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COTTON INNOVATION IN THE WORLD

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Şanlıurfa/Türkiye

Cotton is an important product in terms of the country's economy and social standard of living, with its versatile areas of use, the employment and added value it provides. Due to global climate change, countries are carrying out projects that protect nature and natural resources and are trying to develop low-cost and least harmful production methods. Regenerative cotton and colorful cotton production increase in the World day by day. An innovation system can be defined as the network of organizations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organization into economic use, together with the institutions and policies that affect the system’s behaviour and performance. Innovation systems help to create knowledge, provide access to knowledge, share knowledge, and foster learning. The innovation systems concept embraces not only the science suppliers but the totality and interaction of actors involved in innovation. In other words, the concept extends beyond the creation of knowledge to encompass the factors affecting demand for and use of knowledge in novel and useful ways (World Bank 2006b).

Genetically modified cotton was first approved and grown in some of the country. Some of the country doesn’t grow genetically modified cotton as Turkiye, Özbekistan. Water use efficiency, cotton water productivity has increased. An agriculture sector built on science-based research and development. The authors detail gains to date and future scientific opportunities in each of these key areas: biotechnology, precision agriculture, water management, resistance, greenhouse gas emissions and carbon farming, pesticides, biosecurity, resource use efficiency, and technology adaptation. Drought-resistant cotton seeds will be an important role in cotton production. Smart agriculture will increase its place in cotton production every day

INTRODUCTION

Cotton is an important product for many industrial sectors, especially the textile, oil and feed industry sectors. In addition to its high agricultural production value, it is an input-intensive production branch and is a source of income for a very large segment of agricultural workers, including seed, fertilizer, medicine, machinery industries and trade (Anonymous, 2022 a. Cotton is a plant with very high added value. Cotton breeding, physiology, increasing yield and fiber quality values R&D studies continue to gain momentum.

Another issue that increases the importance of cotton is that cotton production areas in the world are limited in terms of climate conditions. 63% of the world's cotton planting areas are in Asia, 20% in America and 14% in Africa. Although cotton is cultivated in many countries, 84% of cotton production is provided by 7 countries including India, America, China, Pakistan, Brazil, Uzbekistan and Turkey (ICAC, 2019 and ICAC, 2021). In our country, cotton production was carried out in 5.73 million decares of land in 2022, 2.75 million tons of seed cotton and 1.017 million tons of fiber were produced, and the average yield was 480 kg/decare. Compared to the previous year, there was a 25% increase in production area and 18% in fiber production, while there was an 8% decrease in seed cotton yield (Anonymous, 2022 b).

LITERATURE REVIEW

Bradburn A., Kauter Greg., 2013 Over that period, scientific research has helped boost yields and environmental performance: water use efficiency has improved by up to 4% per annum, cotton water productivity has increased overall by 40%, and Australia's cotton yields are 2.5 times the world average. This article outlines the future opportunities for Australia's cotton industry, an agriculture sector built on science-based research and development.

Yorgancılar et al. 2015 Since the genetic resource in the F2 and F3 stages can be precisely determined with the help of MAS, it provides significant advantages in the later stages of breeding programs.

Serdengeçti, M.N., 2020 Molecular markers have many areas of use. Examples of these include; determination of genetic relationships of plant species and varieties used in breeding studies, molecular characterization of plant genetic resources, determination of parents to be used in breeding studies, creation of genetic maps, demonstration of the difference of the variety obtained from other standard varieties in registration studies, which are the last stage of plant breeding studies, and GMO analyses .

Ütebay 2018. Pre-consumer knitted cotton textile wastes were collected in a systematic way and sorted according to fabric tightness (loose/single-jersey and tight/interlock) and previous finishing treatments (untreated greige cotton fabrics and dyed cotton fabrics). Results showed that lower waste ratio of recycled fibres and higher yarn breaking strength values was obtained by the recycling of cotton fibres from wastes composed of single-jersey greige cotton fabrics.

Wang et all 2023.The issue of quality traceability has been a persistent challenge current cotton supply chain, impeding the industry's development. The lack of transparent and timely information transmission hampers effective regulation of cotton quality, thereby significantly impacting both the quality of cotton products and enterprises' brand image. To address this problem, this paper proposes an Ethernet blockchain and smart contract-based platform for quality traceability in the cotton supply chain, enabling efficient management with complete transparency. We have developed five smart contracts and eight algorithms, providing comprehensive implementation, testing, and validation details for their integration into the cotton supply chain system. This approach ensures secure and authentic dissemination of quality information throughout the cotton supply chain while mitigating issues related to isolated product information

Gürsoy 2023,The author emphasized that PAT had the ability to protect crop health, soil, and the environment by effective and optimized application of inputs

Rank 2024. These systems, guided by AI, deliver water through drip irrigation or sprinklers, ensuring each plant receives the optimal amount at the exact time it needs it. This precision irrigation minimizes water wastage, optimizes resource allocation, and leads to significant yield increases, potentially by up to 30%.

Yifan 2024. 3D woven fabric template for efficient personal healthcare and thermal comfort regulation is successfully developed After further encapsulation with transparent fluorosilicone resin, the smart cotton fabric exhibits excellent self-cleaning performance with water/oil repellent. The smart multiresponsive cotton fabrics hold great promise in next-generation wearable systems for efficient personal healthcare and thermal management (Yifan et all 2024).

Cai et all 2024. Therefore, the use of cotton stalk to produce bioenergy is an appealing alternative to the current paradigm of agricultural waste.Cotton stalks have been utilized to produce biofuels such as syngas, bio-oil, bioethanol, lipids, and biogas through thermochemical and biochemical conversion. The detailed lignocellulose structures in cotton stalk are still not well characterized, which makes it difficult to valorize cotton stalk, particularly by routes that require modification.

METHODOLOGY

What are the main challenges innovation in the World., ii) What can be done to revamp this sector in the light of Researcher practices, and iii) What are the benefits of R&D in agriculture?

DISCUSSION AND ANALYSIS

Dr. Shahid Siddique (personal communication, August 2023) said that the main challenge highlighted by the experts at the international level is synthetic fiber. "Although synthetic fiber is cheaper and the cost of production is low, it is non-degradable and causes land and water pollution," he added. but due to high input prices and high cost of production, farmers hesitate to grow this crop. Cotton is the healthiest clothing material and has many different uses. Therefore, cotton farming should be supported in any way. For our own health and for the world to be a livable place, the cultivation of natural products should be supported. What needs to be done to revamp Cotton sector?. Cotton innovation has been transforming the textile and agricultural industries across the world. The developments span from agricultural practices to sustainable and technologically advanced textiles. Here are some ways areas of cotton innovation globally:

1. Biotechnology Innovations

a-GM Cotton: Countries like India, the U.S., and Australia widely adopt genetically modified cotton (e.g., Bt cotton) that resists pests and reduces the need for chemical pesticides.

b-Colored Cotton: Scientists are experimenting with naturally pigmented cotton varieties to reduce the need for synthetic dyes, which are harmful to the environment.

c-Molecular Genetics: Today, one of the most important innovations in cotton is molecular genetics. Breeders combine traditional breeding methods with molecular breeding methods, making the long and laborious breeding process more effective and obtaining high-quality varieties in a shorter time. Molecular breeding can be defined as the selection of plants with desired genetic characteristics using molecular markers, plant genome and linkage maps (Vinod, 2006).

Molecular markers have many areas of use. Examples of these include; determination of genetic relationships of plant species and varieties used in breeding studies, molecular characterization of plant genetic resources, determination of parents to be used in breeding studies, creation of genetic maps, demonstration of the difference of the variety obtained from other standard varieties in registration studies, which are the last stage of plant breeding studies, and GMO analyses (Serdengeçti, M.N., 2020).

Marker Assisted Selection (MAS)

MAS is based on the use of molecular markers that are tightly linked to genes controlling important agronomic characters and can be easily recognized. MAS applied plant breeding studies provide significant progress in increasing the speed and efficiency of selection in classical breeding studies.

Genetic linkage maps of most agronomic traits have been created with molecular markers in many plants. The aim of developing linkage maps is to determine the positions of agronomic traits in the genome and to identify tightly linked markers in order to make indirect selection in breeding through molecular markers.

MAS uses DNA markers tightly linked to agronomically important genes instead of phenotypic selection or to assist phenotypic selection. The combination of MAS and phenotypic selection will guarantee positive results. Backcrossing provides effective selection of the target region, minimizes linkage scans and facilitates the detection of recurrent parents. Since the genetic resource in the F2 and F3 stages can be precisely determined with the help of MAS, it provides significant advantages in the later stages of breeding programs (Yorgancılar et al. / 4 (2):1-12, 2015).

2. Sustainable Cotton Farming

a-Organic Cotton: Farmers are moving towards pesticide- and chemical-free farming, producing organic cotton that reduces environmental impact.

b-Regenerative Agriculture: Techniques like crop rotation, cover cropping, and reduced tillage improve soil health and carbon sequestration.

1. FIRSTLY, varieties with short growing periods that will not affect regional plant diversity are determined and recommended.
2. Switching to minimum-practice agriculture in summer plantings has been encouraged.
3. Soil tillage techniques are applied to ensure water conservation in the soil.
4. The use of organic fertilizers is encouraged to increase the water retention capacity of the soil.
5. Soil health and soil improvement are among the most important issues in agriculture.
6. Practices that improve the physical, chemical and biological structure of the soil, increase the amount of organic matter in the soil, and increase soil fertility by increasing the water retention capacity of the soil are encouraged.
7. In crop rotation, varieties with low water consumption and resistance to drought are being developed.

c-Precision Agriculture: Use of technology such as IoT, AI, and satellite imaging helps optimize water usage, pest control, and yield.

One of the new ways that modern agriculture could potentially maintain or enhance crop yields by minimizing environmental pollution is site-specific application of inputs according to the needs of the crop, which is defined as Precision agriculture. PA is an umbrella term for using modern data-driven technologies to optimize crop management and improve productivity, efficiency, and sustainability in agricultural production. Therefore, PA can be defined as the application of modern information technologies such as GPS, sensors, drones, Internet of Things (IoT), artificial intelligence (AI), and data analytics in the management of crop production. It is seen that studies on PA have gained importance in recent years. The fact that Internet of Things (IoT), artificial intelligence (AI), remote sensing, and image processing (ImP) techniques have been actively used in agriculture by integrating with geographic information systems (GIS) and geographic position systems (GPS) has brought about important developments in the use of precision agriculture technologies (PAT) in agricultural production. Kırkaya stated that in the future, PAT will be widespread used in crop management practices such as sowing, fertilization, irrigation, and weed control. The author emphasized that PAT had the ability to protect crop health, soil, and the environment by effective and optimized application of inputs (Gürsoy 2023,)

d-Drought-Resistant Cotton: Research is underway to develop cotton varieties that require less water and can grow in arid conditions.

3. Smart Cotton Textiles

a-Wearable Technology: Cotton fabrics integrated with sensors and conductive materials can monitor health, detect environmental changes, or provide smart functionalities.

3D woven fabric template for efficient personal healthcare and thermal comfort regulation is successfully developed After further encapsulation with transparent fluorosilicone resin, the smart cotton fabric exhibits excellent self-cleaning performance with water/oil repellent. The smart multiresponsive cotton fabrics hold great promise in next-generation wearable systems for efficient personal healthcare and thermal management (Yifan et all 2024)

b-Performance Fabrics: Innovations like moisture-wicking, antimicrobial, and stain-resistant cotton fabrics are redefining comfort and usability.

4. Circularity and Recycling

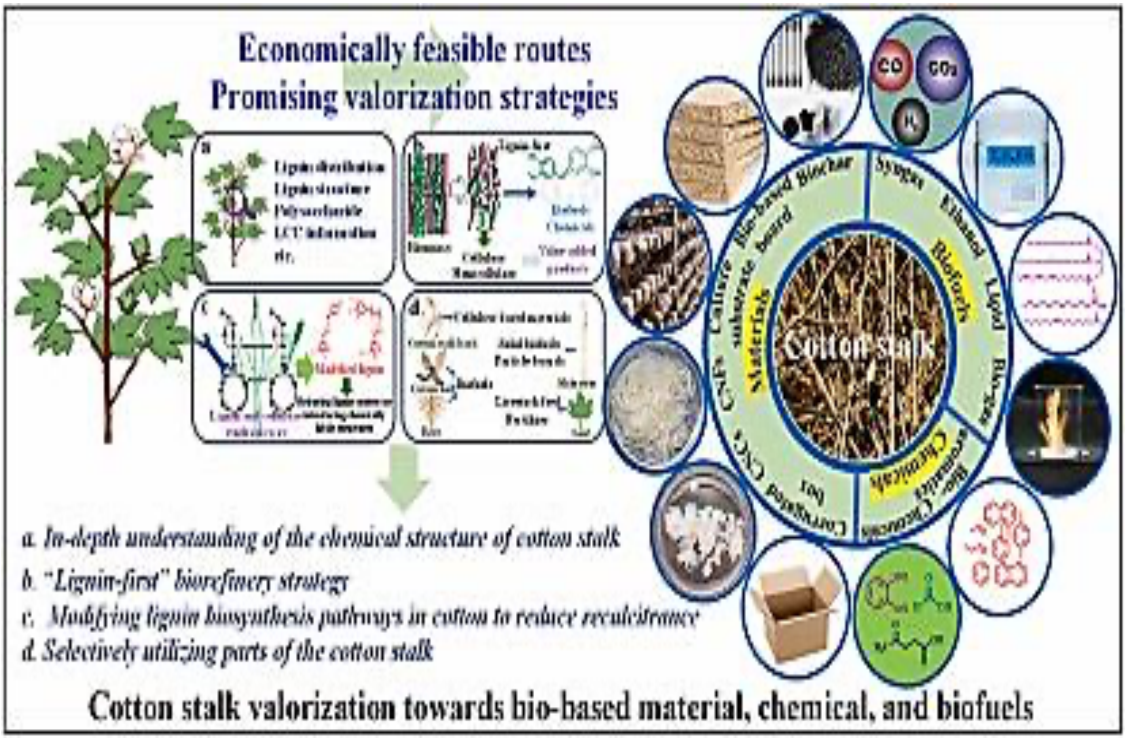
a-Recycled Cotton: Technologies allow post-industrial and post-consumer cotton to be broken down and recycled into new garments. Brands like H&M and Levi’s are adopting recycled cotton in their production.

The market for recycled cotton appears to be growing; however the main obstacle for cotton recycling is the lower quality of the resultant products. Pre-consumer knitted cotton textile wastes were collected in a systematic way and sorted according to fabric tightness (loose/single-jersey and tight/interlock) and previous finishing treatments (untreated greige cotton fabrics and dyed cotton fabrics). Results showed that lower waste ratio of recycled fibres and higher yarn breaking strength values was obtained by the recycling of cotton fibres from wastes composed of single-jersey greige cotton fabrics.(Ütebay et all 2018) In general recycled cotton fibres from dyed fabrics showed lower quality values. As a conclusion, it was indicated that better values for resultant material could be achieved by the selection of loosely knitted greige cotton fabrics.

b-Cotton Bio-Products: Researchers are turning cotton waste into biofuels, bioplastics, and cellulose-based products. Hence, the conversion of cotton stalk is challenging and various obstacles must be overcome to achieve cotton-stalk valorization. Therefore, it is necessary to propose feasible conversion strategies based on the specific properties of cotton stalk.

Although diverse value-added products have been produced from lignocellulosic biomass, bio-based materials, chemicals, and biofuels are promising options considering the currently available technology and market prices. Cotton stalks have relatively high raw materials

The favorable traits of cotton stalk for producing bio-based materials include its good mechanical performance and good fiber quality that suitable for fabric preparation Cotton stalks have been used to manufacture particleboard, hardboard, medium-density fiberboard, and corrugated boxes. Cotton stalk has also been used in biogeopolymer composites for construction materials. Furthermore, cotton stalk fiber has shown potential in pulp and paper production, which could Chemo-catalytic conversion Converting lignocellulose components into chemicals is another way to improve their value. The primary conversion strategies are chemocatalytic and biochemical processes [94. Fig. 3b depicts the conversion process for chemical production from cotton stalk. Cellulose and hemicellulose can be converted into valuable chemicals using chemo-catalytic approaches. Yang et al. produced levulinic and formic acids from cotton-stalk cellulose via two-stage acid hydrolysis. Cotton stalk has a high calorific value (14.5–19.2 MJ/kg), which is similar to that of wood (17.4–18.6 MJ/kg) [10, 46,128]. Therefore, the use of cotton stalk to produce bioenergy is an appealing alternative to the current paradigm of agricultural wasteCotton stalks have been utilized to produce biofuels such as syngas, bio-oil, bioethanol, lipids, and biogas through thermochemical and biochemical conversion. The detailed lignocellulose structures in cotton stalk are still not well characterized, which makes it difficult to valorize cotton stalk, particularly by routes that require modification.



Graphical abstract

5. Traceability and Blockchain

a-With growing consumer demand for transparency, innovations in blockchain technology are enabling traceable cotton supply chains. This helps track cotton from farm to fabric, ensuring ethical sourcing. The issue of quality traceability has been a persistent challenge in the current cotton supply chain, impeding the industry's development. The lack of transparent and timely information transmission hampers effective regulation of cotton quality, thereby significantly impacting both the quality of cotton products and enterprises' brand image. To address this problem, this paper proposes an Ethernet blockchain and smart contract-based platform for quality traceability in the cotton supply chain, enabling efficient management with complete transparency. We have developed five smart contracts and eight algorithms, providing comprehensive implementation, testing, and validation details for their integration into the cotton supply chain system. This approach ensures secure and authentic dissemination of quality information throughout the cotton supply chain while mitigating issues related to isolated product information (Wang et all 2023).

6. Climate-Adapted Cotton Varieties

Research programs like Better Cotton Initiative (BCI) and collaborations with institutions such as ICAC (International Cotton Advisory Committee) focus on developing cotton strains that withstand climate challenges.

7. Water-Saving Innovations

a. Drip irrigation, hydrogel technologies, and AI-driven water management systems are helping cotton farmers reduce their water footprint, especially in water-scarce regions. These systems, guided by AI, deliver water through drip irrigation or sprinklers, ensuring each plant receive the optimal amount at the exact time it needs it. This precision irrigation minimizes water wastage, optimizes resource allocation, and leads to significant yield increases, potentially by up to 30%(Kelaiya and Rank, 2019; Paghadal et al., 2019a; Kumar and Rank, 2021; Rank et al., 2020; Kumar and Rank, 2023).
b. U.S. Cotton Trust Protocol: Aims for sustainable and transparent cotton production.
c. Smart Spinning and Weaving: Automation and digital technologies improve the efficiency and quality of cotton fabric production.

All these advancements are increasing the cotton industry toward a more sustainable, efficient, and technologically advanced future while meeting global demands for eco-friendly textiles to protect nature.

CONCLUSİONS

Although synthetic fiber is cheaper and the cost of production is low, it is non-degradable and causes land and water pollution. Due to high input prices and high cost of production, farmers hesitate to grow cotton. Cotton is the healthiest clothing material and has many different uses. Therefore, cotton farming should be supported in any way. For our own health and for the world to be a livable place, the cultivation of natural products should be supported. Cotton innovation has been transforming the textile and agricultural industries across the world. The developments span from agricultural practices to sustainable and technologically advanced textiles. Supporting innovation in cotton, increasing R&D activities means investing in cotton, which is a healthy product, to take a step to a livable world and to increase the use of healthy products against synthetic.

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GENOTYPIC DIVERSITY FOR DROUGHT TOLERANCE IN EGYPTIAN COTTON

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ABSTRACT

This study aimed to investigate water shortage effects on fifty cotton genotypes and to select drought tolerant genotypes at two seasons (2021-2022). Water treatments were, well watered, 50% and 75% water shortage. Trials were sown at Sakha Experimental Farm, in split-plot arrangement under RCBD, irrigation treatments occupied main plots and sub-plots contained genotypes. Results indicated significant variability among genotypes, water treatments and their interactions. Genotypes varied under each treatment and over treatments due to their different genetic potential. Water stress treatments caused significant reduction for most traits, the reduction increased as water shortage increase. The significant GxT interactions indicated the potential for selecting some drought tolerant genotypes among the tested materials. Seven genotypes (G.3, G.4, G.12, G.17, G.35, G.42 and G.43) were the most tolerant genotypes for both water shortage treatments for cotton yields and can be used as parents in hybridization breeding program to improve cotton productivity under drought conditions. Whereas, the tested genotypes were not tolerant for all fiber traits together and selection must be done for each trait separately. Fiber traits were the lowest affected traits by water stress. Almost all of extra-long staple cotton genotypes were most susceptible to water stress in productivity and fiber quality.

Selection for tolerance to water shortage stress must be practiced under the stress conditions. Using GGE biplot analysis for seed cotton yield/plant, five genotypes (G.39, G.1, G.25, G.27 and G.48) were the ideal genotypes with the highest yield and stability across water treatments. The well-watered treatment was the ideal treatment.

Key words: Genotypic Variability, Water Shortage Tolerance, Egyptian cotton.

INTRODUCTION

Cotton (*Gossypium Spp*. L.) is a significant industrial plant which influences livelihood of the people around the globe, it is the most leading cultivated fiber crop worldwide, it provides about 35%-50% of the total natural fiber produced globally for the textile sector, cotton seed are used for the edible oil sector and pulp rich with protein for the livestock sector (**Abdelraheem *et al*., 2019)**. The continual growing human population increases the demand for cotton and its products for the consumption in the different sectors (**Mahmood *et al*., 2021**).

Climate change possess a significant menace to global agriculture, it cause environmental changes as rising temperature and growing drought conditions, (the lack of adequate and regular water supply), moreover futurity climatic changes will continue and water shortage may become a severe barrier in crop production (**Matniyazova *et al.,* 2022**). While demands on water available for agricultural purposes is rising, intensify climate conditions and growing human demands of water are restricting its availability for agriculture (**Reddy *et al.,* 2004**).

The sowing of cotton crop faces many defiance consequent of changing climatic conditions, which affect crop growth, development and yield potential **(Singh *et al*., 2022**). Among the various abiotic stresses, drought stress was found to have deleterious effects on the performance of cotton plant (**Cinar *et al.,* 2022**).

Cotton is an exemplary crop for cultivation in tropical and subtropical regions (regions which are more exposed to drought stress). Thus, it exhibits moderate tolerance against drought stress through its vegetative stage, whereas, through reproductive stage, cotton is highly sensitive to drought stress (**Niu *et al*., 2018; Singh *et al*., 2022**; **Çelik, 2024**).

Previous studies concluded that drought stress has significant effects on both of vegetative and reproductive stages of cotton crop. During the start of vegetative stage, drought stress reduces internodal spaces, resulting in reduced plant height and length of both vegetative and fruiting branches (**Ullah *et al*., 2019**), during squaring results significant shorter plants with fewer nodes **(Snowden *et al*., 2014),** reduces leaf surface area which cause inhibition of photosynthesis and diminished assimilate production (**Ergashovich *et al*., 2020; Ullah *et al*., 2022; Çelik, 2023**).

While drought at the reproductive phase harshly affects anther growth, pollen viability, and ultimately seed cotton yield (**Singh *et al*., 2022; Zafar *et al*., 2023**). It also results in higher boll shedding (**Iqbal *et al*., 2019**), reduce boll formation and boll retention, and ultimately impacting yield **(Ergashovich *et al*., 2020)**. Further, drought at the peak flowering period has the extreme deleterious effect on yield (**Snowden *et al*., 2014; Çelik, 2023).** The determined reduction in cotton yield was 34% lower due to drought stress (**Ullah *et al*., 2019**), while **Tokel *et al*.**, (**2022**) found that yield losses reached 67% and drought stress had more adverse effects on cotton crop than other environmental stresses.

In addition, water deficit stress adversely impacts quality of cotton fibers, essentially during the fiber formation and development interval. Moreover, in the latter period of the flowering stage, the lack of water retarding development of the late-formed bolls, diminish the length and strength of the formative fiber, and increasing the possibility of boll shedding (**McWilliams, 2004; Snowden *et al*., 2014; Ergashovich *et al*., 2020**). In the same connection, drought stress reduce fiber length, uniformity, strength and fineness **(Wang *et al*., 2016; Sun *et al*., 2021; Bibi *et al*., 2024)**.

Drought tolerance is the ability of a genotype to grow and develop under drought-stress conditions. It is a complex characteristic controlled by multiple genes related to several morphological and physiological characteristics of crop plants (**Cushman and Bohnert, 2000)**.

Introducing germplasm with improved yield at drought conditions is a main goal for plant breeder worldwide (**Cattivelli *et al*., 2008**). Many processes have been used to improve drought tolerance in plants. The most common process is direct selection by examining the available germplasm under drought stress conditions and rating genotypes for stress tolerance or susceptibility basing on the reduction in yield then selecting the highest yielding genotypes. Thereafter, crossing among the selected tolerant genotypes followed by conventional selection procedures in the segregating generations (**Cinar *et al*., 2022; Ullah *et al*., 2022; Çelik, 2024**).

According to the results of previous studies there is considerable amount of genetic variability for response to drought stress in cotton genotypes undergone to water shortage in upland cotton (*G. hirsutum* L.) by **Zonta *et al*., 2017**; **Ullah *et al*., 2019; Rehman *et al*., 2022; Sun *et al*., 2023**; **Zafar *et al*., 2023; Gören and Tan, 2024** as well as in Egptian cotton (*G. barbadense* L.) by **El-Dahan *et al*., 2018; Yehia, 2020; Abdel-Monaem *et al*., 2022; Abo Sen *et al*., 2022; Mahdy *et al*., 2022; Yehia and El-Absy, 2023.** Therefore, cotton breeder can be select some drought tolerant genotypes to be used as parents in hybridization cycles in breeding program that aim to increase drought tolerance in cotton with high yielding ability.

The major objective of the present study is to assess the Egyptian cotton genotypes for drought tolerance by measuring their performance and yield potential under full irrigation and water shortage in the field conditions, as well as to define drought tolerant genotypes appropriate for using as genetic materials in hybridization breeding program aiming to improve cotton productivity and fiber quality under drought conditions.

MATERIALS AND METHODS

Field trials were carried out at Sakha Agriculture Research Station, Kafr El-Sheikh Governorate, Egypt (Longitude: 31 W, Latitude: 31 N, Elevation: 36) through two successive growing seasons (2021-2022). The soil type of the experimental area was loam in texture.

Plant material

The genetic materials comprised fifty cotton genotypes **(Table 1)** belonging to *Gossypium barbadense* L. representing a high extent of cotton characters. Genotypes contained 34 long-staple genotypes and 16 extra-long staple genotypes. Pure and healthy seeds of the tested genotypes were kindly supplied by

Cotton Research Institute, Agriculture Research Center, Giza, Egypt.

Experimental design and field procedures

The fifty cotton genotypes were assessed in the field under three water regimes, i.e., well-watered (treatment 1), 50% water shortage (treatment 2) and 75% water shortage (treatment 3) as follows:

- Well-watered (normal irrigation as control or treatment 1) that contained eight irrigations, one irrigation at planting time and one supplemental irrigation each 15 days with total subsequent 7 irrigations as demanded for normal crop cultivation.
- 50% water shortage (treatment 2) that comprised five irrigations, one irrigation at planting and one subsequent irrigation each 30 days.
- 75% water shortage (treatment 3) that contained only three irrigations, one irrigation at planting and one subsequent irrigation each 45 days.

Irrigating the experiment was done using a basin irrigation system.

Table 1: Name and fiber category of the fifty cotton genotypes used in this study.

No.	Genotype	Category	No.	Genotype	Category
1	**Ashmouny**	Long staple	26	**Giza 95**	Long staple
2	**Dendara**	"	27	**Giza 96**	Extra-long
3	**Menoufy**	"	28	**Giza 97**	Long staple
4	**Giza 45**	Extra-long	29	**Pima S1**	"
5	**Giza 68**	"	30	**Pima S2**	"
6	**Giza 69**	Long staple	31	**Pima S3**	"
7	**Giza 70**	Extra-long	32	**Pima S4**	"
8	**Giza 71**	"	33	**Pima S5**	"
9	**Giza 74**	"	34	**Pima S6**	"
10	**Giza 75**	Long staple	35	**Pima S7**	"
11	**Giza 76**	Extra-long	36	**Pima S62**	"
12	**Giza 77**	"	37	**Pima Early**	"
13	**Giza 80**	Long staple	38	**Pima High Percentage**	"
14	**Giza 81**	"	39	**Suvin**	"
15	**Giza 84**	Extra-long	40	**(Giza 89 x Pima S6)x Suvin**	"
16	**Giza 85**	Long staple	41	**(Giza 86 x Giza 89)**	"
17	**Giza 86**	"	42	**(Giza 89 x Pima S6)x (Behtim 10 x Giza 67x Giza 72x Deleciro) x (Giza 89 x Giza 86)**	"
18	**Giza 87**	Extra-long	43	**(Giza 68x Giza 45) x (Giza 84 x Giza 45 x Giza 45) x Giza 87**	Extra-long
19	**Giza 88**	"	44	**(Giza 93 x Giza 71)**	"

No.	Genotype	Category	No.	Genotype	Category
20	**Giza 89**	Long staple	45	**(Giza 92 x Pima S1)**	"
21	**Giza 90**	"	46	**(Giza 89 x Pima S6)**	Long staple
22	**Giza 91**	"	47	**(Giza 84 x Giza 77)**	Extra-long
23	**Giza 92**	Extra-long	48	**Giza 90 x Australy**	Long staple
24	**Giza 93**	"	49	**Giza 96 x Giza 76**	Extra-long
25	**Giza 94**	Long staple	50	**Giza 98**	Long staple

The experiments were sown by adopting split-plot arrangement under randomized complete block design (RCBD) with three replicates in both years of the study. The three irrigation treatments occupied the main plots while sub-plots contained the fifty cotton genotypes.

The experiential plot for each genotype contained two sown rows followed by one idle row with a four-meter-long for the row. The row-to-row distance was 70cm; while hills within the row were spaced 35cm (11 hills/row) with two plants per hill.

Planting took place in the first week of May, while harvest was done at the last week of October in both seasons

All the agronomic and cultural practices were given as recommended for cotton crop uniformly to all the treatments except irrigations.

Measurement of studied traits

A random number of ten guarded plants for each of the genotypes per replication and treatment were used to determine the following valuable economic traits of the genotypes under optimal and deficit irrigation conditions:

Boll weight in grams (BW), seed cotton yield per plant in grams (SCY), lint yield per plant in grams (LY), lint percentage (L%), as well as the fiber quality traits, fiber fineness as micronaire reading in µg/inch (FF), fiber strength as Pressely index (FS), fiber length (FL) in mm and fiber uniformity ratio (UR%).

The fiber quality traits were measured at the fiber technology lab at the Cotton Research Institute, ARC, Egypt.

Statistical analysis

Initially, individual data for each year were analyzed then homogeneity of variance test was implemented to determine if the combined analysis of variance could be used. After affirming homogenous error variance, the combined analysis of variance was adopted.

The analysis of variance (ANOVA) was performed on the data for detecting whether the differences are significant or non-significant among cotton genotypes, treatments, and genotypes by treatment interactions for all the studied traits (**Steel *et al*., 1997**). Differences among means were compared with Fisher's Least Significant Difference (LSD) test at alpha levels of 0.01 and 0.05.

RESULTS AND DISCUSSION

Analysis of variance for the studied traits as combined over the two growing seasons are given in **Table (2).** Data concerning mean square values for water treatments manifested significant variance ($p \leq 0.01$) for all traits, which indicates different effects of the three water treatments on the tested genotypes. Also, highly significant variances for all traits in the study were recorded among genotypes and genotype × treatment interactions, which indicating differential responses of genotypes among each other and genotypes across irrigation treatments.

Table (2): Mean squares gained from the analysis of variance for 50 cotton genotypes under three water treatments combined over two years for the estimated traits.

S.O.V	d.f	BW (g)	SCY/P(g)	LY/P (g)	L%
Years	1	8.851	73028.76*	10488.83	5.26
Treatments (T)	2	20.779**	57078.38**	6206.34**	316.15**
Error A	8	0.1400	1409.2920	241.869	4.135
Genotypes (G)	49	0.187**	1398.76**	276.09**	40.11**
TG	98	0.190**	758.658**	106.42**	7.16**
Error B	588	0.0630	232.1370	34.593	1.603
S.O.V	**d.f**	**Mic. (µg/in)**	**FS (Press. I)**	**FL(mm)**	**UR%**
Years	1	143.50	6.17	0.037	193.46
Treatments (T)	2	3.24**	30.95**	156.29**	249.87**
Error A	8	0.21	0.26	0.328	1.013
Genotypes (G)	49	0.33**	0.45**	3.30**	2.13**
TG	98	0.11**	0.47**	1.44**	1.70**
Error B	588	0.037	0.126	0.541	0.691

* and ** indicate significant at 0.05 and 0.01 probability levels, respectively.
BW: Boll weight, SCY: Seed cotton yield, LY: Lint yield, L%: Lint%, Mic: Micronaire value, FS: Fiber strength as Pressely index, FL: Fiber length and UR: Uniformity ratio.

Effect of water treatments on the studied traits:

The effects of the three treatments of irrigation tested in this study (Normal-watered; 50% water shortage and 75% water shortage) concerning the different studied traits over the fifty cotton genotypes and two years of investigation are presented in **Table (3) and Figure (1)**.

Water treatments had highly significant effects on all the studied traits. Data presented in **Table 3** exhibited that yield and its component traits showed significant reduction under water shortage treatments except L% that had significant desirable increase under water stress; while, fiber quality traits revealed significant reduction under water shortage treatments except for micronaire reading that had significant undesirable increase under water stress. The reduction recorded for the studied traits increased as water shortage increase. The relative reduction ranged from -5.56% for L% under T3 to 30.87% for SCY/P under T3. These results were emphasized by the drawn figure for each trait presented in **Figure (1).**

Table (3): The effect of three water treatments on the studied traits combined over years and genotypes.

Treatment	BW (g)		SCY/P(g)		LY/P (g)		L%	
T1(Control)	3.06	--	79.58	--	28.81	--	35.86	--
T2(50% WS)	2.87	**6.22%**	61.81	**19.40%**	23.20	**16.25%**	37.35	**-4.23%**
T3(75% WS)	2.54	**16.91%**	52.42	**30.87%**	19.80	**27.80%**	37.83	**-5.56%**
LSD 0.05	**0.07**		**7.07**		**2.93**		**0.38**	
LSD 0.01	**0.10**		**10.28**		**4.26**		**0.56**	
	Mic. (µg/in)		**FS (Press. I)**		**FL(mm)**		**UR%**	
T1(Control)	3.61	--	10.72	--	35.08	--	86.14	--
T2(50% WS)	3.77	**-4.68%**	10.35	**3.36%**	34.20	**2.51%**	84.99	**1.33%**
T3(75% WS)	3.80	**-5.34%**	10.08	**5.94%**	33.65	**4.08%**	84.34	**2.09%**
LSD 0.05	**0.09**		**0.10**		**0.11**		**0.19**	
LSD 0.01	**0.13**		**0.14**		**0.16**		**0.28**	

BW: Boll weight, SCY: Seed cotton yield, LY: Lint yield, L%: Lint%, FS: Fiber strength, Mic: Micronaire value, FL: fiber length and UR: Uniformity ratio. WS: Water stress
Numbers followed by % are reduction percentages due to water treatment effects than the control.

The reduction recorded in most of the productivity traits as a result of insufficient water availability could be ascribed to the higher boll shedding (**Iqbal *et al*., 2019**), and decreased boll formation and reduced the number of bolls and seeds per boll (**Hu *et al*., 2019; Chattha *et al*., 2021; Yehia and El-Hashash, 2022),** in addition, **Ergashovich *et al*., (2020)** found that drought stress impacts vegetative and reproductive growth through reducing boll formation and boll retention, and ultimately impacting yield. Insufficient water for cotton plants also disturbs the cell turgor ability and the fiber development (**Abdelraheem *et al*., 2020**). Moreover, fiber quality traits of cotton plants were also reduced under water deficit environment, water stress decrease fiber length, uniformity and strength, while it increase fiber thickness (**Zafar *et al*., 2023; Bibi *et al*., 2024)** because plant employs all assimilates for seed cotton yield (**Shareef *et al.* 2018; Ali *et al*., 2022**). **El-Dahan *et al*., (2018)** found that fiber traits were the lowest affected traits by water stress as compared to other economic traits.

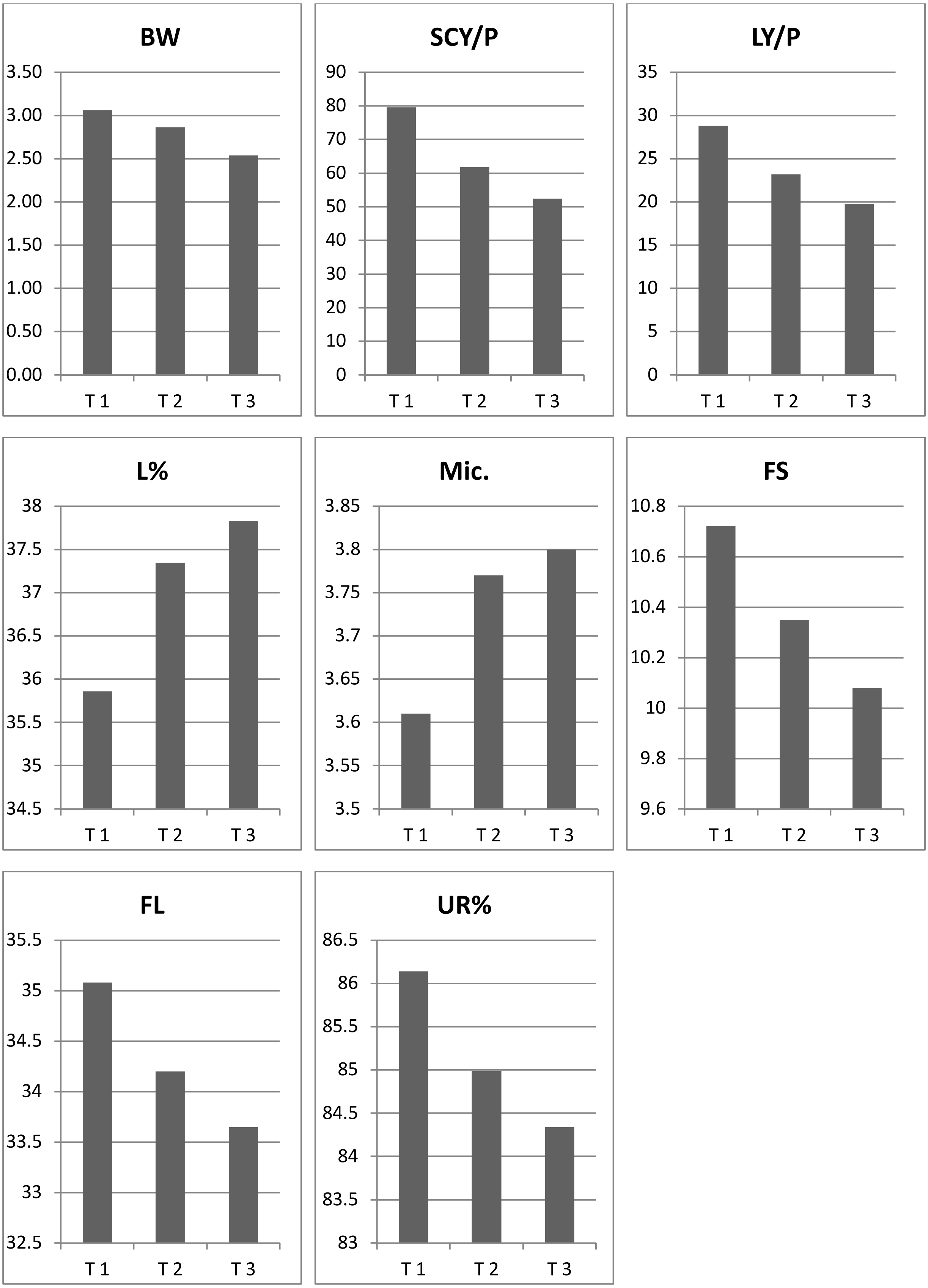

Figure 1: Effect of three water treatments on the studied traits combined over years and genotypes

Genotypic mean performance:

The studied fifty cotton genotypes exhibited highly significant differences ($p \leq 0.01$) with concern to all traits in the study, which indicating that genotypes performed differently over water treatments due to their different genetic potential and the presence of considerable genetic diversity among these genotypes for the studied traits, which permit for future genetic improvement of such traits. Similar differences among cotton genotypes with respect to the economic traits were recorded under various water treatments by**: El-Dahan *et al*., 2018; Ergashovich *et al*., 2020; Rehman *et al*., 2022; Sun *et al*., 2023**; **Gören and Tan, 2024**.

Water treatment x Genotype interactions

Data in **Table (2)** showed that, the interactions of water treatments by genotypes were highly significant ($p \leq 0.01$) which indicated the different genotypes performance across water treatments for the studied traits and thus one genotype cannot be recommended for all treatments. But there is potential for selecting some drought tolerant genotypes among the tested genotypes for all the studied traits.

The mean values and the relative reduction percentages in cotton productivity traits under the water stress treatments as compared to the well watered treatment (control) are presented in **Table (4)**.

For boll weight, the range was from 1.76g for G.46 under T3 to 3.43g for G.41 under T1 (control). The reduction percentage averaged 6.22% and 16.91% for T2 and T3, respectively as compared to T1. The highest difference was 17.81% for G.23 and 37.44% for G.46 for T2 and T3, respectively, whereas the lowest difference was -7.09 for G.47 and 0.60% for G.15 in the same order.

The lowest differences under T2 were detected for 9 genotypes that showed difference values with negative sign which mean that boll weight was increased under T2 as compared to T1, these genotypes were: G.47, G.50, G.39, G.38, G.43, G.44, G.13, G.46 and G.20 which showed negative values of -7.09%, -3.49%, -2.85%, -2.40%, -1.47%, -1.07%, -0.75%, -0.53% and -0.38%, respectively. On the other hand, all the differences under T3 had positive sign which mean that all genotypes decreased in boll weight as compared to T1. The lowest differences were detected for 6 genotypes that showed relative reduction less than 8%, these genotypes are G.15, G.11, G.7, G.16, G.8 and G.14 with relative reductions reached 0.60%, 3.90%, 4.93%, 6.46%, 7.53% and 7.91%, respectively.

Table 4: Mean performance for 50 cotton genotypes under three water treatments and their relative reduction% for the productivity traits

G.	BW					SCY					LY					L%				
	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%
1	3.07	2.58	15.95	2.64	14.03	102.1	83.4	18.31	56.8	44.35	35.5	32.3	9.07	21.3	39.95	34.70	38.39	-10.64	37.41	-7.81
2	2.98	2.88	3.36	2.68	9.88	69.3	56.4	18.53	47.3	31.72	23.9	20.0	16.20	16.7	30.19	34.69	35.30	-1.76	35.11	-1.22
3	3.13	2.87	8.37	2.71	13.58	63.2	65.3	-3.39	64.3	-1.74	22.3	23.2	-4.03	23.1	-3.36	35.34	35.48	-0.40	35.91	-1.62
4	2.98	2.84	4.77	2.45	17.80	47.1	56.4	-19.8	52.8	-12.2	15.8	20.5	-29.7	19.0	-20.1	33.52	36.52	-8.94	36.72	-9.53
5	2.95	2.74	7.03	2.64	10.36	83.5	68.1	18.44	63.7	23.65	29.0	25.6	11.67	23.5	19.01	34.70	37.41	-7.81	36.84	-6.17
6	2.99	2.50	16.45	2.32	22.31	65.3	50.9	21.95	51.4	21.22	23.2	18.5	20.55	18.2	21.71	35.60	36.10	-1.42	35.49	0.29
7	2.88	2.69	6.84	2.74	4.93	61.6	51.2	16.88	46.0	25.27	20.6	18.8	8.58	15.8	23.01	33.48	36.19	-8.10	34.67	-3.58
8	2.96	2.89	2.53	2.74	7.53	73.7	53.3	27.72	46.4	37.01	25.0	19.2	23.12	15.9	36.62	33.98	35.89	-5.62	34.67	-2.02
9	3.11	2.60	16.58	2.63	15.52	81.9	58.8	28.22	41.8	49.02	29.2	20.9	28.33	15.5	46.82	35.62	35.66	-0.11	37.26	-4.61
10	3.04	2.84	6.33	2.64	13.01	82.6	60.6	26.60	42.8	48.22	28.7	21.9	23.63	15.6	45.68	34.85	36.32	-4.23	36.90	-5.90
11	3.03	2.96	2.25	2.91	3.90	80.7	74.1	8.25	48.7	39.63	28.4	27.3	3.87	17.2	39.61	35.19	36.54	-3.84	35.13	0.16
12	3.06	2.80	8.53	2.65	13.24	49.3	57.8	-17.3	49.2	0.27	18.5	22.0	-19.4	18.6	-0.64	36.95	38.18	-3.33	36.76	0.50
13	3.05	3.08	-0.75	2.78	8.85	74.0	56.3	23.88	55.8	24.63	28.7	21.0	26.86	21.9	23.84	38.68	37.98	1.82	39.21	-1.36
14	3.03	2.74	9.56	2.79	7.91	73.6	60.1	18.33	56.6	23.07	26.6	22.9	13.91	21.7	18.67	35.05	37.95	-8.27	39.05	-11.40
15	2.85	2.63	7.56	2.83	0.60	56.6	48.1	15.04	42.5	24.89	20.5	17.8	13.14	15.2	25.53	35.64	36.89	-3.51	35.91	-0.77
16	3.03	2.78	8.24	2.84	6.46	80.1	49.0	38.82	47.2	41.13	26.5	16.1	39.41	16.7	36.82	33.01	33.09	-0.25	35.44	-7.39
17	3.23	2.87	11.26	2.48	23.17	64.5	67.3	-4.37	61.8	4.15	24.4	26.5	-8.53	22.5	7.59	37.29	38.82	-4.09	38.90	-4.30
18	3.15	2.93	7.01	2.81	10.97	64.6	58.0	10.20	39.1	39.53	22.1	19.6	11.31	13.2	40.47	33.92	34.53	-1.80	33.87	0.17
19	3.10	2.67	13.63	2.64	14.60	131.3	55.7	57.58	52.8	59.79	45.2	20.8	54.09	19.8	56.26	34.28	36.95	-7.78	38.83	-13.3
20	2.93	2.94	-0.38	2.68	8.34	99.0	70.7	28.57	55.4	44.06	36.5	27.1	25.85	21.2	41.96	36.78	38.25	-4.00	39.10	-6.29
21	2.96	2.73	7.64	2.54	14.20	67.7	75.0	-10.9	55.7	17.73	25.8	29.0	-12.7	21.6	16.25	38.18	38.60	-1.10	39.25	-2.81
22	2.95	2.68	9.14	2.64	10.53	99.5	63.3	36.32	52.7	47.02	36.0	23.8	33.97	21.8	39.61	36.22	38.00	-4.92	41.35	-14.14
23	3.16	2.59	17.81	2.52	20.13	83.0	66.6	19.80	52.5	36.77	30.0	25.5	14.96	18.9	37.07	35.84	37.97	-5.94	36.69	-2.36
24	3.11	2.70	13.25	2.73	12.22	64.9	52.4	19.27	61.6	5.12	23.7	20.5	13.21	23.3	1.64	36.43	39.28	-7.83	38.12	-4.64
25	3.11	2.91	6.47	2.27	27.03	100.2	74.2	25.91	59.8	40.33	39.1	28.7	26.66	22.8	41.67	39.08	38.13	2.43	38.07	2.56
26	3.12	2.82	9.52	2.52	19.39	77.1	66.9	13.25	54.0	30.01	29.4	26.1	11.10	20.7	29.55	37.29	38.72	-3.82	38.41	-2.99
27	3.17	2.83	10.67	2.50	21.24	89.1	84.5	5.15	54.9	38.39	33.0	34.3	-4.09	21.3	35.49	36.45	40.51	-11.1	38.46	-5.50
28	3.27	2.95	9.76	2.47	24.55	97.3	64.2	34.03	42.3	56.58	37.2	26.3	29.33	16.0	57.05	38.20	40.89	-7.06	37.65	1.43
29	3.06	2.92	4.74	2.47	19.28	81.6	76.1	6.79	65.4	19.91	27.2	26.7	1.79	23.6	13.24	33.37	34.95	-4.72	36.15	-8.34
30	3.32	2.86	14.08	2.75	17.15	67.4	56.1	16.78	49.3	26.92	22.2	19.0	14.55	18.2	17.97	33.69	33.91	-0.67	36.02	-6.92
31	3.14	2.84	9.53	2.67	14.82	75.5	61.5	18.54	42.1	44.22	25.7	21.9	14.93	15.4	39.92	34.40	35.85	-4.23	37.07	-7.75
32	3.07	2.90	5.54	2.56	16.78	72.0	55.9	22.41	47.5	33.98	26.3	20.3	23.02	18.0	31.79	36.26	36.21	0.13	38.14	-5.18
33	3.05	2.88	5.55	2.65	13.13	60.1	55.8	7.04	62.0	-3.17	22.3	21.2	5.24	23.7	-6.21	37.12	37.92	-2.15	38.26	-3.05
34	3.04	3.01	0.86	2.70	11.19	74.3	52.6	29.23	45.7	38.53	26.4	20.4	22.97	17.5	33.87	35.48	38.43	-8.32	38.78	-9.31
35	3.17	3.04	3.85	2.47	22.12	53.9	73.9	-37.1	57.7	-7.04	19.5	27.6	-41.5	20.7	-6.12	35.81	37.34	-4.30	35.78	0.08
36	2.98	2.72	8.85	2.26	24.38	76.7	55.3	27.88	35.0	54.39	27.5	20.5	25.50	13.5	50.88	35.41	37.07	-4.70	38.87	-9.78
37	3.01	2.90	3.49	2.48	17.37	53.6	43.9	18.17	50.7	5.56	19.7	16.6	15.74	20.8	-5.61	37.06	37.03	0.07	41.50	-11.91
38	2.92	2.99	-2.40	2.54	13.03	110.9	62.0	44.13	44.6	59.81	39.7	23.9	39.89	16.9	57.48	35.66	38.12	-6.88	37.89	-6.25
39	3.13	3.22	-2.85	2.61	16.66	98.8	82.6	16.39	63.6	35.61	44.6	30.8	31.01	26.0	41.81	38.56	37.55	2.61	40.70	-5.54
40	3.13	3.06	2.46	2.36	24.58	101.8	68.3	32.92	54.2	46.76	40.1	26.3	34.44	22.7	43.36	39.40	38.68	1.83	41.84	-6.20
41	3.43	3.16	7.82	2.63	23.30	91.2	58.4	35.91	61.5	32.52	35.3	21.8	38.16	22.8	35.30	38.54	37.55	2.57	37.28	3.27
42	3.25	3.17	2.46	2.30	29.26	76.2	76.4	-0.26	72.8	4.52	26.6	27.6	-4.08	29.6	-11.5	34.76	40.24	-15.8	40.63	-16.88
43	3.07	3.11	-1.47	1.96	36.18	60.7	67.0	-10.4	57.9	4.74	21.4	25.5	-19.6	22.4	-4.70	35.17	38.02	-8.10	38.71	-10.07
44	3.07	3.11	-1.07	2.09	31.97	73.1	45.1	38.29	53.0	27.48	25.7	16.2	37.06	19.7	23.28	35.15	35.95	-2.26	37.64	-7.09
45	3.01	2.91	3.13	2.59	13.80	87.2	72.6	16.78	55.4	36.52	31.3	27.7	11.64	21.4	31.80	35.93	37.48	-4.31	38.74	-7.81
46	2.82	2.83	-0.53	1.76	37.44	104.1	50.5	51.52	45.0	56.82	38.0	19.1	49.70	18.7	50.84	36.33	37.70	-3.77	41.41	-13.97
47	2.81	3.01	-7.09	2.26	19.41	77.6	45.3	41.62	40.0	48.49	25.8	16.5	36.08	14.6	43.49	33.25	36.32	-9.23	36.58	-10.03
48	3.11	2.76	11.01	2.34	24.70	103.9	72.7	30.09	58.5	43.70	38.9	28.5	26.61	23.9	38.51	38.02	38.98	-2.53	41.16	-8.39
49	3.13	2.91	7.13	2.15	31.17	84.1	57.4	31.79	52.7	37.36	30.3	21.8	28.19	19.6	35.48	36.02	37.70	-4.66	37.28	-3.50
50	2.90	3.00	-3.49	2.56	11.56	111.7	60.5	45.79	54.3	51.35	41.2	24.3	40.94	21.7	47.25	36.64	39.79	-8.59	39.82	-8.68
M	**3.06**	**2.87**	**6.22**	**2.54**	**16.91**	**79.6**	**61.8**	**19.40**	**52.4**	**30.87**	**28.81**	**23.20**	**16.25**	**19.80**	**27.80**	**35.86**	**37.35**	**-4.23**	**37.83**	**-5.56**
LSD 5%	**0.28**					**17.28**					**6.67**					**1.44**				
LSD 1%	**0.37**					**22.73**					**8.77**					**1.89**				

BW: Boll weight, SCY: Seed cotton yield, LY: Lint yield, L%: Lint%, Mic: Micronaire value; FS: Fiber strength, FL: fiber length and UI: Uniformity ratio.
T1: Well watered treatment (control), T2: 50% water shortage treatment; T3: 75% water shortage treatment; RD%: Relative reduction. G.: Genotypes; M: Mean

For seed cotton yield per plant, under the control treatment eight genotypes showed the highest yield that surpassed 100g per plant, these genotypes were, G.19, G.50, G.38, G.46, G.48, G.1, G.40 and G.25 which yielded 131.3g, 111.7g, 110.9g, 104.1g, 103.9g, 102.1g, 101.8g and 100.2g, respectively.

While under T2 (50% water shortage), it is important to take note that none of the superior genotypes under T1 proved to be tolerant for water shortage, where eight genotypes showed the lowest differences due to water shortage stress which were, G.35, G.4, G.12, G.21, G.43, G.17, G.3 and G.42 that showed differences with negative sign of -37.1%, -19.8%, -17.3%, -10.9%, -10.4%, -4.4%, 3.4% and -0.3%, respectively. On the contrary, ten genotypes were the most sensitive to the stress of 50% water shortage, these genotypes were G.28, G.41, G.22, G.44, G.16, G.47, G.38,G.50, G.46 and G.19, these genotypes showed yield reduction more than 33% and ranged from 34.0% for G.28 to 57.6% for G.19.

Concerning T3 (75% water shortage), it was noticed that none of the superior genotypes under T1 (control treatment) tolerated 75% water shortage, ten genotypes showed the lowest differences due to water shortage stress which were, G.4, G.35, G.33, G.3, G.12, G.17, G.42, G.43, G.24, and G.37 that showed differences with negative or low value of positive sign reached -12.2%, -7.0%, -3.2%, -1.7%, 0.3%, 4.2%, 4.5%, 4.7%, 5.1% and 5.6%, respectively. On the contrary, six genotypes (G.50, G.36, G.28, G.46, G.19 and G.38) were the most sensitive to the stress of 75% water shortage, these genotypes showed yield reduction more than 50%.

For lint yield per plant, nine genotypes showed the highest yield under the control treatment that exceeded 36g/plant, these genotypes were, G.19, G.39, G.50, G.40, G.38, G.25, G.48, G.46 and G.28 which yielded 45.2g, 44.6g, 41.2g, 40.1g, 39.7g, 39.1g, 38.9g, 38.0g and 37.2g, respectively. While under T2 (50% water shortage), none of the superior genotypes under T1 was tolerant to water shortage, while nine genotypes exhibited the lowest differences under T2 i.e., G.35, G.4, G.43, G.12, G.21, G.17, G.27, G.42 and G.3 that exceeded the corresponding values in the control treatment and thus had negative signs with values of -41.5%, -29.7%, -19.6%,-19.4%, -12.7%, -8.5%, -4.1%, -4.1% and -4.0%, respectively. Contrarily, eight genotypes showed the highest sensitivity to the stress of T2, these genotypes were G.19, G.46, G.50, G.38, G.16, G.41, G.44 and G.47 and showed yield reduction more than 36% and ranged from 36.1% for G.47 to 54.1% for G.19.

With regard to T3 (75% water shortage), the superior genotypes under T1 did not tolerate 75% water shortage, while eight genotypes had higher means than their corresponding values under T1 (control) and showed differences with negative signs these genotypes were, G.4, G.42, G.33, G.35, G.37, G.43, G.3, and G.12 that had mean relative reduction of -20.1%, -11.5%, -6.2%, -6.1%, -5.6%, -4.7%, -3.4% and -0.6%, respectively. Whereas eight genotypes (G.38, G.28, G.19, G.36, G.46, G.50, G.9 and G.10) were the most sensitive to the stress of 75% water shortage, with yield reduction more than 45%.

For lint%, eight genotypes showed the highest values under the control treatment that exceeded 38%, these genotypes were G.40, G.25, G.13, G.39, G.41, G.28, G.21 and G.48 with lint% of 39.40%, 39.08%, 38.68%, 38.56%, 38.54%, 38.20%, 38.18% and 38.02%, respectively.

While under T2 it was noticed that water stress increased L% for most of the studied genotypes that caused negative values for the relative reduction percentage under T2. Ten genotypes exhibited the highest values under T2 and surpassed their corresponding values under T1 which were G.42, G.27, G.1, G.47, G.4, G.50, G.34, G.14, G.43 and G.7 with relative reduction of -15.76%, -11.13%, -10.64%, -9.23%, -8.94%, -8.59%, -8.32%, -8.27%, -8.10% and -8.10%, respectively. Contrarily, seven genotypes had the highest sensitivity to the stress of T2, these genotypes were G.39, G.41, G.25, G.40, G.13, G.32 and G.37 and showed reduced L% than T1 and ranged from 0.07% for G.37 to 2.61% for G.39.

With respect to T3, eight genotypes had higher means (>10%) than their corresponding values under T1 (control) and showed differences with negative signs these genotypes were, G.42, G.22, G.46, G.19, G.37, G.14, G.43, and G.47 that had mean relative reduction of -16.88%, -14.14%, -13.97%, -13.27%, -11.98%, -11.40%, -10.07% and -10.03%, respectively. Whereas eight genotypes (G.41, G.25, G.28, G.12, G.6, G.18, G.11 and G.35) were the most sensitive to the stress of 75% water shortage.

To sum, results confirmed the negative effects of water shortage on yield and yield components and the existence of genotypic variability for water stress tolerance in the tested materials which resulted in a shift in their ranking among water treatments for such traits. It is important to note that the superior genotypes under T1 (control) were not advantageous under the stress conditions of water shortage of T2 and T3. Seven genotypes proved to be the most tolerant genotypes for both water shortage treatments with regard to seed and lint cotton yields/plant as they exhibited lowest differences between the control treatment and both of water stress treatments, these genotypes are G.3, G.4, G.12, G.17, G.35, G.42 and G.43. These genotypes can be used as parents in hybridization in breeding program aims to produce tolerant genotypes for the stress of water deficit in cotton.

Similar genotypic differences among cotton genotypes for water stress treatments with regard to yield and its component traits were reported in upland cotton by: **Snowden *et al*., 2014; Ullah *et al*., 2019; Ergashovich *et al*., 2020; Tokel *et al*., 2022; Çelik, 2024**; **Gören and Tan, 2024** as well as in Egyptian cotton by: **El-Dahan *et al*., 2018; Yehia, 2020; Abdel-Monaem *et al*., 2022; Abo Sen *et al*., 2022; Mahdy *et al*., 2022; Yehia and El-Absy, 2023.**

The mean values and the relative reduction percentages in fiber quality traits under the water stress treatments as compared to the well watered treatment (control) are presented in **Table (5)**.

With regard to micronaire reading that refers to fiber fineness, shifting from well-watered conditions (T1) to water shortage conditions (T2 and T3) led to insignificant reduction in the fiber fineness. Ten genotypes had the lowest values (desirable direction) under T1 with micronaire reading less than 3.50µg/in which were G.50, G.18, G.49, G.32, G.5, G.48, G.46, G.47, G.16 and G.7, it is worst to state that these genotypes were the most sensitive to the stress of water shortage.

Under 50% of water shortage stress (T2), nine genotypes (G.10, G.24, G.26, G.27, G.23, G.37, G.28, G.25 and G.44) exhibited the lowest differences (0.47%, 0.64%, 0.85%, 0.88%, 2.18%, 2.26%, 3.23%, 3.76 and 4.72%, respectively) with positive sign due to the reduction in T2 than T1 (desirable direction in fiber fineness). The rest of genotypes showed undesirable negative values of relative reduction due to the increment in micronaire reading in T2 than in T1 which refers to more coarseness of fibers.

Table 5: Mean performance for 50 cotton genotypes under three water treatments and their relative reduction% for the fiber quality traits

G.	FF					FS					FL					UR%				
	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%	T1	T2	RD%	T3	RD%
1	3.51	3.68	-4.85	3.88	-10.8	10.70	10.20	4.68	10.18	4.93	35.06	33.90	3.30	33.20	5.30	86.10	85.08	1.18	84.83	1.47
2	3.51	3.74	-6.55	3.75	-6.63	10.68	10.44	2.17	9.92	7.07	34.71	34.12	1.71	33.45	3.62	85.46	84.42	1.21	84.31	1.35
3	3.54	3.87	-9.39	3.80	-7.50	10.65	10.17	4.53	10.19	4.35	35.18	34.12	3.01	32.39	7.92	85.36	84.89	0.54	84.38	1.14
4	3.63	3.69	-1.71	3.68	-1.46	10.44	10.23	2.01	10.58	-1.34	35.30	34.30	2.84	33.72	4.48	85.74	85.45	0.33	84.23	1.76
5	3.46	3.83	-10.5	3.89	-12.3	10.61	10.57	0.38	10.29	2.98	35.20	34.10	3.12	33.03	6.17	86.52	85.64	1.01	84.61	2.20
6	3.59	3.73	-3.82	3.77	-4.99	10.68	10.53	1.33	10.18	4.68	35.20	34.26	2.67	34.91	0.82	86.13	84.13	2.32	85.22	1.05
7	3.49	3.81	-9.27	3.68	-5.54	10.50	10.29	2.02	9.98	5.00	35.18	34.91	0.77	34.50	1.94	86.03	85.13	1.05	84.87	1.34
8	3.57	3.70	-3.70	3.64	-1.93	10.70	10.66	0.40	10.13	5.30	35.87	34.37	4.17	34.96	2.53	87.05	85.48	1.80	84.85	2.53
9	3.51	3.56	-1.31	3.73	-6.06	10.63	10.82	-1.81	9.99	5.96	35.15	34.47	1.93	33.75	3.98	85.85	85.11	0.86	84.04	2.10
10	3.63	3.61	0.47	3.68	-1.60	10.74	10.39	3.23	9.73	9.33	35.30	34.48	2.34	33.33	5.57	85.85	84.61	1.45	84.43	1.65
11	3.79	4.06	-7.13	4.10	-8.24	10.87	10.35	4.77	9.13	16.05	35.04	34.12	2.63	33.39	4.70	84.98	84.83	0.19	84.71	0.32
12	3.70	4.52	-22.1	4.55	-23.0	10.89	10.57	2.95	9.62	11.67	35.22	34.20	2.88	31.97	9.23	86.44	84.49	2.26	84.89	1.79
13	3.76	3.91	-4.07	4.30	-14.5	10.59	10.21	3.59	9.29	12.22	34.70	34.14	1.62	31.90	8.07	85.71	84.45	1.47	84.66	1.23
14	3.55	3.84	-8.29	4.11	-15.8	10.71	10.47	2.22	9.83	8.22	34.71	34.30	1.20	32.58	6.16	85.20	84.24	1.12	84.01	1.40
15	3.65	3.77	-3.21	3.68	-0.90	10.88	10.16	6.62	9.82	9.80	34.81	34.46	1.00	33.38	4.11	84.90	84.90	0.00	83.72	1.39
16	3.48	3.75	-7.91	3.56	-2.39	10.74	10.32	3.92	9.55	11.06	35.32	34.31	2.87	34.12	3.41	86.38	85.95	0.49	85.28	1.26
17	3.70	3.93	-6.44	3.95	-6.90	10.65	10.36	2.74	10.20	4.23	35.00	34.47	1.52	33.92	3.09	85.98	85.41	0.66	84.40	1.83
18	3.41	3.48	-1.91	3.72	-9.03	10.82	10.48	3.07	10.18	5.92	34.85	34.58	0.77	34.23	1.79	86.72	85.19	1.76	84.41	2.66
19	3.66	3.72	-1.47	3.64	0.57	10.68	10.56	1.08	9.79	8.27	35.73	34.42	3.66	34.15	4.40	86.83	85.10	1.99	84.97	2.14
20	3.58	3.72	-3.83	4.06	-13.3	10.38	9.89	4.69	10.28	0.96	34.99	34.31	1.94	33.21	5.09	86.03	83.82	2.56	84.72	1.52
21	3.68	3.76	-2.26	3.71	-1.03	10.47	10.29	1.75	9.24	11.71	35.15	34.21	2.67	33.23	5.47	86.33	84.32	2.33	84.15	2.52
22	3.68	3.85	-4.76	3.63	1.36	11.01	9.64	12.39	9.17	16.72	34.52	34.04	1.39	33.08	4.19	85.58	84.21	1.60	84.22	1.59
23	3.80	3.72	2.18	3.61	5.05	10.59	10.33	2.51	9.64	8.98	34.85	34.03	2.33	33.33	4.36	85.14	84.78	0.42	84.21	1.09
24	3.63	3.62	0.22	3.74	-3.23	10.86	10.54	2.93	10.01	7.84	35.58	34.93	1.81	34.50	3.03	86.20	84.28	2.23	84.64	1.81
25	3.78	3.63	3.76	3.67	2.86	10.95	10.65	2.71	10.22	6.69	34.82	34.25	1.63	35.02	-0.58	86.25	85.21	1.21	84.74	1.75
26	3.90	3.87	0.85	3.83	1.72	10.80	10.24	5.20	10.37	4.01	34.74	34.85	-0.58	34.57	0.49	86.55	86.16	0.45	84.18	2.73
27	3.75	3.72	0.88	3.68	1.87	10.80	10.23	5.25	10.18	5.71	35.15	34.92	0.65	34.21	2.68	85.93	85.78	0.17	84.47	1.70
28	3.88	3.75	3.23	3.89	-0.31	10.89	10.54	3.24	9.91	8.95	35.01	34.17	2.40	34.21	2.30	86.25	85.43	0.96	84.44	2.10
29	3.73	3.80	-2.01	3.64	2.23	10.55	10.42	1.23	10.18	3.55	34.83	34.48	1.01	34.27	1.61	85.55	85.25	0.36	84.09	1.70
30	3.61	3.89	-7.87	3.73	-3.33	10.73	10.52	1.94	10.37	3.34	35.50	34.18	3.71	34.26	3.50	86.30	84.43	2.17	85.43	1.00
31	3.66	3.72	-1.61	3.86	-5.47	10.63	10.33	2.82	10.04	5.49	34.88	34.51	1.06	33.87	2.90	86.78	84.41	2.73	84.56	2.55
32	3.46	3.88	-12.2	3.74	-8.25	10.63	10.50	1.22	10.19	4.08	34.75	33.81	2.69	33.80	2.73	86.08	85.03	1.21	83.83	2.60
33	3.65	3.69	-1.15	3.68	-0.77	10.96	10.50	4.17	10.45	4.70	34.90	34.59	0.88	33.13	5.07	85.25	85.23	0.02	84.16	1.28
34	3.50	3.66	-4.51	3.65	-4.14	10.81	10.81	-0.03	9.84	8.93	35.84	34.41	3.99	32.93	8.14	86.18	84.85	1.54	84.39	2.07
35	3.60	3.73	-3.47	3.73	-3.47	10.95	10.43	4.79	9.98	8.83	34.96	34.21	2.14	33.78	3.36	86.35	85.35	1.16	83.65	3.13
36	3.52	3.53	-0.37	3.46	1.65	10.45	10.41	0.35	10.28	1.60	35.77	34.09	4.67	34.59	3.28	86.65	84.67	2.29	84.14	2.89
37	3.68	3.59	2.26	3.76	-2.26	10.63	10.61	0.14	10.37	2.43	35.23	34.92	0.87	35.03	0.58	85.18	85.12	0.07	83.86	1.54
38	3.62	3.83	-5.88	3.63	-0.28	10.63	10.57	0.56	10.59	0.38	35.86	34.64	3.40	34.21	4.61	86.54	85.53	1.17	85.09	1.68
39	3.71	3.87	-4.32	4.00	-7.90	10.48	10.22	2.46	10.53	-0.55	34.62	34.15	1.36	33.58	3.02	85.88	85.71	0.19	84.17	1.98
40	3.68	4.06	-10.3	4.12	-12.1	10.60	10.34	2.47	10.08	4.95	34.46	33.67	2.30	34.06	1.18	86.08	84.58	1.75	83.85	2.59
41	3.51	4.11	-17.1	4.12	-17.4	10.69	10.14	5.17	10.39	2.77	35.12	32.40	7.75	32.11	8.57	86.04	83.58	2.86	83.71	2.71
42	3.68	3.87	-5.08	4.08	-10.7	10.53	10.28	2.41	10.27	2.51	34.90	33.76	3.27	32.98	5.50	87.01	84.97	2.34	83.98	3.48
43	3.47	3.76	-8.39	3.84	-10.7	10.45	10.55	-0.99	10.81	-3.43	35.03	35.03	0.00	34.23	2.30	86.93	85.65	1.47	84.83	2.41
44	3.71	3.53	4.72	3.53	4.94	10.70	10.40	2.83	9.88	7.64	35.19	34.66	1.50	33.95	3.53	87.23	86.02	1.39	83.31	4.50
45	3.63	3.68	-1.60	3.67	-1.16	10.62	10.30	3.01	10.36	2.44	35.23	34.21	2.89	32.58	7.51	86.70	85.08	1.86	83.87	3.26
46	3.47	3.86	-11.1	3.71	-6.71	10.91	9.89	9.37	9.85	9.72	35.21	32.48	7.74	33.57	4.65	86.63	85.18	1.67	84.22	2.78
47	3.47	3.54	-2.0	3.70	-6.45	10.96	10.27	6.30	10.54	3.83	35.17	33.51	4.71	33.10	5.87	87.16	85.18	2.28	83.08	4.68
48	3.47	4.10	-18.2	3.97	-14.3	11.00	10.02	8.91	10.72	2.61	34.53	33.09	4.15	32.42	6.11	87.17	84.43	3.15	84.00	3.64
49	3.45	3.45	-0.06	3.70	-7.31	11.17	10.21	8.60	10.43	6.58	35.04	34.38	1.87	34.57	1.34	86.15	85.65	0.58	83.94	2.56
50	3.35	3.76	-12.2	3.71	-10.7	10.99	9.94	9.62	10.18	7.44	34.70	33.36	3.84	33.39	3.76	85.73	85.23	0.58	84.08	1.92
M	**3.61**	**3.77**	**-4.71**	**3.80**	**-5.37**	**10.72**	**10.35**	**3.36**	**10.08**	**5.94**	**35.08**	**34.21**	**2.48**	**33.65**	**4.07**	**86.14**	**84.99**	**1.33**	**84.34**	**2.09**
LSD	**0.22**					**0.40**					**0.83**					**0.94**				
LSD	**0.29**					**0.53**					**1.10**					**1.24**				

BW: Boll weight, SCY: Seed cotton yield, LY: Lint yield, L%: Lint%, Mic: Micronaire value; FS: Fiber strength, FL: fiber length and UI: Uniformity ratio.
T1: Well watered treatment (control), T2: 50% water shortage treatment; T3: 75% water shortage treatment; RD%: Relative reduction. G.: Genotypes; M: Mean

Under 75% of water shortage stress (T3), nine genotypes (G.19, G.22, G.36, G.26, G.27, G.29, G.25, G.44 and G.23) exhibited the lowest differences (0.57%, 1.36%, 1.65%, 1.72%, 1.87%, 2.23%, 2.86%, 4.94% and 5.05%, respectively) with positive sign due to the reduction in T3 than T1. The rest of genotypes showed undesirable negative values of relative reduction due to the increment in micronaire reading in T3 than in T1 which refers to more coarseness of fibers.

Generally, six genotypes proved to be tolerant to the stress condition of water deficit (50% and 75% water shortage) with regard to fiber fineness as they gave finer fibers under stress conditions, these genotypes were, G.23, G.25, G.26, G.27, G.28 and G.44. These genotypes can be used in breeding program to enhance fiber fineness under water stress conditions.

Regarding fiber strength expressed as Pressely index, shifting from well-watered treatment (T1) to water shortage stress (T2 and T3) led to a significant reduction in the strength of the fibers. Nine genotypes (G.46, G.35, G.25, G.33, G.47, G.50, G.48, G.22 and G.49) had the highest values (>10.90) under the control treatment (T1) with range of 10.91 to 11.17. The rest of genotypes ranged from 10.38 for G.20 to 10.89 for G.12.

Under 50% of water shortage stress (T2), eight genotypes (G.38, G.8, G.5, G.36, G.37, G.34, G.43 and G.9) exhibited the lowest differences with differences lower than the unity, the values were 0.56%, 0.40%, 0.38%, 0.35%, 0.14%, -0.03%, -0.99% and -1.81%, respectively. The rest of genotypes showed positive values due to the reduction in Pressely index under T2 as compared to T1, the range was from 1.08% for G.19 to 12.39% for G.22.

Under 75% of water shortage stress (T3), six genotypes (G.36, G.20, G.38, G.39, G.4 and G.43) exhibited the lowest differences with differences lower than the unity, the values were 0.56%, 0.40%, 0.38%, 0.35%, 0.14%, -0.03%, -0.99% and -1.81%, respectively. The rest of genotypes showed positive values due to the reduction in Pressely index under T3 than T1, the range was from 2.39% for G.42 to 16.72% for G.22.

Generally, six genotypes proved to be tolerant to the stress condition of water deficit (50% and 75% water shortage) with regard to fiber strength expressed as Pressely index as they exhibited the lowest differences under both treatments, these genotypes are: G.36, G.20, G.38, G.39, G.4 and G.43, these genotypes can be used in breeding program to enhance fiber strength under water stress conditions.

For fiber length, it was greater under well-watered treatment (T1), but it was significantly decreased under water shortage stress (T2 and T3). Seven genotypes (G.8, G.38, G.34, G.36, G.19, G.24 and G.30) had the highest values (>35.50mm) under the control treatment (T1) with range of 35.51mm for G.30 to 35.87mm for G.8. The rest of genotypes ranged from 34.46mm for G.40.to 35.32mm for G.16.

Under 50% of water shortage stress (T2), eight genotypes (G.26, G.43, G.27, G.7, G.18, G.37, G.33 and G.15) exhibited the lowest differences (≥ 1.00%), the values were -0.58%, 0.00%, 0.65%, 0.77%, 0.77%, 0.87%, 0.88% and 1.00%, respectively. The rest of genotypes showed positive values due to the reduction in fiber length under T2 as compared to T1, the range was from 1.01% for G.29 to 7.75% for G.41.

However, out of the fifty genotypes in this study, only four genotypes had extra-long staple that exceeded the lowest level of fibers (34.90mm) for this category, these genotypes were: G.7, G.24, G.27 and G.43 with fiber length of 34.91mm, 34.93mm, 34.92mm and 35.03mm, respectively.

Under 75% of water shortage stress (T3), nine genotypes (G.25, G.26, G.37, G.6, G.40, G.49, G.29, G.18 and G.7) exhibited the lowest differences with differences lower than 2.00%, the values were -0.58%, 0.49%, 0.58%, 0.82%, 1.18%, 1.34%, 1.61%, 1.79% and 1.94%, respectively. The rest of genotypes showed positive values due to the reduction in fiber length under T3 than T1, the range was from 2.30% for G.43 to 9.23% for G.12. Out of the extra-long staple genotypes tested in this study, only two (G.8 and G.37 with fiber length of 34.96mm and 35.03mm, respectively) surpassed the lowest length of fibers (34.90mm) for this category.

It is worst to state that most of the 16 extra-long staple genotypes tested in this study failed to maintain its fiber length under the stress of water shortage except for the aforementioned four genotypes under T2 and two genotypes under T3.

The fiber uniformity ratio (UR%), generally, this trait exhibited the highest level of stability regardless of water treatment as compared to the other traits as the differences due to water deficit stress were 1.33% and 2.09% for T2 and T3 respectively.

Uniformity ratio was significantly greater under well-watered treatment (T1), but it was significantly decreased under water shortage stress (T2 and T3) which did not differ significantly. **A.S.T.M., D-1776-1998**, defined UR% more than 85% is considered as very high, accordingly, all the tested genotypes had very high length uniformity ratio except for two genotypes (G.15 and G.11) that had only high values (83% - 85%).

Ten genotypes (G.45, G.18, G.41, G.19, G.43, G.42, G.8, G.47, G.48 and G.44) had the highest values (≥86.70%) under the control treatment (T1) with range of 86.70% for G.45 to 87.23% for G.44. The rest of genotypes ranged from 85.14% for G.23to 86.65% for G.36.

Under 50% of water shortage stress (T2), all genotypes showed positive difference values due to the reduction in the uniformity ratio except for one genotype (G.15) that gave the same value under both of T1 and T2. Eleven genotypes (G.15, G.33, G.37, G.27, G.11, G.39, G.4, G.29, G.23, G.26 and G.16) exhibited the lowest differences (less than 0.50%), that ranged from 0.00% for G.15 to 0.49% for G.16. The rest of genotypes showed more reduction under T2 as compared to T1, the range was from 0.54% for G.3 to 2.73% for G.31. Twenty eight genotypes showed very high UR% values and 22 genotypes showed high values.

Under 75% of water shortage stress (T3), all genotypes showed positive difference values due to the reduction in the uniformity ratio in T3 as compared to T1, eleven genotypes (G.11, G.30, G.6, G.23, G.3, G.13, G.16, G.33, G.7, G.2 and G.15) exhibited the lowest differences with values less than 1.40%, the values were 0.32%, 1.00%, 1.05%, 1.09%, 1.14%, 1.23%, 1.26%, 1.28%, 1.34%, 1.35% and 1.39%, respectively. The rest of genotypes ranged from 1.40% for G.14 to 3.64% for G.48. Out of the tested genotypes, only four genotypes (G.38, G.6, G.16 and G.30) exhibited very high values of UR% under the stress of 75% water deficit, while the rest of genotypes showed high values.

Five genotypes proved to be tolerant to the stress of both treatments of water deficit which are G.11, G.15, G.16, G.23 and G.33 these genotypes can be used in breeding program to enhance uniformity of fibers under water stress conditions.

Similar genotypic differences among cotton genotypes for water stress treatments with regard to fiber quality traits were found in cotton by: **Wang *et al*., 2016; Shareef *et al.* 2018; Iqbal *et al*., 2019; Abo Sen *et al*., 2022; Ali *et al*., 2022; Mahdy *et al*., 2022; Çelik, 2023; Gören and Tan, 2024.**

To sum, results confirmed the negative effects of water shortage on fiber quality traits measured in this study and the existence of genotypic variability for water stress tolerance in the tested materials which resulted in a shift in their ranking among water treatments for such traits.

It is important to note that the superior genotypes under T1 (control) were not advantageous under the stress conditions of water shortage of T2 and T3 for fiber traits. The tolerant genotypes for the stress of water shortage varied among fiber quality traits as none of the tested genotypes exhibited tolerance for water stress with respect of all fiber traits. Moreover, genotypes that showed water stress tolerance for productivity traits were not tolerant for fiber traits except two genotypes (G.4 and G.43) that were also tolerant for fiber strength.

Consequently, selection for tolerance to water shortage stress must be done under the stress conditions for yield and its components, while tolerant genotypes must be selected for each of fiber quality traits separately.

The GGE biplot analysis:

Phenotypic mean performance of fifty cotton genotypes across three water treatments (environments) combined over two growing seasons for seed cotton yield/plant is presented in **Table 6**.

The maximum seed cotton yield/plant (79.58g) was obtained under T1 followed by T2 that yielded 61.97g then T3 that ranked last and yielded 52.48g. While genotypes varied under T1 from 47.07g for G.4 to 131.28g for G.19 and from 43.89g for G.37 to 84.48g for G.27 under T2 as well as from 34.97g for G.36 to 72.76g for G.42 under T3. Overall mean for genotypes ranged from 49.10g for G.15 to 81.66g for G.39. Out of the fifty cotton genotypes 23 genotypes surpassed the overall mean and 27 genotypes had lower yield.

Genotype main effects and genotype by environment interactions (GGE biplot) analysis has been used by plant breeders to define high yielding and stable genotypes. The GGE biplot graphically evaluates both effects of genotypes and genotype by environment interactions which are more important to select the high yielding and stable genotypes **(Yan and Kang, 2003; Yang *et al*., 2009).**

Table 6: Mean performance of the fifty cotton genotypes across three water treatments (environments) over two growing seasons for seed cotton yield/ plant (g).

Gen.	T1	T2	T3	Mean	Gen.	T1	T2	T3	Mean
1	102.13	83.43	56.83	**80.80**	**26**	77.11	66.89	53.97	**65.99**
2	69.26	56.42	47.29	**57.66**	**27**	89.07	84.48	54.88	**76.14**
3	63.19	65.33	64.28	**64.26**	**28**	97.33	64.21	42.26	**67.94**
4	47.07	56.39	52.83	**52.10**	**29**	81.61	76.07	65.36	**74.34**
5	83.45	68.07	63.72	**71.75**	**30**	67.40	56.10	49.26	**57.58**
6	65.26	50.93	51.41	**55.87**	**31**	75.54	61.53	42.13	**59.73**
7	61.59	51.19	46.03	**52.93**	**32**	71.99	55.86	47.53	**58.46**
8	73.68	53.25	46.41	**57.78**	**33**	60.08	55.85	61.98	**59.30**
9	81.92	58.80	41.76	**60.83**	**34**	74.33	52.60	45.70	**57.54**
10	82.56	60.60	42.75	**61.97**	**35**	53.88	73.85	57.68	**61.80**
11	80.73	74.07	48.74	**67.85**	**36**	76.66	55.28	34.97	**55.63**
12	49.31	57.83	49.18	**52.11**	**37**	53.64	43.89	50.65	**49.39**
13	73.97	56.31	55.75	**62.01**	**38**	110.91	61.97	44.57	**72.48**
14	73.57	60.09	56.60	**63.42**	**39**	98.78	82.59	63.61	**81.66**
15	56.63	48.12	42.54	**49.10**	**40**	101.76	68.26	54.18	**74.73**
16	80.13	49.03	47.17	**58.78**	**41**	91.16	58.43	61.51	**70.37**
17	64.48	67.30	61.80	**64.52**	**42**	76.21	76.40	72.76	**75.12**
18	64.62	58.03	39.07	**53.90**	**43**	60.74	67.04	57.86	**61.88**
19	131.28	55.69	52.79	**79.92**	**44**	73.08	45.09	52.99	**57.05**
20	99.00	70.72	55.38	**75.03**	**45**	87.22	72.59	55.37	**71.73**
21	67.65	75.02	55.66	**66.11**	**46**	104.11	50.47	44.95	**66.51**
22	99.47	63.34	52.70	**71.84**	**47**	77.65	45.33	39.99	**54.32**
23	83.01	66.58	52.49	**67.36**	**48**	103.94	72.67	58.52	**78.37**
24	64.93	52.42	61.61	**59.65**	**49**	84.09	57.36	52.67	**64.70**
25	100.15	74.20	59.76	**78.04**	**50**	111.65	60.53	54.32	**75.50**
Mean						**79.58**	**61.97**	**52.48**	**64.68**
LSD $_{0.05}$						**18.20**	**19.25**	**29.47**	**9.97**
LSD $_{0.01}$						**13.80**	**14.60**	**22.34**	**13.12**

Gen.:Genotype, T1: Well waterd treatment (Control), T2: 50% water shortage treatment and T3: 75% water shortage treatment.

Environment is evaluated to discriminate between genotypes and to represent the target region by using the desirability index which is the distance from ideal location **(Yan, 2001; Yan and Hunt, 2003)**. This study investigates the stability of fifty cotton genotypes to define the most stable genotypes across three different environments (water treatment) using GGE biplot method.

Genotypes mean performance and stability:

The results of GGE-biplot analysis manifested that PC1 and PC2 explained 69.73% and 23.16%, respectively of GGE sum of squares representing total of

92.89% variance for seed cotton yield/ plant.

According to **Yan (2001); Yan and Hunt (2003)** the performance and stability for genotypes were assessed by an average environment coordinate (AEC) view of the GGE biplot, it is also known as (Mean vs. Stability) view as it eases genotypes comparison for their mean performance and stability across various environments. In this technique, the average environment is appointed by the average of PC1 and PC2 values, symbolized by a small circle as shown in **Figure 2**.

Genotypes rating based on mean seed cotton yield and stability in three environments was done through the double-dimensional graph of average environments coordinates (AEC). The first line with an arrow that pass through small circle (environments mean) and the origin point is used to estimate genotype performance. Genotypes locate to the right of the axis have higher yield. While, the second line that is perpendicular to the first line is used to assess genotype stability. Genotypes locate close to this axis are more stable. According to **Yan and Kang (2003)** the desirable genotype must has high yielding together with high stability.

Therefore, from **Figure (2)** it is obvious that ten genotypes (G.39, G.27, G.45, G.11, G.5, G.23, G.26, G.1, G.41 and G.25) exhibited the highest seed cotton yield above the overall mean and also had the highest stability. These genotypes could be exploited as parents in hybridization in cotton breeding program to obtain high yielding genotypes with high stability for water shortage stresses.

On the other hand, twelve genotypes (G.19, G.48, G.50, G.42, G.20, G.40, G.29, G.38, G.22, G.28, G.46 and G.21) had high yield performance that surpassed the overall mean with low stability.

To the left side of the axis where the genotypes with lower yield performance than overall mean, nine genotypes (G.4, G.2, G.3, G.8, G.18, G.6, G.7, G.30 and G.44) exhibited low yield performance and high stability. The rest of genotypes (19 genotypes) showed low yield performance with low stability for water treatments.

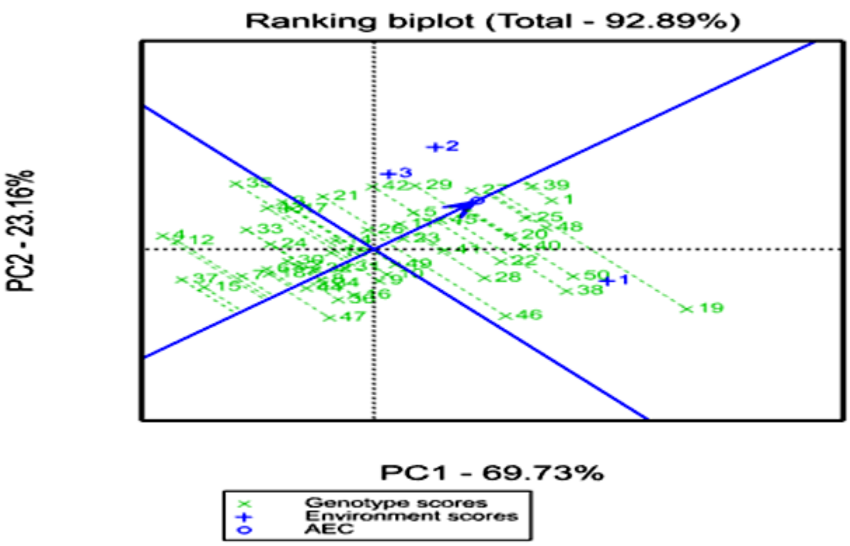

Figure 2: Simultaneous evaluation of seed cotton yield and stability of the fifty cotton genotypes in the three environments by GGE biplot method.

Ranking genotypes and environments based on the ideal ones:

GGE biplot rating genotypes and environments based on both ideal genotype and ideal environment is given in **figures 3 and 4**, respectively for seed cotton yield.

Plant breeders have to differentiate the ideal genotype depending on the mean performance together with stability. The ideal (most desired) genotype possess high mean performance with high stability and placed on the first central circle of the biplot while genotypes that were placed near the ideal genotype (using ideal genotype as a center) known as the desired genotypes (**Yan and Kang, 2003; Yan and Tinker 2006**).

Accordingly, **figure 3** cleared that five genotypes (G.39, G.1, G.25, G.27 and G.48) which located on the first central circle of the biplot were considered as ideal genotypes attained the highest mean yield and high stability under the tested water treatments, while the genotypes G.20, G.29, G.45, G.40 and G.5 were placed near the centric circle, owing high yield and stability but they are lower than the ideal genotypes and were rated as desirable genotypes followed by nine genotypes (G.42, G.22, G.42, G.41, G.11, G.23, G.50, G.26 and G.28) with lower yield and stability than the ideal and the desired genotypes but they still locates in the drawn circles by the GGE biplot analysis and could be rated with the desired genotypes.

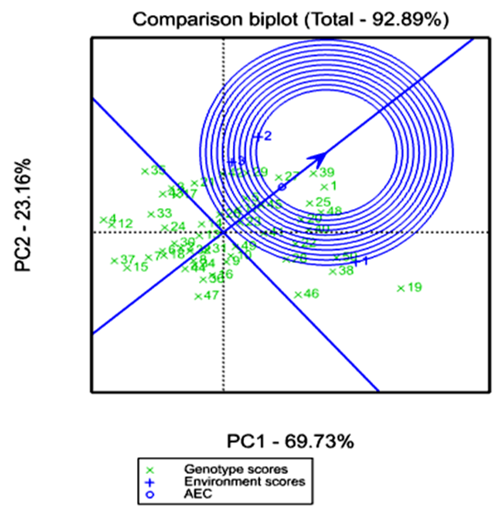

Figure 3: The GGE biplot for comparison the 50 cotton genotypes with the ideal genotypes

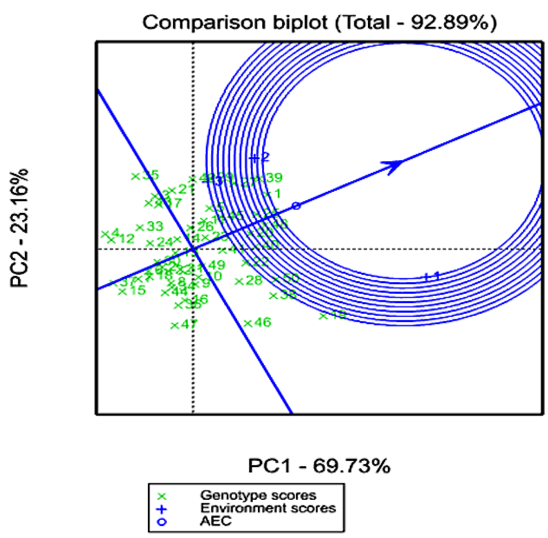

Figure 4: The GGE biplot for comparison the environments based on the ideal environment

The rest of genotypes (31 genotypes) were classified as undesirable genotypes by the GGE biplot. These far away genotypes from the ideal ones can be discarded in early cycles of breeding while the closer genotypes can be used in further tests (**Yan *et al* 2007**). Therefore, cotton breeder can use the ideal genotypes as a criterion for selection among the rest of desirable genotypes (**Ali *et al.*, 2017; Baker, 2017; Ullah *et al.*, 2022**).

Further, the ideal environment placed in the first centric circle in the biplot, and the environments placed near the ideal environment were considered as the desirable environments (**Yan and Kang, 2003**). Therefore, in this study, E1 is considered as the ideal environment followed by E2 as the desirable environment as presented in **figure 4**, while E3 was rated as inappropriate environment. **Ali *et al.* (2017)** concluded that the ideal environment possess the highest ability for discriminating the tested genotypes.

Our finding agreed with those reported by: **Sezener *et al.*, 2015; Said, 2016; Baker, 2017; Shaker *et al.*, 2019; Abdelmoghny *et al.*, 2020 and Ullah *et al.*, 2022** who used the GGE biplot technique in cotton and defined some ideal genotypes with high cotton yielding and phenotypic stability and can be grown across all the tested environments.

CONCLUSION

This study aimed to investigate water shortage effects on fifty cotton genotypes and to select drought tolerant genotypes, the studied water treatments were well watered as control, 50% water shortage and 75% water shortage. The results indicated significant variability among genotypes, water treatments and the interactions of G x T. Genotypes varied under each of water treatments and over all treatments due to their different genetic potential. Water shortage treatments caused significant reduction than the control treatment for all traits (except L% and Micronaire reading), the reduction increased as water shortage increase. The significant G x T interactions indicated the potential for selecting some drought tolerant genotypes among the tested materials for all the studied traits. Seven genotypes proved to be the most tolerant genotypes for water shortage treatments for seed and lint cotton yields and can be used as parents in hybridization in breeding program. Whereas, none of the tested genotypes exhibited tolerance for all fiber traits and selection must done for each trait separately. Selection for tolerance to water shortage stress must be done under the stress conditions.

Using the GGE biplot analysis for the seed cotton yield/plant, we were able to define five genotypes (G.39, G.1, G.25, G.27 and G.48) as ideal genotypes with the highest mean yield and high stability under the tested water treatments, followed by the genotypes G.20, G.29, G.45, G.40 and G.5 which were rated as desirable genotypes. The well-watered treatment (E1) was considered as the ideal treatment followed by 50% water shortage (E2) as the desirable treatment.

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