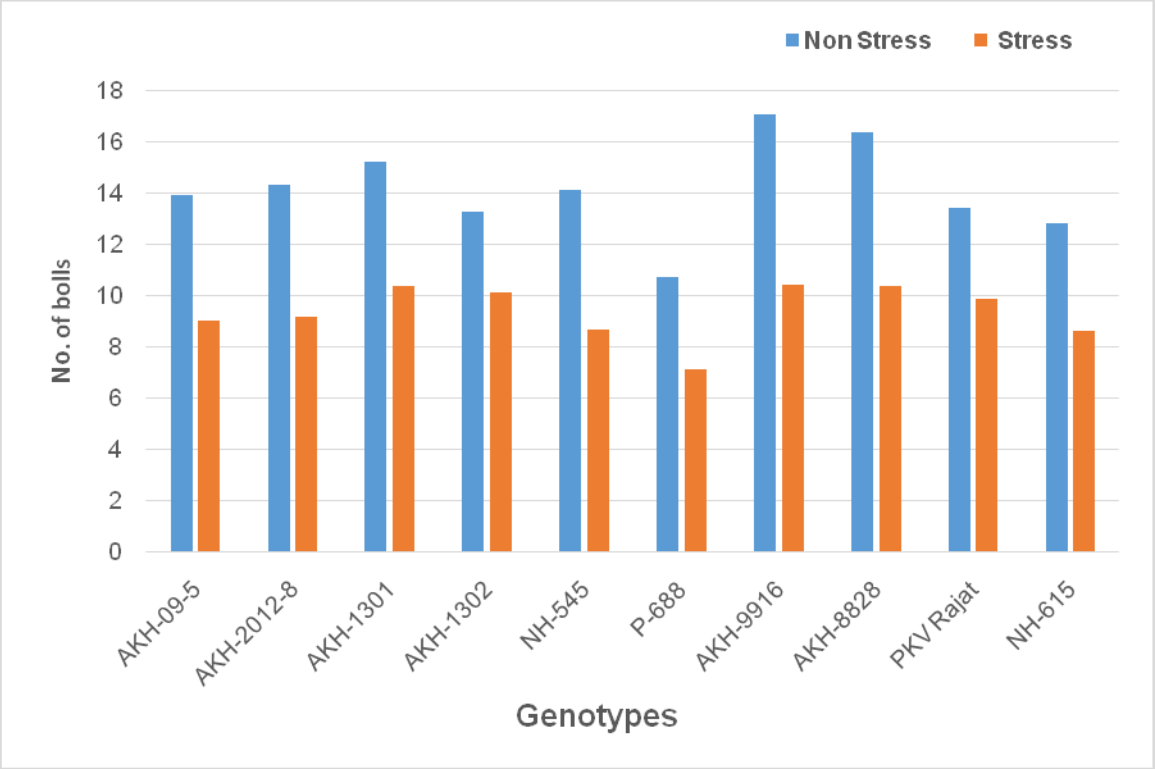

Fig. 4.9. Effect of water stress and non stress condition on number of bolls of different cotton genotypes at harvest

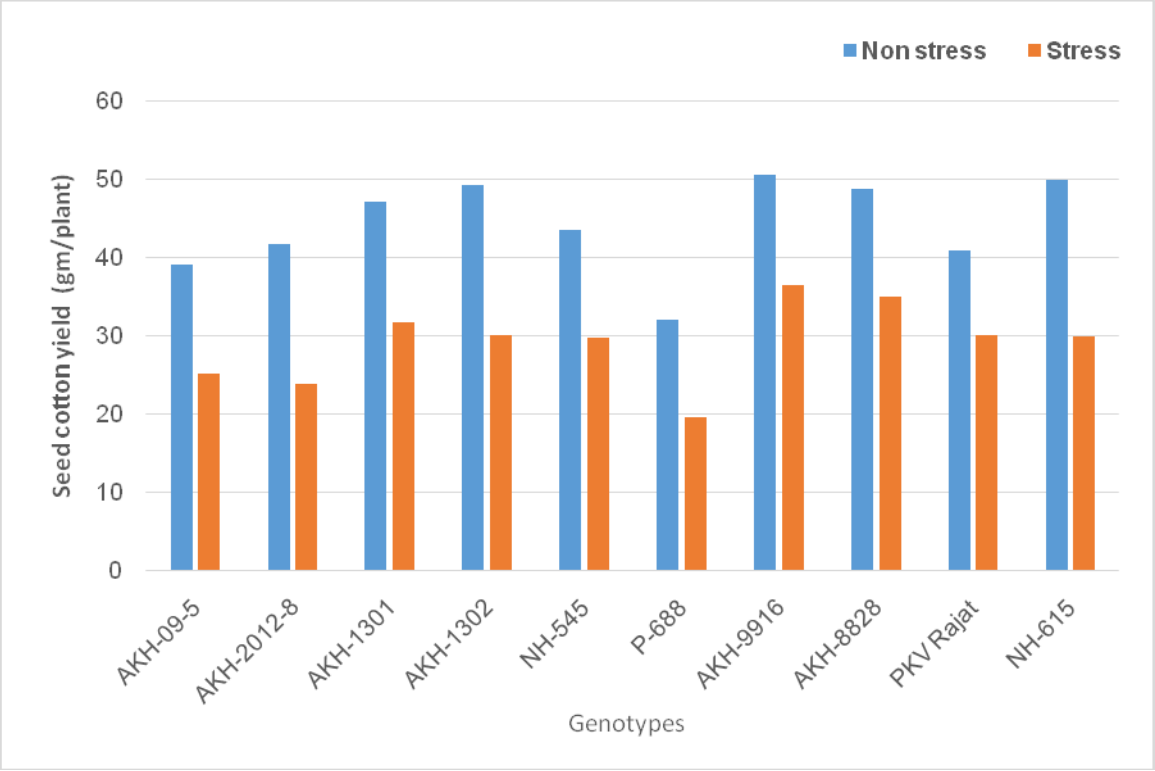

Fig. 4.10. Effect of water stress and non stress condition on Seed cotton yield (gm/plant) of different cotton genotypes at harvest

better performance over released varieties (genotype) in respect to seed cotton yield.

Karademir *et al*. (2011) evaluated the effect of water stress and non-stress conditions on cotton yield and fiber quality properties. By evaluating twelve cotton genotypes for yield and fiber quality properties they found significant differences among genotypes and water treatments for seed cotton yield.

4.3.3 Test weight (g)

Data on test weight (g) as influenced due to water stress and non stress condition in different genotypes are presented in table. 4.12.

Table 4.12. Effect of water stress and non stress condition on seed cotton yield and yield contributing traits of different cotton genotypes at harvest

Sr. No.	Cotton Genotypes	No. of bolls / plant		Seed cotton yield (gm / plant)		Test weight (gm / plant)	
		Non Stress	Stress	Non stress	Stress	Non Stress	Stress
1	**AKH-09-5**	13.96	9.03	38.96	25.03	96.88	74.54
2	**AKH-2012-8**	14.36	9.20	41.70	23.80	84.69	65.79
3	**AKH-1301**	15.26	10.4	47.13	31.63	92.20	69.91
4	**AKH-1302**	13.30	10.16	49.23	30.06	86.36	70.98
5	**NH-545**	14.16	8.70	43.40	29.63	87.09	71.87
6	**P-688**	10.73	7.13	32.03	19.43	78.86	69.61
7	**AKH-9916**	17.10	10.46	50.53	36.36	98.12	73.63
8	**AKH-8828**	16.40	10.40	48.66	34.86	92.11	71.29
9	**PKV Rajat**	13.46	9.90	40.84	29.96	84.20	68.04
10	**NH-615**	12.83	8.66	49.80	29.83	86.67	65.44
	GM	14.16	9.40	44.23	29.06	88.72	70.11
	SE(m±)	0.66	0.35	0.82	0.82	1.24	0.44
	CD@5%	1.98	1.05	2.44	2.45	3.69	1.31

Data under water stress and non water stress condition showed significant differences among the genotypes. Under non stress

condition, all genotypes recorded higher test weight than water stress condition. Genotype under non stress condition AKH-9916 (98.12 gm) showed highest test wt. and remained at par with AKH-09-5 (96.88 gm). Under stress condition genotype AKH-09-5 (74.54 gm) was significantly higher over mean value and followed by AKH-9916 (73.63 gm) and NH-545 (71.87 gm). Genotype NH-615 (65.44 gm) was recorded lowest test wt. among all genotypes.

Under non-stress condition AKH-09-5 (96.88 gm/plant) was recorded superior test weight over released variety AKH-8828 (92.11 gm/ plant). Genotype AKH-09-5 (74.54 gm/ plant) was noted superior for test weight over released genotype AKH-8828 (71.29 gm/ plant) under water stress condition also.

4.4 Stress indices

4.4.1 Drought Intensity (DI)

Data on drought intensity showed significant differences among all genotypes. The lower value of drought intensity indicates the more tolerance towards drought. Lowest mean was observed in PKV Rajat (0.26), AKH-9916 and AKH-8828 (0.28). Highest mean value was observed in AKH-2012-8 (0.42), NH-615 (0.39), P-688 and AKH-1302 (0.38). Genotype NH-545 (0.30) recorded lowest drought intensity over released genotype NH-615 (0.39) which showed less drought tolerance.

4.4.2 Drought tolerance efficiency (DTE)

Data showed significant difference in drought tolerance efficiency in different cotton genotypes. Highest mean value for DTE was recorded in PKV Rajat (73.1 %) followed by AKH-8828 (71.53 %) and AKH-9916(70.88 %). No one genotype among all ten showed higher DTE over general mean. Genotype NH-545 (69.19%) was found more tolerant when compared with released variety NH-615 (59.83%).

4.4.3 Yield Stability Index (YSI)

Data on yield stability index as influenced due to water stress and non stress condition presented in table 4.13. It showed significant

differences among different genotypes. Highest mean value of YSI was recorded by PKV Rajat (0.72), AKH-8828 (0.71) and AKH-9916 (0.70). None of the genotype among all ten showed high YSI over general mean. Higher yield stability index was recorded in NH-545 (0.68) over released genotype NH-615 (0.59).

Table 4.13. Effect of water stress and non stress condition on stress indices of different cotton genotypes

Sr. No.	Cotton Genotype	DI	DTE	YSI	PHSI
1	**AKH-09-5**	0.34	64.83	0.64	84.84
2	**AKH-2012-8**	0.42	57.26	0.57	81.05
3	**AKH-1301**	0.32	67.41	0.67	83.03
4	**AKH-1302**	0.38	61.09	0.60	83.34
5	**NH-545**	0.30	69.19	0.68	84.13
6	**P-688**	0.38	60.92	0.60	81.31
7	**AKH-9916**	0.28	70.88	0.70	88.90
8	**AKH-8828**	0.28	71.53	0.71	87.21
9	**PKV Rajat**	0.26	73.10	0.72	88.99
10	**NH-615**	0.39	59.83	0.59	81.77
	GM	0.33	65.60	0.65	84.46
	SE(m±)	0.03	3.13	0.03	1.22
	CD@5%	0.09	9.32	0.09	3.63

DI – Drought Intensity, DTE – Drought Tolerance Efficiency, YSI – Yield Stability Index and PHSI – Plant Height Stress Index.

4.4.4 Plant height stress index (PHSI)

Plant height stress index showed significant differences among different genotypes. Among all ten genotypes significantly highest plant height stress index was found in PKV Rajat (88.99) followed by AKH-9916 (88.90) over general mean (84.46).

CHAPTER V

SUMMARY AND CONCLUSIONS

An experiment was conducted on “Physiological evaluation of cotton genotypes for moisture stress.” during *kharif* season of 2018-19 in randomized block design with three replications at experimental field of Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (M.S.) under non stress and water stress condition. The seeds of ten cotton genotypes were sown in field and in earthen pots. One set of experiment was sown under non stress condition (open field). Another set of experiment was kept (earthen pots) under rainout shelter (controlled condition) with desired quantity of irrigation up to the initiation of bolls (75 DAS). First water stress was imposed at 75 DAS for 12 days (initial stage of boll development). After imposition of first water stress life saving irrigation was applied (only one time) and again, second water stress was imposed for 12 days. These pots were treated as water stress condition

The various morpho-physiological observations were recorded from 30 DAS onwords and biochemical parameters were at vegetative and boll development (90 and 120 DAS) stages. Seed cotton yield and its attributes along with stress indices were recorded at harvest. The important salient findings of present investigation are summarized as under.

1. Plant height was significantly higher in AKH-1302 (88.07 cm) at harvest under non stress condition and under stress conditions AKH-9916 (77.88 m) was recorded significantly highest. Statistically least plant height was observed in genotype P-688 at different growth stages under both conditions.
2. On the basis of data recorded at 120 DAS, genotype AKH-8828 (62.43) observed statistically more number of leaves followed by AKH-9916 (61.83) in non stress and genotype AKH-9916 (36.13) under water stress.

3. At 90 DAS, AKH-1301 (2451.97 cm^2/plant) was maintained significantly more leaf area in non stress and AKH-9916 (1690.55 cm^2/plant) in water stress condition.

4. The genotype AKH-1302 (55.96 g/plant) recorded superior total dry matter over the released genotype PKV Rajat (50.50 g/plant) under non stress and AKH-1301 (32.23 g/plant) over AKH-8828 (30.63 g/plant) recorded more in water stress condition at harvest.

5. It was observed that, at 120 DAS under non stresss condition AKH-1301 (79.36%) recorded statistically more RLWC over released genotype PKV Rajat (72.53%) where in water stress condition AKH-1302 (68.96%) recorded superior over PKV Rajat (60.40%) and found at par with AKH-09-5 (67.20%).

6. The genotype AKH-1302 (57.66 cm) was found statistically higher for root length in non stress over the mean value of all genotype (52.86 cm) at harvest. In water stress condition the released genotype AKH-8828 (51.83 cm) was found significantly higher for root length than the mean value (43.68 cm) followed by new genotype AKH-1301 (49.43 cm) at harvest.

7. In respect of root : shoot ratio at harvest, the new genotype AKH-1302 (0.34) was remained statistically higher under non stress condition and AKH-1301 (0.25) was recorded significantly highest root : shoot ratio over the mean value of all genotype (0.19) under water stress condition.

8. At 120 DAS, the new genotype AKH-1301 (81.8 µg/g fresh weight) recorded significantly more leaf proline content under stress condition and found at par with AKH-9916 (81.46 µg/g fresh weight). The genotype, P-688 recorded least proline content in both stress (69.16 µg/g fresh weight) and non stress (42.9 µg/g fresh weight) condition.

9. At 120 DAS, under water stress condition, AKH-9916 (1.76 mg/g) was remained significantly higher for total chlorophyll content and found at

par with AKH-1301 (1.54 mg/g) which was remained superior over the released variety NH-615 (1.22 mg/g).

10. In respect of CSI, at 120 DAS, the genotype AKH-9916 was remained significantly higher in both non stress (34.92%) and stress (28.67%) condition over the mean value of all genotype followed by AKH-1301 (24.89%). Under both condition NH-615 was recorded lowest CSI.
11. The stastisticaly low drought intensity was observed in PKV Rajat (0.26), AKH-9916 (0.28) and AKH-8828 (0.28).
12. The new genotype NH-545 (69.19%) was found more drought tolerant eficiency than the released variety NH-615 (59.83%). However, the more drought tolerant efficiency was recorded in PKV Rajat (73.10%).
13. Statistically higher value for yield stability index was noted by PKV Rajat (0.72), AKH-8828 (0.71) and AKH-9916 (0.70), the released genotype. None of the new genotype recorded more YSI over the general mean of all genotype tested.
14. Amongst all the ten genotypes tested, significantly more plant height stress index was recorded by PKV Rajat (88.99) followed by AKH-9916 (88.90) over general mean (84.46).
15. Amongst all genotypes AKH-8828 (10.23) recorded more sympodia (fruiting branches) followed by AKH-9916 (10.13), AKH-1301 (9.9) under non stress condition. In stress condition, AKH-9916 (10.46) recorded significantly more fruiting branches followed by AKH-1301 (9.96).
16. Significantly more number of bolls were recorded by AKH-9916 (17.10) per plant followed by AKH-8828 (16.40) over mean value of all genotypes (14.16) in non stress. The genotype AKH-1301 (15.26) was found superior over released genotype NH-615 (12.83) under non stress condition also AKH-1301 (10.40) was remained superior followed by AKH-1302 (10.16) over released genotype NH-615 (8.66) in stress condition.

17. The genotype AKH-9916 (98.12 g) showed highest test wt. and found at par with AKH-09-5 (96.88 g) in non stress condition. Under stress condition AKH-09-5 (74.54 g) was remained significantly more over mean value followed by AKH-9916 (73.63 g) and NH-545 (71.87 g).
18. Under non stress condition AKH-9916 (50.53 g/ plant) was recorded significantly more seed cotton yield followed by NH-615 (49.80 g/plant), AKH-1302 (49.23 g/plant) and AkH-8828 (48.66 g/plant). Under water stress condition, AKH-9916 (36.36 g/plant) was remained significantly higher which was followed by AKH-8828 (34.86 g/plant) and AKH-1301 (31.63 g/plant).
19. The genotype AKH-1302 (49.23 g/plant) produce statistically more seed cotton yield per plant than the released variety PKV Rajat (40.84 g/plant) followed by AKH-1301 (47.13 g/plant) under non stress condition. Under water stress condition none of the new genotype recorded statistically more seed cotton yield than the released varieties.

However, the present findings needed further confirmation on multilocation basis.

CONCLUSIONS

Amongst the ten genotypes tested, the genotypes AKH-9916 and AKH-8828 was recorded significantly higher seed cotton yield owing to significant contribution of physiological parameter i.e. leaf area, total dry matter production and relative water content, biochemical parameters i.e. proline content and total chlorophyll content, and stress indices under both, stress and non stress condition. Whereas among new genotypes, AKH-1301 and AKH-1302 showed better performance with respect of physiological, biochemical parameters and yield as compared to other new genotypes.

CHAPTER VI

IMPLICATIONS

In the present investigation the genotypes AKH-9916, AKH-8828 and AKH-1301 found promising on the basis of their significant morpho-physiological parameters *viz*., higher leaf area, root: shoot ratio, total dry matter production and number of bolls, biochemical parameters *viz.,* higher proline content and total chlorophyll content. Present study will be useful for cotton breeders /researchers for utilization of different promising cotton genotypes for further genetic improvement.

CHAPTER VII

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Signature of Student

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Appendix

Weekly Weather data for the year 2018 recorded at Meteorological Observatory Department of Agronomy Dr. PDKV., Akola

Weeks	Dates	Actual				2018						Normal				1971-2000		
		T MAX (oC)		T MIN (oC)		BSH (hrs)		WS (km/hr)		RH I (%)		RH II (%)		Evap (mm)		RF (mm)		CRF (mm)	Rainy Days	
		N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A		N	A
26	25-1Jul	34.1	32.3	24.2	23.7	5.3	3.9	13.4	5.8	80	86	55	56	7.3	6.4	38.2	111.0	297.5	2.3	5.0
27	2-8	33.5	32.7	24.4	24.3	5.2	3.8	12.9	5.9	81	83	58	61	6.8	6.3	34.7	54.8	352.3	2.4	5.0
28	9-15	32.3	28.4	23.7	23.6	3.8	1.0	12.0	8.2	84	93	62	80	5.5	4.2	52.2	140.3	492.6	2.8	6.0
29	16-22	32.0	29.9	23.9	24.1	3.3	0.6	11.2	7.3	84	88	65	71	5.6	3.2	58.6	35.1	527.7	2.6	3.0
30	23-29	31.7	28.0	23.3	23.5	4.3	0.7	11.9	4.4	85	90	64	74	5.3	3.2	44.2	30.7	558.4	2.6	4.0
31	30-5 Aug	31.1	32.2	23.1	24.2	3.6	5.8	11.7	8.1	88	81	66	56	4.6	6.0	49.3	3.2	561.6	2.5	1.0
32	6-12	30.2	30.8	22.9	24.3	3.5	1.4	11.6	9.4	87	84	69	65	4.2	5.2	59.9	4.8	566.4	2.9	1.0
33	13-19	30.5	29.4	22.8	24.0	4.4	1.2	11.7	8.5	86	89	66	74	4.5	4.1	40.6	97.8	664.2	2.2	3.0
34	20-26	30.5	27.6	22.6	22.6	4.3	1.8	11.0	9.2	88	91	66	77	4.3	4.0	46.7	106.4	770.6	2.0	3.0
35	27-2 Sep	30.4	28.5	22.7	23.4	4.4	0.1	10.6	6.6	86	88	64	70	4.2	2.9	47.1	1.0	771.6	2.4	0.0
36	3-9	31.1	29.8	22.5	21.9	5.7	3.8	9.1	8.1	85	84	61	56	4.7	4.5	28.5	1.0	772.6	1.5	0.0
37	10-16	32.2	32.6	22.4	24.0	7.1	8.6	9.0	2.6	85	81	56	48	5.1	5.6	18.9	0.0	772.6	1.1	0.0
38	17-23	33.4	33.3	22.3	23.1	7.2	4.4	8.5	3.3	83	85	53	52	5.3	4.9	24.6	62.4	835.0	1.4	2.0
39	24-30	33.7	33.6	21.9	22.7	7.6	8.5	5.4	0.6	83	85	50	49	4.9	4.5	24.4	0.0	835.0	1.5	0.0
40	1-7 Oct	33.9	35.1	20.2	21.3	8.1	8.6	7.5	0.6	81	78	45	38	5.5	4.9	21.8	0.0	835.0	1.1	0.0
41	8-14	34.1	35.4	18.7	18.6	4.2	8.6	4.1	0.8	76	77	40	29	5.3	5.1	16.0	0.0	835.0	0.9	0.0
42	15-21	33.9	34.8	18.1	19.3	8.4	8.5	4.4	0.5	74	72	36	30	5.5	5.1	3.1	0.0	835.0	0.4	0.0
43	22-28	33.1	35.3	18.5	17.1	8.4	8.9	4.1	0.4	73	68	36	22	5.3	5.2	10.0	0.0	835.0	0.6	0.0
44	29-4 Nov	33.0	33.4	15.8	18.1	8.7	8.9	4.7	1.3	72	68	31	32	5.3	5.9	2.3	0.0	835.0	0.3	0.0
45	5-11	32.4	33.6	14.8	16.5	8.6	7.0	4.5	0.5	70	76	30	28	5.2	4.2	3.7	0.0	835.0	0.3	0.0
46	12-18	31.7	33.3	13.7	14.0	8.6	8.9	4.6	0.4	70	66	30	20	4.9	5.0	1.1	0.0	835.0	0.2	0.0
47	19-25	31.0	32.8	13.1	17.2	8.6	7.8	4.4	0.6	71	78	30	34	4.6	4.8	10.1	4.5	839.5	0.3	1.0
48	26-2 Dec	30.3	31.0	12.4	12.3	8.8	8.0	4.6	0.5	71	74	31	27	4.3	4.3	6.8	0.0	839.5	0.3	0.0
49	3-9	29.8	29.8	11.2	15.9	8.7	5.2	4.7	0.9	70	76	29	41	4.3	4.0	1.3	0.0	839.5	0.2	0.0
50	10-16	29.4	28.9	10.3	12.3	8.8	6.6	4.5	1.1	70	83	27	31	4.2	4.1	1.3	0.0	839.5	0.2	0.0
51	17-23	29.5	26.5	10.6	10.2	8.7	7.5	4.7	1.1	69	116	29	34	4.3	4.2	0.9	0.0	839.5	0.1	0.0
52	24-31	29.2	27.5	10.7	9.6	8.6	8.4	4.8	1.5	70	59	31	23	4.3	5.0	2.6	0.0	839.5	0.2	0.0
2019																				
1	1-7 Jan	29.0	29.8	10.3	9.4	8.7	8.4	4.9	0.7	78	68	30	22	4.2	4.0	1.7	0.0	0.0	0.2	0.0
2	8-14	29.2	28.1	11.3	10.0	8.6	7.8	6.3	1.2	71	72	30	30	4.5	5.4	3.4	0.0	0.0	0.2	0.0
3	15-21	29.9	29.4	11.6	10.4	8.9	7.6	5.4	1.2	69	66	28	24	4.8	5.2	0.9	0.0	0.0	0.1	0.0
4	22-28	30.8	28.1	11.8	14.0	9.1	6.1	5.5	1.7	67	75	27	36	5.2	5.0	1.1	0.0	0.0	0.2	0.0
5	29-4 Feb	31.1	28.1	12.1	10.7	9.3	7.9	5.8	1.5	61	61	25	22	5.6	5.3	2.8	0.0	0.0	0.2	0.0