Journal of Wildlife and Biodiversity
Online ISSN: 2588-3526

Volume 9(2): 388-408 (2025) (http://www.wildlife-biodiversity.com/

Research Article

Multifactorial ANOVA analysis of genotype and environment effects on morphological and agronomic traits in *G. barbadense* L. cotton

Jaloliddin Shavkiev[1], Abdulahat Azimov[1], Shukhrat Khamdullayev[1], Asomiddin Ahmedjanov[1], Eshmurod Karimov[1], Urazbek Mamarasulov[1], Xushnud Nurmetov[2]

[1]Institute of Genetics and Experimental Biology, Academy of Sciences of Uzbekistan, Tashkent Region, Kibray district, Yukori-Yuz, Uzbekistan
[2]Chirchik State Pedagogical University, Tashkent Region, Chirchik city, Amir Temur 111700, Uzbekistan
Received: 19 January 2025 / Revised: 12 May 2025 / Accepted: 11 May 2025/ Published online: 19 May 2025.
How to cite: Shavkiev, J., et al. (2025). Multifactorial ANOVA analysis of genotype and environment effects on morphological and agronomic traits in G. barbadense L. cotton, Journal of Wildlife and Biodiversity, 9(2), 388-408. DOI: https://doi.org/10.5281/zenodo.15521377

Abstract

This study investigates the influence of genotype and environmental stress (optimal, drought, and salinity conditions) on morphological and agronomic traits in ten fine-fiber cotton genotypes using multifactorial ANOVA. Traits such as plant height, number of fruiting branches, number of opened bolls, total boll number, boll weight, vegetative period, and overall yield were analyzed. Results showed that genotype had no statistically significant effect on most traits ($P > 0.05$), whereas environmental factors significantly impacted all studied parameters ($P < 0.0001$ in most cases). Genotypes such as *T-2024*, *Duru-gavhar-4 (T-5560)*, *Angor (T-1981)*, and *T-2090* demonstrated relative stability and adaptability to stress conditions and may be considered valuable in breeding programs for stress-tolerant cotton cultivars.
Keywords: *G. barbadense* L., multifactorial ANOVA, stress, drought, salt, yield attributes, selection.

Introduction

Gossypium barbadense is a fine and high-quality fiber cotton species, also known as "Egyptian cotton" or "Pima cotton." It is primarily cultivated in the southern regions of the United States, Egypt, Peru, and Uzbekistan. *G. barbadense* L. produces long, fine, and strong fibers used in the production of premium-grade textiles (Amanov et al., 2020; Shavkiev et al., 2022; Chorshanbaev et al., 2023a). In terms of fiber yield, *G. barbadense* L. often outperforms *G. hirsutum* L. Some of its genotypes are also relatively resistant to salinity and insect pests. When crossed with G. hirsutum L and G. barbadense L. serves as an important genetic source for developing high-quality and stable cotton cultivars (Chorshanbiev et al., 2023b; Azimov et al., 2024a; Samanov et al., 2024). Pima cotton (*Gossypium barbadense* L.) is considered a valuable cotton species due to its high-quality, long, and durable fibers, and is primarily grown for the production of luxury textile products (Nabiev et al., 2020). In recent years, due to climate change, declining water resources, and increasing soil salinity, identifying stress-tolerant varieties of this species and incorporating them into breeding programs has become increasingly relevant.

Under salinity stress, the accumulation of sodium and chloride ions in the soil disrupts nutrient uptake in plants, which in turn hinders growth and reduces yield. Water deficiency causes physiological stress that significantly impairs photosynthesis, shortens the vegetative period, and reduces boll formation (Shavkiev et al., 2019a; Nabiev et al., 2020; Shavkiev et al., 2021b). Therefore, identifying Pima cotton genotypes with resistance to salinity and drought is crucial for developing climate-resilient varieties in the future. Such varieties are especially important for semi-arid, irrigated agricultural regions like Uzbekistan, where efficient water use and reclamation of saline soils are critical. Thus, studying the genotypic responses of Pima cotton under stress conditions remains a key direction in cotton breeding programs. Cotton is a globally important fiber crop that is increasingly exposed to abiotic stresses such as drought and soil salinity, which significantly reduce productivity. Studies show that plant response to environmental stress is strongly influenced by both genotype and environmental conditions, often resulting in genotype-by-environment interactions that affect agronomic traits (Tuberosa, 2012; Farooq et al., 2017; Shavkiev et al., 2023; Azimov et al., 2024b). Multifactorial ANOVA is a useful statistical method to dissect the effects of genotype, environment, and their interactions on trait variation (Akinwale et al., 2014).

Previous research highlights that while genotypic differences can be subtle, environmental stress such as drought often causes significant reductions in plant height, fruiting branch number, and boll retention (Shavkiev et al., 2019b; Sarwar et al., 2020; Khamdullaev et al., 2021). Moreover, salinity stress tends to delay vegetative growth and boll maturation (Ashraf & Foolad, 2007). Identifying genotypes with consistent performance across stress environments is essential for breeding stress-tolerant cotton varieties. Genotypes such as *Gossypium hirsutum* and its hybrids have been reported to show varying degrees of tolerance to salinity and drought, with traits such as boll weight and yield per plant serving as key indicators of stress adaptation (Patil et al., 2011). Some studies suggest that early maturing genotypes may escape the worst of environmental stresses, while others emphasize the role of root architecture and osmotic adjustment mechanisms in drought tolerance (Zhang et al., 2016; Makamov et al., 2023). Understanding genotype × environment (G×E) interactions is fundamental in crop improvement, especially under stress conditions. Cotton (Gossypium spp.) is a highly plastic crop, meaning its phenotypic expression—such as plant height, yield, and boll development—can vary widely depending on the genotype and environmental conditions (Tuberosa, 2012; Shavkiev et al., 2021). These interactions complicate breeding decisions but also offer opportunities to identify stable genotypes across environments.

G×E interaction analysis, particularly through multifactorial ANOVA, has become a powerful tool for breeders to dissect complex traits. For example, Akinwale et al. (2014) emphasized that while genotypic differences may be subtle, their interaction with environment can significantly affect phenotypic outcomes. This statistical approach allows breeders to quantify the relative contribution of genotype, environment, and their interaction on observed traits. Drought is one of the most significant abiotic stresses in cotton-growing regions, especially in arid and semi-arid zones such as Central Asia. Drought stress often leads to reduced plant height, fewer fruiting branches, and diminished boll retention, as reported by Farooq et al. (2017). The physiological basis of drought tolerance includes maintenance of turgor pressure, deeper rooting systems, and efficient stomatal control. Genotypes that maintain higher productivity under limited water availability are considered drought-tolerant. For example, Sarwar et al. (2020) observed that certain cotton genotypes showed stable boll weight and yield under drought due to better osmotic adjustment and delayed senescence. These traits are critical in selecting parent materials for stress-resilient breeding programs.

Soil salinization is a growing issue due to improper irrigation practices, especially in irrigated agriculture systems like those in Uzbekistan. Salinity affects cotton plants by inducing ionic and osmotic stress, which disrupts cellular metabolism and hinders growth (Ashraf & Foolad, 2007; Azimov et al., 2024c). Cotton, although moderately tolerant to salinity, shows genotype-specific variability in salt tolerance. Studies by Zhang et al. (2016) and Patil et al. (2011) report that traits such as root biomass, leaf area index, and chlorophyll retention can be reliable indicators of salinity tolerance. Salinity generally prolongs the vegetative phase and delays reproductive maturity—consistent with findings in your study. Stability across environments is a key selection criterion for modern breeding. A genotype that performs consistently under both stress and optimal conditions is more valuable than one that excels only under controlled environments. According to Kang (1993), yield stability indices and regression analysis are commonly used alongside ANOVA to select elite lines. In recent studies, genotypes like *Duru-gavhar-4* and *T-2024* showed tolerance to saline and drought conditions without significant reductions in boll weight or overall yield. This is in line with findings by Ali et al. (2021), who identified that even under extreme environmental conditions, certain cotton genotypes retained over 80% of their productivity.

Morphological traits such as plant height, number of fruiting branches, and vegetative period are not only indicators of growth but also play a predictive role in yield under stress conditions. As shown in studies by Kumar et al. (2018), shorter vegetative periods may allow genotypes to escape late-season drought, while taller plants may offer better canopy cover and light interception.

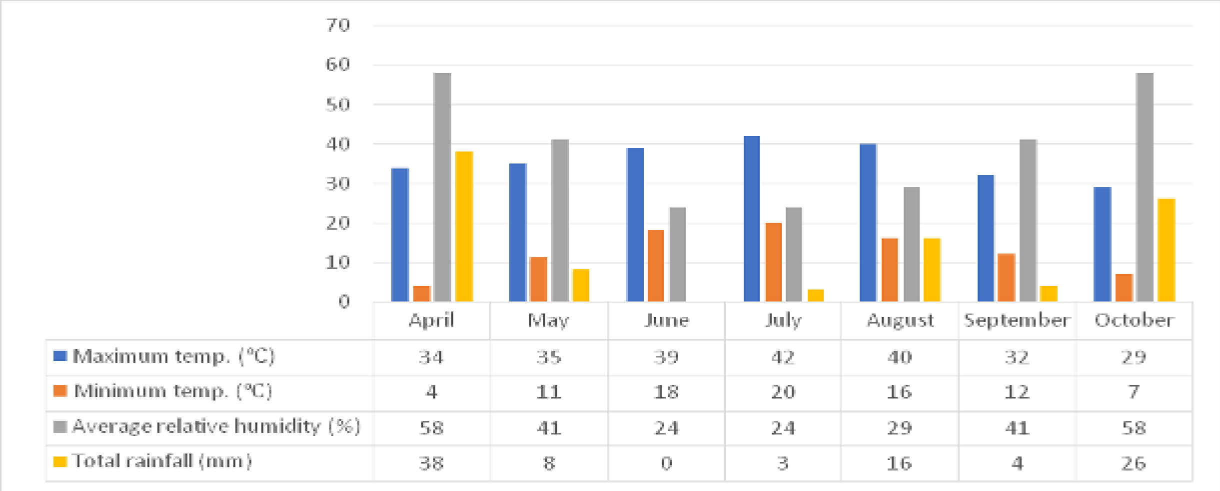
In your study, traits like boll number, boll weight, and overall yield were affected by environmental stress, supporting the hypothesis that selection under stress conditions must be trait-specific and environment-targeted. This study aligns with existing literature by confirming the dominant effect of environmental factors on trait expression and further identifies several promising genotypes (*T-2024*, *T-2090*, *Duru-gavhar-4*) that exhibit resilience under water deficit and salt stress, making them valuable for cotton improvement programs in arid regions.

Materials and methods

Plant material and growing conditions

The study was conducted during the crop season 2023-2024 in the Tashkent region of Uzbekistan (41.389°N, 69.465°E), characterized by cold winters and prolonged hot and dry summers, with an annual photoperiod of 16 hours of light and eight hours of darkness. The research focused on evaluating the genetic potential and drought tolerance of ten Pima cotton (*G. barbadense* L.) genotypes originating from Uzbekistan. The genotypes used in the present study include Angor (T-1981), T-479, T-2025, T-2024, T-5570, T-481, T-563, Bo‘ston (T-663), Duru-gavhar-4 (T-5560) and T-2090

The experiment was conducted using a randomized complete block design (RCBD) with a factorial arrangement and three replications under both optimal (normal and salt) and deficit irrigation (water deficit) conditions. Cotton plants were grown in furrows 20 meters long, with a plant spacing of 20 cm and a row spacing of 90 cm. Optimal irrigation-maintained soil moisture at 70–72%, while deficit irrigation was maintained at 54–55%, as measured using a moisture tester. The full (optimal) and deficit irrigation treatments were separated by a designated distance. Figure 1 presents details on maximum and minimum temperatures, air humidity, and total rainfall recorded during the study period.



https://pogoda1.ru/tashkent(Maximum temp. (°C), Minimum temp. (°C), Average relative humidity (%))

https://en.tutiempo.net/ (Total rainfall (mm))

Figure 1. Maximum and minimum temperatures, air humidity, and the total rainfall during the upland cotton study period.

The irrigation schedule followed a 1-2-1 sequence, meaning one application before flowering, two during the flowering phase, and one before boll opening. Specifically, 900 m³/ha of water was applied before flowering, two applications of 1200 m³/ha each were provided during the flowering phase, and 900 m³/ha was applied before the boll-opening stage. Additionally, an irrigation technique was developed in response to Water deficit. This method follows a 1-1-0 sequence, in which 2100 (900+1200) m³/ha of water is applied once during flowering (Shavkiev *et al.*, 2022). This adjustment offers a water-efficient solution for cotton cultivation under limited water availability.

Result

Plant Height in Pima Cotton Genotypes

Under optimal water supply conditions, the plant height reaches its highest value in the "Bo‘ston (T-663)" genotype (88.33±1.82 cm), which indicates the genotype's good growth potential in these conditions. The shortest height is observed in the "T-2025" genotype (73.83±3.61 cm), but the high standard deviation (SD = 6.25) suggests variability.

Table 1. Plant height (cm) in Pima cotton genotypes

Genotypes	Optimal Condition		Water Deficit Condition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	77,04±3,27	5,67	61,92±2,69	4,65	55,25±0,58	1,00
T-479	76,33±1,52	2,63	58,13±3,25	5,63	47,25±0,87	1,50

T-2025	73,83±3,61	6,25	57,92±1,67	2,89	53,83±2,30	3,99
T-2024	77,58±1,86	3,21	55,58±3,48	6,03	61,00±0,58	1,00
T-5570	85,42±2,73	4,73	53,25±1,53	2,65	47,00±1,53	2,65
T-481	78,67±1,72	2,98	53,13±3,97	6,88	56,60±0,20	0,35
T-563	76,88±1,80	3,13	48,42±3,26	5,65	48,96±1,56	2,71
Bo‘ston (T-663)	88,33±1,82	3,15	53,75±2,17	3,75	45,54±1,27	2,21
Duru-gavhar-4 (T-5560)	78,75±1,44	2,50	51,83±4,65	8,05	47,46±0,70	1,21
T-2090	78,67±2,51	4,35	56,33±3,11	5,39	49,50±0,29	0,50

Note: *X – mean value, SE – standard error, SD – standard deviation*

In conditions of Water deficit, plant height significantly decreases. The highest value is observed in the "Angor (T-1981)" genotype (61.92±2.69 cm), while the lowest is recorded in the "T-563" genotype (48.42±3.26 cm). The "Duru-gavhar-4 (T-5560)" genotype stands out with a high standard deviation (SD = 8.05), indicating variability in its adaptability to Water deficit. Overall, Water Deficitreduced plant height by an average of 13-28 cm. Under salinity conditions, the highest plant height is observed in the "T-2024" genotype (61.00±0.58 cm), while the lowest is recorded in the "Bo‘ston (T-663)" genotype (45.54±1.27 cm). The "T-2025" genotype (SD = 3.99) demonstrates variability in its adaptation to salinity. Salinity reduced plant height by an average of 20-30 cm compared to the optimal condition, although the "T-2024" genotype showed relatively better results under these conditions.

Table 2. Multi-Factor ANOVA analysis of the effect of genotype and environment (optimal, Water deficit, and salinity conditions) on the number of plant height trait

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	120,36	9	13,37	0,58	0,7993
Environment	4584,44	2	2292,22	98,80	0,0001
Genotypes × Environment	417,62	18	23,20		
Total	5122,43	29			

Analysis of the Effect of Environment on Plant Height in the Studied Genotypes

To determine the effect of the environment on plant height in the studied genotypes, a multi-factor ANOVA was conducted considering genotype and environment factors (optimal, Water deficit, and salinity conditions). According to the results, the differences in plant height between genotypes were statistically insignificant (P-Value = 0.79 > 0.05). The F-Ratio value (0.58) is also low, indicating that the genotypes did not show significant differences in plant height. This suggests that the genotypes studied in the experiment (e.g., "Angor (T-1981)", "T-479", "Bo‘ston (T-663)", and others) shared similar characteristics in terms of plant height.

The effect of the environment was statistically highly significant (P-Value = 0.0001 < 0.05). The F-Ratio value (98.80) confirms the strong impact of the environmental factor on plant height. This indicates that there were significant differences in plant height under optimal conditions, Water deficit, and salinity conditions. For example, the "Bo‘ston" genotype had a height of 88.33 cm under optimal conditions, but this decreased to 45.54 cm under salinity conditions, illustrating the strong effect of the environment. The interaction between genotype and environment, as shown by the SS (417.62) and MS (23.20) values, indicates that genotypes responded differently to various environmental conditions. For example, the "T-2024" genotype had a height of 61.00 cm under salinity conditions, showing better results than other genotypes, which confirms the existence of an interaction effect.

Number of Fruit Branches in Pima Cotton Genotypes

Under optimal conditions, the highest number of fruit branches was observed in the "T-479" genotype (9.75±0.87), while the lowest was recorded in the "Duru-gavhar-4 (T-5560)" genotype (6.00±0.52). The "Angor (T-1981)" (SD = 2.13) and "T-5570" (SD = 2.08) genotypes exhibited high variability, indicating that their number of fruit branches was not stable. In most genotypes, the number of fruit branches ranged from 7 to 9, confirming a good yield potential under optimal conditions. In conditions of Water deficit, the number of fruit branches significantly decreases. The highest value was observed in the "T-2024" genotype (6.33±0.74), while the lowest was recorded in the "T-481" genotype (3.88±0.36). The "Duru-gavhar-4 (T-5560)" genotype (6.08±0.82) showed good adaptation to Water deficit, as its value did not differ significantly from the optimal condition. Overall, Water deficit reduced the number of fruit branches by an average of 2-4.

Table 3. Number of Fruit Branches (pieces) in *Pima Cotton* Genotypes

Genotypes	Optimal Condition		Water Deficit Condition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	9,63±1,23	2,13	5,25±0,80	1,39	4,35±0,09	0,15
T-479	9,75±0,87	1,50	6,00±0,29	0,50	3,50±0,29	0,50
T-2025	9,00±1,18	2,05	5,92±0,65	1,13	4,38±0,51	0,88
T-2024	6,83±0,46	0,80	6,33±0,74	1,28	5,35±0,06	0,10
T-5570	8,92±1,20	2,08	4,55±0,17	0,30	4,38±0,36	0,63
T-481	7,50±1,00	1,01	3,88±0,36	0,63	5,25±0,29	0,50
T-563	8,13±0,79	1,38	4,25±0,14	0,25	5,54±0,46	0,79
Bo‘ston (T-663)	7,92±1,08	1,88	5,25±0,87	1,50	5,04±0,17	0,29
Duru-gavhar-4 (T-5560)	6,00±0,52	0,90	6,08±0,82	1,42	4,55±0,14	0,25
T-2090	7,13±0,79	1,38	5,83±0,44	0,76	4,79±0,31	0,54

Note: *X – mean value, SE – standard error, SD – standard deviation*

Under salinity conditions, the highest number of fruit branches was observed in the "T-563" genotype (5.54±0.46), while the lowest was recorded in the "T-479" genotype (3.50±0.29). The "T-2025" genotype (SD = 0.88) showed high variability, indicating low stability in its adaptation to salinity. The number of fruit branches decreased by an average of 2-5 compared to optimal conditions, but the "T-563" and "T-2024" genotypes showed relatively better results. According to the multi-factor ANOVA analysis for the number of fruit branches, the differences between genotypes were statistically insignificant (P-value = 0.9719 > 0.05). The F-Ratio value (0.28) is very low, indicating that the genotypes did not show significant differences in the number of fruit branches.

Table 4. Multi-Factor ANOVA analysis of the effect of genotype and environment (optimal, Water deficit, and salinity conditions) on the number of fruit branches trait

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	2,91	9	0,32	0,28	0,9719
Environment	64,25	2	32,12	27,77	0,0001
Genotypes × Environment	20,82	18	1,15		
Total	87,99	29			

The effect of the environment was statistically highly significant (P-Value = 0.0001 < 0.05). The F-Ratio value (27.77) showed that the environmental factor had a significant impact on the number of fruit branches. This indicates that there were considerable differences in the number of fruit branches under optimal, Water deficit, and salinity conditions. For example, the "T-479" genotype had 9.75 fruit branches under optimal conditions, but this decreased to 3.50 under salinity conditions, illustrating the high effect of the environment.

Number of Open Bolls in Pima Cotton Genotypes

Under optimal conditions, the highest value for the trait was observed in the "T-2025" genotype (11.67±1.30), while the lowest was recorded in the "Duru-gavhar-4 (T-5560)" and "T-2090" genotypes (8.50±1.04 and 8.50±0.76, respectively). The number of open bolls under optimal conditions ranged from 8.50 to 11.67, with most genotypes falling between 9 and 10. Under Water deficit conditions, the highest value was observed in the "T-2090" genotype (7.67±0.60), showing relatively better performance compared to other genotypes under Water deficit. The lowest value was recorded in the "Angor (T-1981)" genotype (5.08±0.71). Overall, Water deficit reduced the number of open bolls by an average of 2–4 (ranging from 5.08 to 7.67). The "T-479," "T-2025," and "T-2090" genotypes showed relatively better tolerance.

Table 5. Number of Open Bolls (pieces) in Pima Cotton Genotypes

Genotypes	Optimal Condition	Water Deficit Condition	Salinity Condition

	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	9,33±0,33	0,58	5,08±0,71	1,23	4,33±0,17	0,29
T-479	10,92±1,54	2,67	7,17±0,44	0,76	4,90±0,21	0,36
T-2025	11,67±1,30	2,25	7,00±0,76	1,32	4,75±0,38	0,66
T-2024	9,83±0,93	1,61	7,00±1,04	1,80	6,08±0,55	0,95
T-5570	10,83±1,67	2,89	6,42±1,04	1,81	4,33±0,60	1,04
T-481	9,75±1,01	1,75	6,17±0,83	1,44	5,50±0,50	0,87
T-563	9,38±1,35	2,34	6,25±1,14	0,25	5,75±0,80	1,39
Bo‘ston (T-663)	9,17±0,73	1,26	6,50±1,26	2,18	5,08±0,71	1,23
Duru-gavhar-4 (T-5560)	8,50±1,04	1,80	6,83±0,83	1,44	5,33±0,33	0,58
T-2090	8,50±0,76	1,32	7,67±0,60	1,04	5,29±0,61	1,06

Note: *X – mean value, SE – standard error, SD – standard deviation*

Under salinity conditions, the highest number of open bolls was observed in the "T-2024" genotype (6.08±0.55), while relatively lower results were recorded in the "Angor (T-1981)" and "T-5570" genotypes. The number of open bolls decreased by 4–7 compared to optimal conditions (ranging from 4.33 to 6.08). The "T-2024" and "T-563" genotypes showed relatively stable results. It was found that the genotypes studied, such as "Angor," "T-479," "T-2025," and others, exhibited genetically similar characteristics in terms of the number of open bolls. While the number of open bolls under optimal conditions ranged from 8.50 to 11.67, multi-factor ANOVA analysis showed that these differences were not due to genotype, but to other factors. The effect of the environment was statistically highly significant (P-Value = 0.0001 < 0.05). The F-Ratio value (85.86) confirmed the strong impact of the environmental factor on the number of open bolls. This indicates that significant differences in the number of open bolls occurred under optimal, Water deficit, and salinity conditions. For example, the "T-2025" genotype opened 11.67±1.30 bolls under optimal conditions, but this decreased to 7.00±0.76 under Water Deficitand 4.75±0.38 under salinity conditions. The environmental effect was identified as the main cause of this decline. The SS (11.85) and MS (0.65) values for the interaction between genotypes and environment indicated that genotypes responded differently to various environments. Specifically, the "T-2024" genotype opened 6.08±0.55 bolls under salinity conditions, showing better results compared to other genotypes (e.g., "Angor (T-1981)" – 4.33±0.17). Additionally, "T-2090" led under Water Deficitwith 7.67±0.60 bolls.

Table 6. Multi-Factor ANOVA analysis of the effect of genotype and environment (optimal, Water deficit, and salinity conditions) on the number of open bolls trait

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	5,59	9	0,62	0,94	0,5128
Environment	113,13	2	56,56	85,86	0,0001
Genotypes × Environment	11,85	18	0,65		
Total	130,59	29			

Based on this analysis, the environment (optimal, Water deficit, and salinity) has a major effect on the number of open bolls, while the genotypes show similar results under general conditions. For breeding purposes, the "T-2024" (stable under salinity) and "T-2090" (drought-tolerant) genotypes can be considered, as they have maintained relatively high values under stress conditions.

Total Number of Bolls in Pima Cotton Genotypes

Under optimal conditions, the highest result was observed in the "T-563" genotype (15.88±0.25), while the lowest result was recorded in the "Duru-gavhar-4" variety (8.75±1.44), which produced fewer bolls. The total number of bolls under optimal conditions ranged from 8.75 to 15.88, with most genotypes showing results between 10 and 15 bolls. Under Water Deficitconditions, the highest number of bolls was recorded in the "Duru-gavhar-4" variety (10.50±1.98), which showed relatively higher results under Water deficit. The lowest result was observed in the "T-481" genotype (5.50±1.01). Water Deficitreduced the total number of bolls to an average range of 5.50 to 10.50 bolls. The "T-2024" and "Duru-gavhar-4" genotypes showed stable results compared to the optimal conditions.

Table 7. Total Number of Bolls (in pieces) in Pima Cotton Genotypes

Genotypes	Optimal Condition		Water Deficit Condition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	12,13±0,51	0,88	7,83±1,30	2,25	7,05±0,12	0,20
T-479	15,29±0,76	1,32	9,38±0,65	1,13	5,55±0,12	0,20
T-2025	15,25±1,32	2,05	9,00±0,66	1,15	6,00±0,58	1,00
T-2024	10,25±1,80	1,32	10,17±1,52	2,63	12,50±0,29	0,50
T-5570	14,50±1,81	3,13	7,18±0,28	0,49	6,79±0,89	1,54
T-481	10,38±1,44	1,38	5,50±1,01	1,75	7,30±0,17	0,30
T-563	15,88±0,25	1,88	6,33±0,36	0,63	9,67±0,38	0,67
Bo‘ston (T-663)	11,92±2,18	3,50	7,50±1,44	2,50	7,17±0,10	0,17
Duru-gavhar-4 (T-5560)	8,75±1,44	0,50	10,50±1,98	3,44	7,63±0,22	0,38
T-2090	11,25±1,04	3,50	8,83±0,55	0,95	7,75±0,14	0,25

Note: *X – mean value, SE – standard error, SD – standard deviation*

Under salinity conditions, the highest result was recorded in the "T-2024" genotype (12.50±0.29), while the lowest result was observed in the "T-479" genotype (5.55±0.12), where salinity had a strong negative effect on this genotype. The total number of bolls under salinity ranged from 5.55 to 12.50, with "T-2024" and "T-563" genotypes showing relatively higher results. According to the multi-factor ANOVA analysis of the total number of bolls trait, the differences in the total number of bolls between genotypes were statistically insignificant. Although the number of bolls under optimal conditions ranged from 8.75 to 15.88, it was concluded that this difference was not related to genetic factors but to other influences. The environmental effect was statistically highly significant (P-Value = 0.0002 < 0.05). The number of bolls was higher under optimal conditions (average 12-15 bolls), while it decreased under Water Deficit(5.50–10.50 bolls) and salinity conditions (5.55–12.50 bolls), which indicates the strong impact of the environment.

Table 8. Multi-Factor ANOVA Analysis of the Effect of Genotype and Environment (Optimal, Water deficit, Salinity Conditions) on the Total Number of Bolls (pieces)

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	24,74	9	2,74	0,54	0,8275
Environment	140,90	2	70,45	13,81	0,0002
Genotypes × Environment	91,81	18	5,10		
Total	257,46	29			

The interaction between genotypes and the environment for the trait has a high SS value (91.81), which constitutes a large portion (about 35%) of the total variation (257.46). This indicates that the genotypes respond differently to the environment. Specifically, "T-2024" has 10.25 bolls under optimal conditions, which increases to 12.50 bolls under salinity, while "T-479" decreases from 15.29 bolls in optimal conditions to 5.55 bolls under salinity. This confirms the strength of the interaction. For selection purposes, the genotypes "T-2024" (resistant to salinity) and "Duru-gavhar-4" (adaptable to Water deficit) should be considered.

"Vegetation period in fine-fiber cotton genotypes: In optimal conditions, the vegetation period ranged from 121.3 days to 128.4 days, showing certain differences in growth periods among genotypes. The longest vegetation period was recorded in the "T-5570" genotype (128.4±0.5 days, SD = 0.9), indicating slower but more stable development under optimal conditions, with a low standard deviation (0.9), confirming high stability of results. The shortest period was observed in the "T-2025" genotype (121.3±1.0 days, SD = 1.7), which shows faster development but with a slightly higher standard deviation (1.7), indicating some variability in the results. The "Angor (T-1981)" (125.4±0.6 days, SD = 1.0) and "Duru-gavhar-4 (T-5560)" (127.3±0.6 days, SD = 1.0) genotypes stood out with relatively longer periods. Most of the genotypes had a vegetation period ranging from 122 to 126 days, showing average development speed under optimal conditions.

In conditions of Water deficit, the vegetation period shortened from 109.5 days to 115.6 days, indicating that stress accelerated the growth process. The shortest period was recorded in the "T-2024" genotype (109.5±0.8 days, SD = 1.4), representing a 15.8-day reduction from the optimal condition of 125.3 days, confirming that Water Deficitsignificantly accelerated development. The longest period was observed in the "Angor (T-1981)" genotype (115.6±0.7 days, SD = 1.2), which showed stable development under water stress, with a 9.8-day reduction from the optimal condition (125.4 days). The "T-479" (112.4±0.4 days, SD = 0.7) and "T-563" (112.6±0.5 days, SD = 0.9) genotypes also displayed stable performance with relatively shorter periods. Overall, Water deficit shortened the vegetation period by 9 to 16 days compared to the optimal condition, clearly showing the effect of stress on accelerated growth.

Table 9. Vegetation Period (Days) Indicators of Pima Cotton Genotypes.

Genotypes	Optimal Condition		Water Deficit Condition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	125,4±0,6	1,0	115,6±0,7	1,2	132,3±0,6	1,1
T-479	121,8±0,8	1,4	112,4±0,4	0,7	131,4±0,5	0,9
T-2025	121,3±1,0	1,7	111,6±0,7	1,1	132,3±0,6	1,0
T-2024	125,3±0,8	1,5	109,5±0,8	1,4	134,6±0,4	0,6
T-5570	128,4±0,5	0,9	112,4±0,7	1,3	137,3±0,5	0,9
T-481	123,8±0,5	0,9	112,4±0,6	1,1	133,6±0,8	1,4
T-563	125,6±0,5	0,8	112,6±0,5	0,9	135,2±0,6	1,1
Bo‘ston (T-663)	125,4±0,5	0,8	112,3±0,7	1,2	133,7±0,6	1,1
Duru-gavhar-4 (T-5560)	127,3±0,6	1,0	111,5±0,5	0,9	136,0±0,5	0,9
T-2090	122,9±0,9	1,5	112,4±0,6	1,1	131,8±0,6	1,1

Note: *X – mean value, SE – standard error, SD – standard deviation*

Under salinity conditions, the vegetation period ranges from 131.4 to 137.3 days, indicating that stress slows down the growth process. The longest period was recorded in the "T-5570" genotype (137.3±0.5 days, SD = 0.9), which represents an extension of 8.9 days compared to the 128.4 days under optimal conditions, confirming that salinity slows down development. The shortest period was observed in the "T-479" genotype (131.4±0.5 days, SD = 0.9), but this also showed an extension of 9.6 days compared to the 121.8 days under optimal conditions. The "T-2024" (134.6±0.4 days, SD = 0.6) and "Duru-gavhar-4 (T-5560)" (136.0±0.5 days, SD = 0.9) genotypes also exhibited longer periods. Salinity extended the vegetation period by an average of 8–10 days compared to optimal conditions, confirming its role in delaying growth. A multi-factor ANOVA analysis was conducted to assess the impact of genotype and environment on the vegetation period. The differences between the genotypes were found to be statistically insignificant (P-Value = 0.0751 > 0.05), with an F-Ratio value of 2.19, indicating that the genotypes in the experiment ("T-5570", "Angor (T-1981)", "T-2024", etc.) had genetically similar traits in terms of vegetation period. However, the P-Value was close to the threshold (0.05), suggesting the possibility of genetic differences. The environmental effect, however, was statistically highly significant (P-Value = 0.0001 < 0.05), with an F-Ratio value of 438.67, confirming that the conditions of optimal environment, Water deficit, and salinity had a strong influence on the vegetation period. For example, the "T-2024" genotype had a vegetation period of 125.3 days under optimal conditions, which shortened to 109.5 days under Water deficit, and extended to 134.6 days under salinity, demonstrating the major role of environmental factors in trait variation.

Table 10. Multi-factor ANOVA analysis of the effect of genotype and environment (optimal, Water deficit, and salinity conditions) on the vegetation period trait.

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	52,57	9	5,84	2,19	0,0751
Environment	2340,72	2	1170,36	438,67	0,0001
Genotypes × Environment	48,02	18	2,66		
Total	2441,31	29			

The interaction between genotypes and environment was also significant (SS = 48.02, MS = 2.66). This indicates that the genotypes respond differently to various conditions. For example, "Angor (T-1981)" shortened its period to 115.6 days under Water Deficitbut extended it to 132.3 days under salinity, showing its variability in stress adaptation. "T-5570," on the other hand, exhibited the longest period under salinity (137.3 days), demonstrating slow growth.

Among the total variation (Total SS = 2441.31), the environmental effect (SS = 2340.72) accounted for about 96%, marking almost all the changes, while the genotype effect (SS = 52.57) and interaction effect (SS = 48.02) contributed very little. According to the analysis results, under optimal conditions, the vegetation period ranged from 121.3 to 128.4 days, with "T-5570" and "Duru-gavhar-4" exhibiting longer periods. Water Deficitreduced the period by 9–16 days, with "T-2024" showing the fastest development, while "Angor (T-1981)" maintained stability. Salinity extended the period by 8–10 days, with "T-5570" and "T-2024" demonstrating slow development. ANOVA analysis confirmed the strong environmental influence on the vegetation period (P-Value = 0.0001), while the differences between genotypes were not significant (P-Value = 0.0751). The interaction effect (SS = 48.02) showed that genotypes responded differently to stress.

From a breeding perspective, "T-2024," which developed quickly under Water deficit, and the stable "Angor (T-1981)," as well as "T-479" and "T-2090" which maintained an average period under salinity, are recommended. These genotypes, which managed their vegetation period flexibly under stress conditions, could be useful for developing varieties adapted to adverse conditions. In fine fiber cotton genotypes, the cotton weight per boll under optimal conditions ranged from 2.32 g to 3.45 g, showing an average yield capacity. The highest result was recorded in the "T-2025" genotype (3.45±0.20 g, SD = 0.35), confirming its high potential in boll quality and cotton weight under optimal conditions. At the same time, the average standard deviation (0.35) indicates some variability in the results. The lowest result was observed in the "T-481" genotype (2.32±0.14 g, SD = 0.25), but the low standard deviation (0.25) indicates that this genotype has stable but lower yield characteristics. Among other genotypes, "Angor (T-1981)" (3.34±0.03 g, SD = 0.05) and "Duru-gavhar-4 (T-5560)" (3.21±0.12 g, SD = 0.21) also stood out with high results, particularly the "Angor" genotype, which demonstrated very stable characteristics with a low standard deviation (0.05). Overall, most genotypes showed results in the range of 2.5–3.3 g, indicating average productivity under optimal conditions.

Under Water Deficitconditions, cotton weight per boll ranged from 2.12 g to 3.23 g, showing an average decrease compared to optimal conditions. The highest result was recorded in the "Angor (T-1981)" genotype (3.23±0.09 g, SD = 0.15), indicating its high tolerance to water stress and showing almost no difference from its result under optimal conditions (3.34 g). The lowest result was observed in the "T-2024" genotype (2.12±0.17 g, SD = 0.29), representing a significant decrease (0.48 g) from its optimal condition result (2.60 g), indicating its low adaptability to Water deficit. At the same time, the "T-2090" (2.83±0.26 g, SD = 0.45) and "Duru-gavhar-4" (2.77±0.15 g, SD = 0.26) genotypes showed moderately stable results under Water deficit, but "T-2090" demonstrated variability with a higher standard deviation. As a general trend, Water Deficitreduced cotton weight per boll by an average of 0.1–0.5 g compared to optimal conditions, although some genotypes (such as "Angor" and "T-479") maintained stability.

Table 11. Cotton Weight Per Boll (G) Indicators In Pima Cotton Genotypes.

Genotypes	Optimal Condition		Water DeficitCondition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	3,34±0,03	0,05	3,23±0,09	0,15	2,58±0,23	0,40
T-479	3,07±0,03	0,05	3,06±0,23	0,40	2,33±0,08	0,14

T-2025	3,45±0,20	0,35	2,69±0,28	0,48	2,53±0,06	0,11
T-2024	2,60±0,12	0,20	2,12±0,17	0,29	2,71±0,22	0,37
T-5570	3,09±0,06	0,10	2,58±0,20	0,34	2,36±0,20	0,35
T-481	2,32±0,14	0,25	2,56±0,15	0,26	2,61±0,05	0,09
T-563	2,89±0,16	0,28	2,71±0,08	0,13	2,53±0,07	0,12
Bo'ston (T-663)	2,81±0,13	0,23	2,66±0,11	0,19	2,95±0,05	0,09
Duru-gavhar-4 (T-5560)	3,21±0,12	0,21	2,77±0,15	0,26	3,15±0,15	0,26
T-2090	2,56±0,28	0,49	2,83±0,26	0,45	2,55±0,08	0,14

Under salinity conditions, the cotton weight per boll ranged from 2.33 g to 3.15 g. The highest result was recorded in the "Duru-gavhar-4 (T-5560)" genotype (3.15±0.15 g, SD = 0.26), confirming its high adaptability to salinity stress and showing almost no decrease compared to its result under optimal conditions (3.21 g). The lowest result was observed in the "T-479" genotype (2.33±0.08 g, SD = 0.14), indicating a significant decrease (0.74 g) from its optimal condition result (3.07 g), which reflects low salinity tolerance. Among other genotypes, "Bo'ston (T-663)" (2.95±0.05 g, SD = 0.09) and "T-2024" (2.71±0.22 g, SD = 0.37) showed moderately stable results under salinity, with "Bo'ston" demonstrating high stability with low standard deviation. Overall, salinity reduced cotton weight per boll by an average of 0.2–0.8 g compared to optimal conditions, but genotypes like "Duru-gavhar-4" and "Bo'ston" maintained high quality under these conditions.

A multi-factor ANOVA analysis was conducted to determine the effects of genotype and environment on cotton weight per boll. The differences between genotypes were found to be statistically insignificant (P-Value = 0.24 > 0.05), with an F-Ratio value of 1.44. This indicates that the genotypes studied in the experiment ("T-2025", "Angor (T-1981)", "Duru-gavhar-4", etc.) had similar genetic traits in terms of cotton weight per boll, and the differences between them were mainly related to environmental factors rather than genetic factors. The environmental effect was also found to be statistically insignificant (P-Value = 0.07 > 0.05), with an F-Ratio value of 2.94, suggesting that the impact of optimal, Water deficit, and salinity conditions on trait variability was marginal. Unlike other traits (such as plant productivity or boll number), cotton weight per boll showed less dependency on environmental factors.

Table 12. Multi-factor ANOVA analysis of the effect of genotype and environment (optimal, Water deficit, and salinity conditions) on the cotton weight per boll trait.

Source of Effect	**Sum of Squares (SS)**	**Degrees of Freedom (Df)**	**Mean Square (MS)**	**F-Ratio**	**P-Value**
Genotypes	1,08	9	0,12	1,44	0,24

Environment	0,49	2	0,24	2,94	0,07
Genotypes × Environment	1,49	18	0,08		
Total	3,05	29			

The analysis of cotton weight per boll indicates that under optimal conditions, genotypes showed results ranging from 2.32 g to 3.45 g, with "T-2025" and "Angor (T-1981)" standing out for their high quality. While Water Deficit reduced the cotton weight by an average of 0.1–0.5 g, "Angor (T-1981)" (3.23 g) and "T-479" (3.06 g) maintained stability under this stress. Under salinity conditions, the cotton weight ranged from 2.33 g to 3.15 g, with "Duru-gavhar-4" (3.15 g) and "Boʻston (T-663)" (2.95 g) showing high results. ANOVA analysis confirmed that the differences in cotton weight per boll were not statistically significant based on genotype and environment (P-value> 0.05), but the interaction between genotype and environment (SS = 1.49) played an important role in the variability of the trait. From a breeding perspective, genotypes that maintained stability under stress conditions are particularly noteworthy. "Angor (T-1981)" and "T-479" genotypes are recommended for Water Deficit tolerance, while "Duru-gavhar-4" and "Boʻston (T-663)" are suitable for salinity tolerance. These genotypes, which preserved high boll quality (cotton weight) under adverse conditions, could serve as valuable sources for developing stress-resistant varieties in the future.

The analysis of plant productivity in cotton genotypes shows that under optimal conditions, productivity ranged from 24.60 g to 41.57 g, indicating high yield potential. The highest result was recorded for the "T-2025" genotype (41.57±1.57 g), confirming its excellent growth and yield capacity under fully supplied water and nutrient conditions. The lowest yield was observed in the "T-2090" genotype (24.60±0.87 g), but the low standard deviation indicates its stable, yet low-yielding characteristics. Other genotypes, such as "T-479" (36.96±0.86 g) and "T-5570" (37.37±1.63 g), also exhibited high productivity. Overall, most genotypes showed results between 25–37 g, indicating moderate stability in productivity. Under Water deficit conditions, productivity decreased significantly, ranging from 14.41 g to 23.01 g. The highest result was recorded in the "T-479" genotype (23.01±1.54 g), showing its high tolerance to water stress, with only a small difference from its optimal condition result (36.96 g). The lowest yield was observed in the "T-2024" genotype (14.41±1.13 g), which represents a significant decrease (more than 11 g) compared to its optimal condition result (25.64 g), indicating poor adaptability to Water deficit. Meanwhile, "T-2090" (21.72±0.59 g) and "Duru-gavhar-4" (17.98±1.80 g) showed relatively good results under Water deficit, with "T-2090" maintaining stability with low standard deviation. As a general trend, Water deficit reduced productivity by 10–15 g compared to optimal conditions, confirming the negative impact of stress on productivity.

Table 13. Plant productivity (g) indicators in Pima cotton genotypes

Genotypes	Optimal Condition		Water Deficit Condition		Salinity Condition	
	X±SE	SD	X±SE	SD	X±SE	SD
Angor (T-1981)	31,19±1,38	2,40	16,27±1,62	2,80	11,15±0,53	0,92
T-479	36,96±0,86	1,49	23,01±1,54	2,66	11,02±0,70	1,22
T-2025	41,57±1,57	2,72	18,48±0,63	1,10	12,54±1,04	1,81
T-2024	25,64±1,07	1,85	14,41±1,13	1,95	15,54±0,79	1,36
T-5570	37,37±1,63	2,83	16,17±1,37	2,37	10,28±0,78	1,36
T-481	24,71±1,35	2,33	15,61±1,32	2,29	14,28±0,40	0,69
T-563	27,44±0,83	1,43	16,92±0,94	1,62	14,42±0,47	0,81
Bo‘ston (T-663)	28,97±0,87	1,50	17,89±0,69	1,20	14,93±1,05	1,81
Duru-gavhar-4 (T-5560)	28,81±1,32	2,28	17,98±1,80	3,13	15,98±0,59	1,02
T-2090	24,60±0,87	1,50	21,72±0,59	1,02	13,51±0,61	1,06

The analysis of plant productivity under salinity conditions showed a further decrease in yield, ranging from 10.28 g to 15.98 g. The highest result was recorded in the "Duru-gavhar-4" genotype (15.98±0.59 g), demonstrating its high adaptability to salinity stress with a minimal decrease compared to its optimal condition (28.81 g), showing a decrease of only 13 g. The lowest yield was observed in the "T-5570" genotype (10.28±0.78 g), which exhibited a significant decrease of nearly 27 g from its optimal yield of 37.37 g, indicating low salinity tolerance. Other genotypes, such as "T-2024" (15.54±0.79 g) and "Bo‘ston (T-663)" (14.93±1.05 g), showed relatively stable results under salinity, indicating moderate adaptability to stress. Overall, salinity reduced productivity by 10–25 g compared to optimal conditions, but genotypes like "Duru-gavhar-4" and "T-2024" maintained stability. A multi-factor ANOVA was conducted to determine the impact of genotype and environment on plant productivity. The differences in yield between genotypes were found to be statistically insignificant (P-Value = 0.7176 > 0.05), with an F-Ratio value of 0.68. This indicates that the genotypes studied ("T-2025", "T-479", "Duru-gavhar-4", etc.) were genetically similar in terms of productivity, and the differences between them were primarily due to environmental factors rather than genetic traits. On the other hand, the environmental effects were statistically highly significant (P-Value = 0.0001 < 0.05), with an F-Ratio value of 46.69, highlighting the strong influence of environmental conditions (optimal, Water deficit, and salinity) on productivity. For example, the "T-2025" genotype showed 41.57 g of productivity under optimal conditions, but this decreased to 12.54 g under salinity, emphasizing the crucial role of the environment in yield variability.

The interaction between genotype and environment was also significant in the analysis (SS = 313.17, MS = 17.3981), indicating that different genotypes respond differently to various environments. For instance, the "T-2024" genotype maintained stability under salinity with a yield of 15.54 g, despite a significant decrease from its optimal yield (25.64 g), while "T-5570" experienced a sharp decline from 37.37 g to 10.28 g under salinity, showing low adaptability to stress. Additionally, the "T-2090" genotype demonstrated good adaptation to Water deficit, resulting with a yield of 21.72 g. Overall variability (Total SS = 2044.19) showed that environmental effects (SS = 1624.59) contributed to about 79% of the total variability, while the genotype (SS = 106.43) and genotype-environment interaction (SS = 313.17) accounted for smaller portions.

Table 14. Multivariate ANOVA analysis of the effects of genotype and environment (optimal, water deficit, salinity backgrounds) on plant productivity traits

Source of Effect	Sum of Squares (SS)	Degrees of Freedom (Df)	Mean Square (MS)	F-Ratio	P-Value
Genotypes	106,43	9	11,8258	0,68	0,7176
Environment	1624,59	2	812,297	46,69	0,0001
Genotypes × Environment	313,17	18	17,3981		
Total	2044,19	29			

The analysis of plant productivity shows that under optimal conditions, genotypes exhibited high productivity (ranging from 24.60 to 41.57 g), with genotypes such as "T-2025" and "T-479" showing the best performance in this environment. Although Water deficit reduced productivity by an average of 10–15 g, the "T-479" (23.01 g) and "T-2090" (21.72 g) genotypes demonstrated resilience to this stress. Under salinity conditions, productivity decreased even further (ranging from 10.28 to 15.98 g), but genotypes like "Duru-gavhar-4" (15.98 g) and "T-2024" (15.54 g) maintained stability. ANOVA analysis confirmed that the main factor influencing productivity differences was the environment, not the genotypes (P-Value = 0.0001), highlighting that while the genotypes have similar traits, their adaptability to different environments varied.

From a breeding perspective, the genotypes that showed high performance under stress conditions are particularly noteworthy. For drought tolerance, the genotypes "T-2090" and "T-479" are recommended, while "Duru-gavhar-4" and "T-2024" are suggested for their salinity tolerance. These genotypes, which maintained relatively high productivity under stress conditions, can serve as important sources for developing varieties resistant to unfavorable conditions like drought and salinity in the future.

Discussion

The multifactorial ANOVA results from this study clearly demonstrate that environmental factors had a dominant influence on morphological and agronomic traits in *G. barbadense* cotton genotypes. In contrast, genotypic effects were largely non-significant for most traits, although certain genotypes showed relative stability and adaptability under stress, particularly drought and salinity conditions. Across all tested traits—such as plant height, number of fruit branches, open bolls, total boll number, boll weight, vegetative period, and productivity—the P-values for genotype effects were generally above 0.05, indicating insignificant genetic differences in trait expression under combined environments. However, the environmental factor was statistically highly significant ($P < 0.0001$) for nearly all traits, confirming the strong influence of water deficit and salinity on cotton growth and productivity. These findings align with earlier reports (Farooq et al., 2017; Ashraf & Foolad, 2007), which emphasized that water scarcity and salinity are among the most critical abiotic constraints in cotton-growing regions.

Interestingly, the G×E interaction was notable for traits such as plant height, total boll number, and yield, suggesting that specific genotypes responded differently to each stress condition. For example, T-2024 consistently outperformed others under saline conditions, maintaining higher boll numbers and plant height, while T-2090 and T-479 showed superior performance under drought stress, with higher productivity and boll retention. Duru-gavhar-4 (T-5560) exhibited relatively stable productivity across all stress environments, making it a strong candidate for stress-resilient breeding. One particularly interesting pattern emerged in the vegetative period: drought stress shortened the growth cycle by 9–16 days, likely as an adaptive response, while salinity extended it by 8–10 days, possibly due to delayed developmental processes. These findings mirror physiological responses described by Sarwar et al. (2020) and Zhang et al. (2016), where drought induced early maturation and salinity delayed phenology. Although boll weight and productivity showed numerical variation across genotypes, ANOVA results indicated non-significance ($P > 0.05$) for both genotype and environment effects on boll weight. This may suggest that boll weight is a more stable trait compared to yield components like boll number or open bolls, which are more sensitive to stress.

From a breeding perspective, identifying stress-resilient genotypes is critical for improving cotton performance in semi-arid regions like Uzbekistan. Genotypes such as T-2024 (salinity-tolerant), T-479 and T-2090 (drought-tolerant), and Duru-gavhar-4 (broad adaptability) provide valuable genetic material for developing climate-resilient cultivars.

Conclusion

The multifactorial ANOVA analysis revealed that environmental conditions had a predominant influence on cotton growth and yield traits, while genotypic differences were largely non-significant. Nevertheless, certain genotypes demonstrated notable stability and adaptability under stress conditions. Specifically, T-2024 performed well under saline conditions; T-479, T-2090, and Angor (T-1981) showed strong tolerance to drought; and Duru-gavhar-4 (T-5560) maintained high productivity across adverse environments. These genotypes represent promising genetic resources for the development of new cotton varieties resilient to water deficit and salinity stress, thereby contributing to sustainable cotton production in arid and semi-arid regions.

Acknowledgements

The authors would like to express their sincere gratitude to the Institute of Genetics and Plant Experimental Biology of the Academy of Sciences of Uzbekistan, as well as to the researchers at the Laboratory of Cotton Genetics, Breeding, and Seed Production.

References

Akinwale, M. G., Gregorio, G., Nwilene, F., Akinyele, B. O., Ogunbayo, S. A., & Odiyi, A. C. (2014). Heritability and correlation coefficient analysis for yield and its components in rice (Oryza sativa L.). African Journal of Plant Science, 5(3), 207-212.

Ali, A., et al. (2021). Evaluation of cotton genotypes under salinity stress for yield and fiber quality traits. Plant Stress, 2, 100041.

Ashraf, M., & Foolad, M. R. (2007). Roles of glycine betaine and proline in improving plant abiotic stress resistance. Environmental and Experimental Botany, 59(2), 206-216.

Azimov, A., Aliqulov, E.,Ergashev, O., Shavkiev, J. (2024a).Estimation of dominance and heterosis of morpho-economic traits in intraspecific F1 hybrids of upland cotton, Journal of Wildlife and Biodiversity, 8(3), 162-174. https://doi.org/10.5281/zenodo.11409018

Azimov, A., Shavkiev, J., Ahmedjanov, A.,, Temirova Y., Koraev, A., Nurmetov, Kh., Rasulova, O. (2024b). Genetic analysis and inbreeding depression for yield-related parameters in upland cotton. SABRAO Journal of Breeding and Genetics, 56(4), 1345-1356. http://doi.org/10.54910/sabrao2024.56.4.2.

Azimov, A., Shavkiev, J., Nabiev, S., Khamdullaev, S., Pulatov, S., Rajabov, Z. (2024c). Cobalt-60-γ-radiation effect on morpho-yield and earliness traits in colored cotton (Gossypium hirsutum L.). SABRAO Journal of Breeding and Genetics, 56(6), 2248-2259. http://doi.org/10.54910/sabrao2024.56.6.7.

Chorshanbiev, N.E., Nabiev, S.M., Azimov, A.A., Shavkiev, J.SH., Pardaev, E.A., Quziboev, A.O. (2023a). Inheritance of morpho-economic traits and combining ability analysis in intraspecific hybrids of Gossypium barbadense L. SABRAO Journal of Breeding and Genetics,55(3),640-652. http://doi.org/10.54910/sabrao2023.55.3.4.

Chorshanbiev, N., Shavkiev, J., Nabiev, S., Azimov, A., Burieva, S. (2023b). "Heterosis and combinatorial ability of cotton (G. barbadense L) in Uzbekistan". Modern biology and genetics, 1(1), 56-63.

Farooq, M., Hussain, M., Wahid, A., & Siddique, K. H. M. (2017). Drought stress in plants: an overview. In Drought Stress Tolerance in Plants (pp. 1–20). Springer.

Kang, M. S. (1993). Simultaneous selection for yield and stability in crop performance trials. Agronomy Journal, 85(3), 754–757.

Khamdullaev, S.H., Nabiev, S., Azimov, A., Shavkiev, J., Yuldashov, U. (2021). "Combining ability of yield and yield components in upland cotton (G. hirsutum L.) genotypes under normal and water-deficit conditions". Plant Cell Biotechnology and Molecular Biology, 22(35&36), 176-186.

Kumar, P., et al. (2018). Evaluation of early maturing cotton genotypes under drought stress. Journal of Cotton Research, 1(1), 12–18.

Makamov, A., Shavkiev, J., Kholmuradova, M., Boyqobilov, U., Normamatov, I., Norbekov, J., Khusenov, N., Kushakov, SH., Yuldasheva, Z., Khoshimov, S., Buriev, Z. (2023). Cotton genotypes appraisal for morpho-physiological and yield contributing traits under optimal and deficit irrigated conditions. SABRAO Journal of Breeding and Genetics, 55(1), 74-89. http://doi.org/10.54910/sabrao2023.55.1.7.

Nabiev, S., Usmanov, R., Khamdullaev, SH., Shavkiev, J. (2020). “Study of physiological indicators of the water balance of plants and morphological signs of leaf of fine-fiber varieties in different irrigation regimes”. Journal of biology of Uzbekistan, 1, 51-58.

Patil, S. G., Chimmad, V. P., & Salimath, P. M. (2011). Genetic variability and trait association studies in desi cotton (Gossypium arboreum L.). Karnataka Journal of Agricultural Sciences, 24(2), 112-115.

Samanov, S.H., Arslanov, D., Ernazarova, Z., Iskandarov, A., Muhammad, X., Bunyod, G., Gulomov, G., Sirojjodinov, B., Dusmatova, G., Shavkiev, J. (2024). Characterization of morpho-biological and economic characteristics of interspecific cotton hybrid and degree of dominance, Journal of Wildlife and Biodiversity, 8(4), 119-128. https://doi.org/10.5281/zenodo.13823671

Sarwar, M., Hussain, M., Anjum, S. A., Raza, A., & Anwar-ul-Haq, M. (2020). Cotton crop under drought: Physiological and molecular perspectives. Environmental and Experimental Botany, 172, 103998.

Shavkiev, J., Azimov, A., Khamdullaev, S., Karimov, H., Abdurasulov, F., Nurmetov, K. (2023). Morpho-physiological and yield contributing traits of cotton varieties with different tolerance to water deficit, Journal of Wildlife and Biodiversity, 7(4), 214-228. DOI: https://doi.org/10.5281/10.5281/zenodo.8304871

Shavkiev, J., Azimov, A., Nabiev, S., Khamdullaev, S., Amanov, B., Kholikova, M., Matniyazova, H., Yuldashov, U. (2021a). “Comparative performance and genetic attributes of upland cotton genotypes for yield-related traits under optimal and deficit irrigation conditions”. SABRAO Journal of Plant Breeding and Genetics, 53(2), 157-171.

Shavkiev, J., Hamdullaev, S., Nabiev, S., Usmanov, R., Bozorov, T., Erzhigitov, D. (2019a). “Water sensitivity and tolerance indices upon productivity in upland cotton and other economically valuable traits”. Bulluten of Gulistan State University, 2, 64-68.

Shavkiev, J., Hamdullaev, S., Nabiev, S., Usmanov, R. (2019b). “Water sensitivity and tolerance indices upon productivity in upland cotton and other economic valuable traits”. Bulletin of Gulistan State University, 2, 71-76.

Shavkiev, J., Nabiev, S., Abdulahat, A., Khamdullaev, S. (2021b). “Economic and physiological traits of Pima cotton lines in Uzbekistan and their correlation”. Universum: chemistry and biology, 7(85-2), 14-22.

Shavkiev, J., Nabiev, S., Azimov, A., Chorshanbiev, N., And Nurmetov, K.H. (2022). Pima cotton (*GOSSYPIUM BARBADENSE* L.) lines assessment for drought tolerance in Uzbekistan. SABRAO Journal of Breeding and Genetics, 54 (3), 524-536. http://doi.org/10.54910/sabrao2022.54.3.6

Tuberosa, R. (2012). Phenotyping for drought tolerance of crops in the genomics era. Frontiers in Physiology, 3, 347.

Zhang, X., Shabala, S., Koutoulis, A., Shabala, L., & Johnson, P. (2016). Root traits and osmotic adjustment as key selection criteria for improving cotton (*Gossypium hirsutum* L.) yield under drought stress. Plant Physiology and Biochemistry, 108, 106-114.