Research Article

Integrated physiological and agronomic assessment reveals contrasting drought tolerance strategies in cotton genotypes[1]

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ABSTRACT

Drought limits cotton yield by impairing photosynthesis and growth, yet genotypes differ in their adaptive responses. This study aimed to evaluate upland (*Gossypium hirsutum* var. *latifolium*) and perennial (*G. hirsutum* var. Marie-Galante) cotton cultivars in order to identify physiological mechanisms of drought tolerance and promising germplasm for breeding. A greenhouse experiment was conducted with nine cultivars and two water regimes (irrigated control and drought stress). Growth, gas exchanges, cellular water status, boll production and fiber technological traits were assessed. The BRS Rubi, BRS 286, BRS Seridó, CNPA 5M and CNPA 7MH cultivars exhibited distinct drought-tolerance strategies. BRS Rubi and BRS 286 maintained gas exchange rates similar to the control, preserving the photosynthetic capacity throughout the stress period. CNPA 5M and CNPA 7MH adopted a water-conservation strategy, reducing gas exchanges but sustaining a high relative water content, low electrolyte leakage, satisfactory growth and increased root/shoot ratio. Overall, BRS 286, BRS Seridó, CNPA 5M and CNPA 7MH combined superior physiological performance with higher boll production and improved fiber quality. These genotypes are recommended as parents in diallel crosses, including with high-yielding but drought-sensitive cultivars, to expand breeding opportunities for cotton in water-limited environments.

KEYWORDS: *Gossypium hirsutum*, cotton fiber quality, water stress.

RESUMO

Avaliação fisiológica e agronômica integrada revela estratégias contrastantes de tolerância à seca em genótipos de algodão

A seca limita a produtividade do algodoeiro ao comprometer a fotossíntese e o crescimento, embora genótipos apresentem diferenças em suas respostas adaptativas. Avaliaram-se cultivares de algodão herbáceo (*Gossypium hirsutum* var. *latifolium*) e perene (*G. hirsutum* var. Marie-Galante) com o objetivo de identificar mecanismos fisiológicos de tolerância à seca e germoplasma promissor para o melhoramento genético. O experimento foi conduzido em casa-de-vegetação, utilizando-se nove cultivares e dois regimes hídricos (controle irrigado e estresse hídrico). Foram avaliados: crescimento, trocas gasosas, estado hídrico celular, produção de capulhos e características tecnológicas da fibra. As cultivares BRS Rubi, BRS 286, BRS Seridó, CNPA 5M e CNPA 7MH apresentaram estratégias distintas de tolerância à seca. BRS Rubi e BRS 286 mantiveram taxas de trocas gasosas semelhantes às do controle, preservando a capacidade fotossintética ao longo do período de estresse. CNPA 5M e CNPA 7MH adotaram uma estratégia de conservação de água, reduzindo as trocas gasosas, mas sustentando alto teor relativo de água, baixa perda de eletrólitos, crescimento satisfatório e maior relação raiz/parte aérea. De modo geral, BRS 286, BRS Seridó, CNPA 5M e CNPA 7MH combinaram desempenho fisiológico superior com maior produção de capulhos e melhor qualidade de fibra. Esses genótipos são recomendados como genitores em cruzamentos dialélicos, inclusive com cultivares de alta produtividade porém sensíveis à seca, a fim de ampliar as oportunidades de melhoramento do algodoeiro em ambientes com limitação hídrica.

PALAVRAS-CHAVE: *Gossypium hirsutum*, qualidade da fibra de algodão, estresse hídrico.

INTRODUCTION

Drought is a climatic phenomenon that reduces crop yields across diverse environments worldwide, particularly in semiarid regions. In response to water-deficit signals, plants activate protective mechanisms to limit cellular damage (Silva et al. 2023, Zafar et al. 2023), including the synthesis of organic and

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inorganic osmolytes that maintain cellular hydration and sustain photosynthesis under stress (Ul-Allah et al. 2021, Tang et al. 2022). Genotypes with greater drought tolerance exhibit faster defense responses, supported by a genetic background enriched with tolerance-associated genes (Thomaz et al. 2024).

Cotton (*Gossypium hirsutum* L.) is a globally cultivated crop of major economic importance. Commercial cultivars are predominantly derived from the *latifolium* race, which accounts for about 95 % of the global fiber production and shows a broad adaptation to diverse environments (Barros et al. 2022, Gomes et al. 2022). In Brazil, cotton is mainly grown in the Cerrado (Brazilian Savanna) biome (Barros et al. 2022), but cultivation has also been reestablished in the semiarid region through the adoption of technologies and drought-tolerant cultivars (Gomes et al. 2022). In these regions, recurrent droughts can severely compromise yield, depending on their duration and intensity (Silva et al. 2023, Thomaz et al. 2024, Lima et al. 2025).

When water stress occurs during the early budding stage, physiological damage is intensified due to restricted water availability in plant tissues (Silva et al. 2023, Soares et al. 2023). This limitation disrupts photosynthesis and alters assimilate partitioning, impairing reproductive development (Hu et al. 2019a, Hu et al. 2019b, Hu et al. 2020). Consequently, fruit shedding increases, reducing the boll production and fiber quality (Vasconcelos et al. 2020, Marcelino et al. 2023).

Deploying drought-tolerant cultivars remains the most effective strategy to minimize yield losses. However, many commercial *latifolium* cultivars remain susceptible to drought stress (Silva et al. 2020, Zahid et al. 2021, Gomes et al. 2022, Shani et al. 2025). By contrast, perennial genotypes (*G. hirsutum* subsp. Marie-Galante, "Mocó" type) display a greater tolerance to dry environments than upland genotypes (*G. hirsutum* subsp. *latifolium*) (Silva et al. 2020, Marcelino et al. 2022), although the physiological mechanisms underlying this tolerance remain poorly understood.

Breeding programs routinely evaluate physiological traits under water deficit to identify germplasm that combines drought tolerance with high yield potential. Photosynthesis is particularly sensitive to water availability, and net CO_2 assimilation typically decreases under drought, but tolerant genotypes maintain comparatively higher rates (Ullah et al. 2008). Nonetheless, cotton genotypes may adopt contrasting tolerance strategies, reflecting distinct physiological adjustments to prolonged water limitation.

Although Brazilian commercial cultivars are recognized for their fiber yield and adaptability, knowledge on their drought-tolerance mechanisms under the extended dry periods of the Cerrado region is limited. From this perspective, this study evaluated morphophysiological traits, boll production and fiber quality in upland and perennial cotton cultivars subjected to severe water deficit, aiming to elucidate adaptive mechanisms and identify drought-tolerant germplasm for use as parental lines.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the Embrapa Algodão, in Campina Grande, Paraíba state, Brazil (7º13'50"S, 35º52'52"W and altitude of 551 m), from July 2015 to January 2016. Nine commercial cultivars (Table 1) were evaluated under two water regimes (control and drought stress) in a 9 × 2 factorial design. A completely randomized design with four replicates was used, with each plot consisting of two plants.

Plants were grown in 45-L pots filled with sandy loam soil previously fertilized with nitrogen, phosphorus and potassium. Irrigation was applied daily, with volumes determined by the water balance (applied volume minus drained volume, measured at the following day). To prevent salt accumulation and maintain uniform soil moisture, a leaching fraction was applied fortnightly. Drought stress was imposed at the R1 stage (first flower-bud appearance) by withholding irrigation for 21 days, after which watering was resumed. Control plants received daily irrigation throughout the experiment. During the trial, the average maximum and minimum air temperatures were 31.05 and 24.35 ºC, respectively, and the relative humidity ranged from 49 to 75 %.

Weekly, measurements of main stem height and number of leaves were taken from the start of water withholding until one week after the irrigation was restored. All other growth traits were assessed at the end of the day 21 of the drought period. Leaf area was estimated according to Grimes & Carter (1969). On the final day of the drought treatment, the plants were harvested for biomass partitioning. Shoots and roots were separated, washed free of soil, oven-dried

Table 1. Main characteristics of the commercial cotton cultivars evaluated in this study.

Cultivar	Type	ER	GB/P
FMT 705	U	Savanna	IC/DeltaOpal and IAC 22
FM 966	U	Savanna	MS/Deltapine Acala 90
BRS RUBI	U	Semiarid	IC/CNPA 7H
BRS 286	U	Savanna/Semiarid	IC/CNPA ITA 90 and CNPA 7H
FMT 701	U	Savanna	IC/FiberMax966
CNPA ITA 90	U	Savanna	MS/Deltapine Acala 90
CNPA 5M	MG	Semiarid	Bulk/CNPA 3M
CNPA 7MH	H	Semiarid	ISC/CNPA 91-134
BRS Seridó	U	Semiarid	ISC/113 7MH

U: upland; MG: Marie-Galante (perennial); H: hybrid (upland × perennial); ER: environmental recommendation; GB/P: genetic base/parental; IC: intervarietal crossing; MS: mass selection; ISC: intraspecific crossing (Marie-Galante × *latifolium*).

at 65 ºC to constant weight, and used to calculate the root/shoot ratio on a dry-mass basis.

Gas exchange measurements were taken on day 21 of water withholding, between 08:00 and 09:00 a.m., using a LI-6400XT portable infrared gas analyzer (LI-COR, USA). All readings were collected from the third fully expanded leaf under the following chamber conditions: ambient CO_2 concentration and photosynthetic photon flux density of 1,200 µmol m^{-2} s^{-1} (LED light source). The following parameters were recorded: stomatal conductance (*gs*), net CO_2 assimilation rate (*A*), transpiration rate (*E*) and instantaneous water-use efficiency (*A/E*).

Cell-membrane stability was evaluated by electrolyte leakage (EL). Five leaf discs (113 mm^2 each) per plant were incubated in 10 mL of deionized water at 25 ºC, for 2 h, after which initial conductivity (IC) was measured with a conductivity meter. Samples were then incubated at 80 ºC, for 90 min, and final conductivity (FC) was recorded. EL was calculated as (IC/FC) × 100.

Relative water content (RWC) was determined using a separate set of leaf discs. Fresh mass (FM) was measured immediately after sampling, turgid mass (TM) after floating discs in distilled water at 25 ºC, for 24 h, and dry mass (DM) after oven-drying at 65 ºC, for 48 h. RWC was calculated as: [(FM - DM)/(TM - DM)] × 100.

After harvest, the cultivars were evaluated for yield components and fiber quality. Agronomic traits included total number of mature bolls per plant, average boll mass and lint mass after manual ginning. Fiber properties were determined using High Volume Instruments (HVI 1000, Zellweger), including fiber length, uniformity, short fiber index, strength, yarn elongation, micronaire index, maturity and spinnability index.

Data were subjected to analysis of variance (Anova) using the F test ($p \leq 0.05$) to determine the treatment effects. Genotype means were grouped by the Scott-Knott test ($p \leq 0.05$), and water regime means were compared by the F test. Multivariate analyses were also performed, including canonical variable analysis to evaluate treatment discrimination and the Mahalanobis distance (D^2) to estimate genetic divergence among cultivars.

RESULTS AND DISCUSSION

The Anova revealed significant cultivar × water regime interactions for all traits, indicating genotype-specific responses to drought stress under greenhouse conditions. Visual symptoms of water deficit first appeared in the most sensitive cultivars during the first week of irrigation withholding, and were intensified by the end of the 21-day treatment. The main stem height decreased by 33 % in FMT 705, 34 % in FM 966, 40 % in FMT 701 and 37 % in CNPA ITA 90 after 21 days of drought, with no significant recovery one week after rehydration (Figure 1). The number of leaves also decreased sharply, exceeding 52 % in the most affected genotypes (Figure 2), confirming the sustained impact of water deficit on shoot development, even after irrigation resumed.

By contrast, the cultivars recommended for semiarid environments (BRS Rubi, BRS 286, BRS Seridó, CNPA 5M and CNPA 7MH) exhibited negligible reductions in stem height during the first two weeks of drought (Figure 1). By day 21, however, declines reached 37 % in BRS Rubi and only 16 % in CNPA 5M. Importantly, after rehydration,

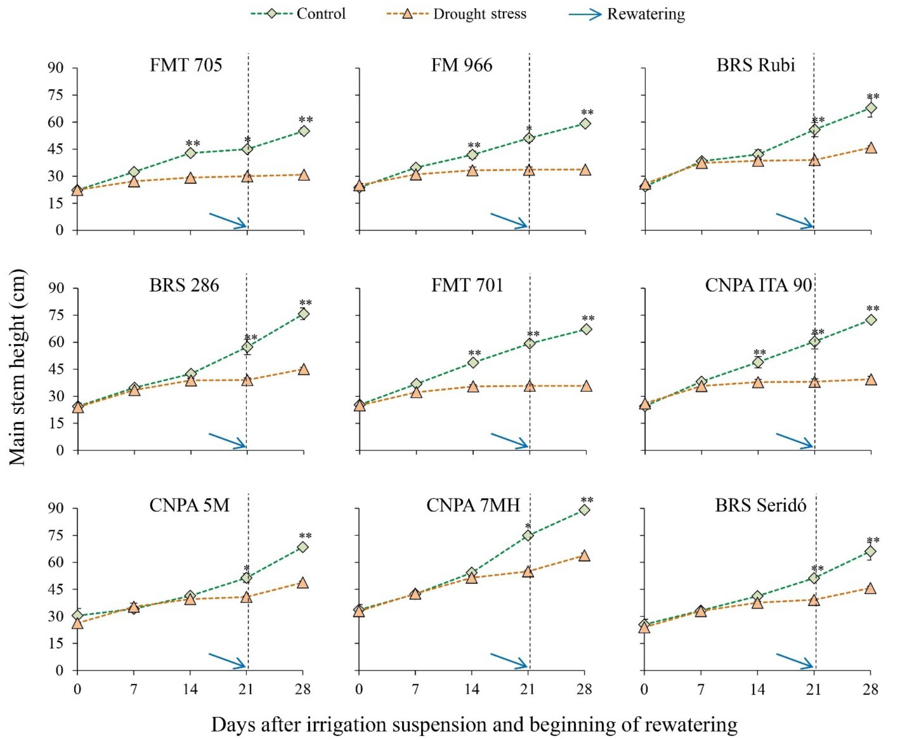

Figure 1. Main stem height of cotton cultivars subjected to 21 days of water suppression and after rewatering. **, *: statistical differences between water conditions at $p \leq 0.01$ and $p \leq 0.05$, respectively, by the F-test. Bars represent the standard error of the mean.

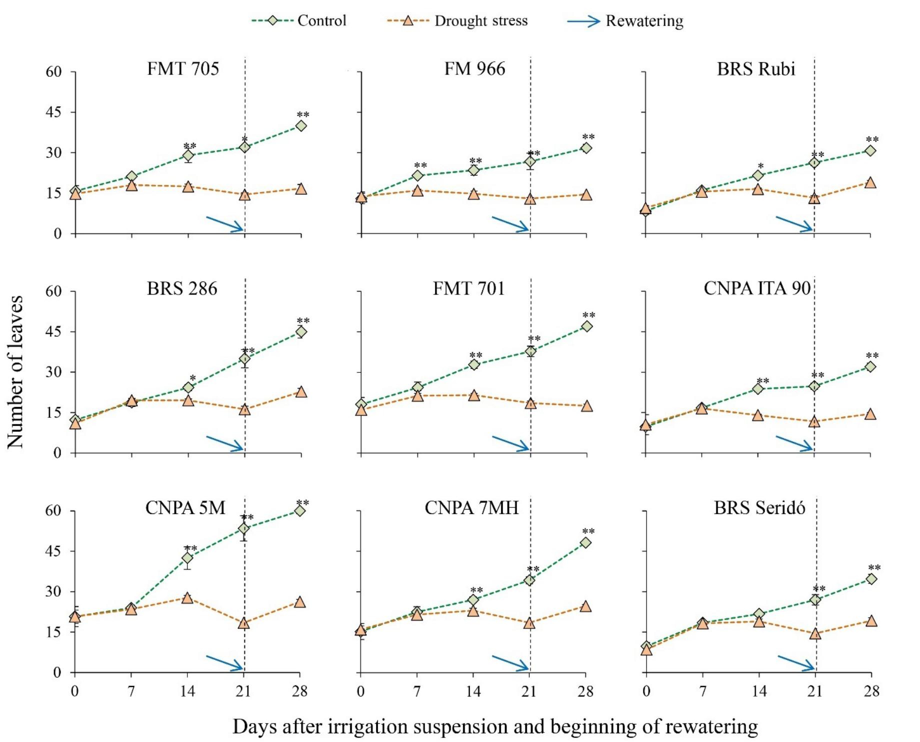

Figure 2. Number of leaves of cotton cultivars subjected to 21 days of water suppression and after rewatering. **, *: statistical differences between water conditions at $p \leq 0.01$ and $p \leq 0.05$, respectively, by the F-test. Bars represent the standard error of the mean.

these cultivars showed a superior recovery of both stem elongation (Figure 1) and number of leaves (Figure 2), when compared to the other genotypes, underscoring their rapid recuperative capacity.

Monitoring the canopy dynamics under water deficit is critical, as leaf abscission and reduced leaf area restrict light interception and impair photosynthesis (Chapepa et al. 2020). In cotton, canopy reduction is a common drought response, particularly in sensitive genotypes, as a strategy to minimize water loss (Li et al. 2019, Silva et al. 2023). In this study, drought-sensitive cultivars experienced severe reductions in leaf area after 21 days without irrigation: 70 % in FMT 705, 66 % in FM 966, 63 % in FMT 701 and 61 % in CNPA ITA 90. In contrast, semiarid-adapted cultivars showed milder reductions, ranging from 37 % in BRS Seridó to 43 % in CNPA 5M. These results are consistent with Silva et al. (2023), who reported growth reductions of 10, 20 and 38 % in BRS Seridó, CNPA 7MH and FM 966, respectively, after just 7 days of water suppression. According to Li et al. (2019), reductions in leaf area and stomatal closure help to prevent xylem embolism, preserving hydraulic function, but limiting photosynthesis and yield.

Biomass allocation patterns revealed distinct adaptation strategies. Increased root growth is a hallmark of drought tolerance, as roots are the first organs to sense and respond to water scarcity (Luo et al. 2016, Singh et al. 2018). Under drought, CNPA 5M and CNPA 7MH showed root/shoot ratio increases of 44 and 40 %, respectively (Figure 3B), indicating a strategic shift that likely mitigated physiological damage and supported vegetative growth (Figures 1 and 2). Similarly, Singh et al. (2018) observed a 50 % increase in this ratio under a 50 % irrigation deficit, reinforcing its role in drought adaptation.

By contrast, FMT 705, FMT 701 and FM 966 displayed only slight increases (~12 %), reflecting a limited morphological adjustment. Rodrigues et al. (2016) reported comparable findings, with low root expansion and elevated oxidative stress in these cultivars, under moderate water deficit.

Figure 4 shows mean physiological parameters in cotton cultivars after 21 days of water suppression. BRS 286, BRS Rubi and BRS Seridó displayed a superior physiological performance under stress. Notably, BRS Rubi and BRS 286 maintained a stomatal conductance similar to control plants (Figure 4A), with no reduction in CO_2 assimilation (Figure 4B) or transpiration (Figure 4C). Thus, these cultivars sustained photosynthesis at levels equivalent to well-watered plants. BRS Seridó also demonstrated a favorable adjustment, with stressed plants showing a 43 % increase in photosynthetic rate (Figure 4B). This response may be linked to compensatory mechanisms in tolerant genotypes which maintain carbon assimilation despite smaller leaf areas (Pettigrew 2004, Silva et al. 2023). The ability to sustain gas exchange under drought translated into a higher instantaneous water-use efficiency (Figure 4D), highlighting the adaptive advantage of these cultivars under water-limited conditions.

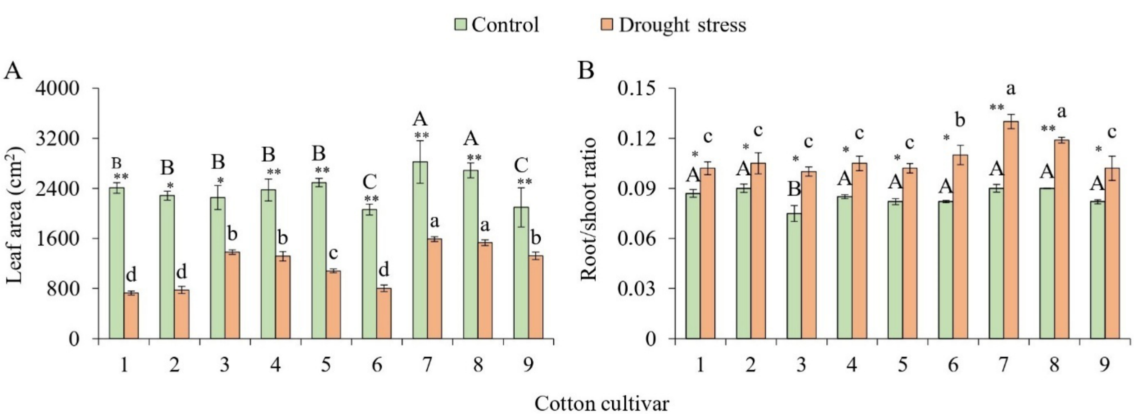

Figure 3. Leaf area (A) and root/shoot ratio (B) of cotton cultivars subjected to 21 days of water suppression. 1 - FMT 705; 2 - FM 966; 3 - BRS Rubi; 4 - BRS 286; 5 - FMT 701; 6 - CNPA ITA 90; 7 - CNPA 5M; 8 - CNPA 7MH; 9 - BRS Seridó. **, *: statistical differences between water regimes at $p \leq 0.01$ and $p \leq 0.05$, respectively, by the F-test. Uppercase and lowercase letters compare cultivars for control and drought stress conditions, respectively (Scott-Knott test; $p \leq 0.05$). Bars represent the standard error of the mean.

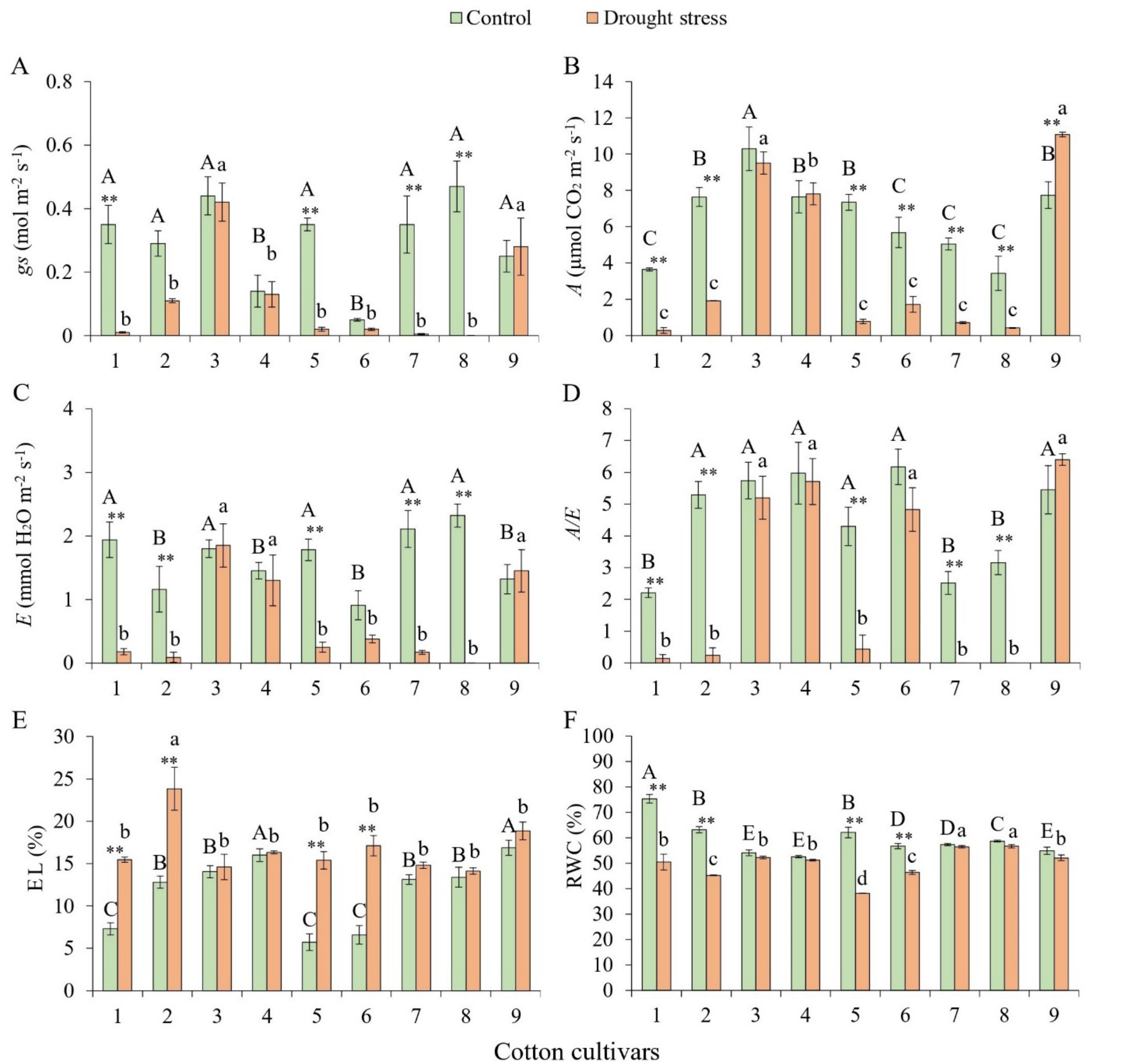

Figure 4. Physiological traits in cotton cultivars subjected to 21 days of water suppression. A) stomatal conductance (*gs*); B) CO_2 assimilation rate (*A*); C) transpiration (*E*); D) instantaneous water-use efficiency (*A/E*); E) electrolyte leakage (EL); F) relative water content (RWC). 1 - FMT 705; 2 - FM 966; 3 - BRS Rubi; 4 - BRS 286; 5 - FMT 701; 6 - CNPA ITA 90; 7 - CNPA 5M; 8 - CNPA 7MH; 9 - BRS Seridó. ** Statistical differences between water regimes at $p \leq 0.01$, by the F-test. Uppercase and lowercase letters compare cultivars for the control and drought stress conditions, respectively (Scott-Knott test; $p \leq 0.05$). Bars represent the standard error of the mean.

BRS 286, BRS Rubi and BRS Seridó are cultivars recommended by the Embrapa for semiarid environments, with BRS 286 also adapted to the Cerrado. BRS 286 and BRS Rubi carry genetic contributions from CNPA 7H, a genotype selected across the Brazilian Northeast region (Embrapa 1993). BRS Seridó was developed through direct selection from Embrapa 113 7MH, derived from a hybrid of *latifolium* and Marie-Galante germplasm (Embrapa 2006).

In this study, CNPA 7MH and CNPA 5M exhibited drought-tolerance responses distinct from BRS 286, BRS Rubi and BRS Seridó. After 21 days of water suppression, CNPA 7MH and CNPA 5M markedly reduced the gas exchange (Figures 4A-D). Despite this decline, both cultivars maintained a satisfactory growth (Figures 1-3) and preserved cellular integrity, as indicated by the stable electrolyte leakage (Figure 4E) and relative water content (Figure 4F), comparable to well-watered plants. This response suggests a tolerance mechanism based on downregulating gas exchange to limit water loss while sustaining growth and physiological stability.

Zahid et al. (2021) highlighted the relative water content as a key parameter for selecting drought-tolerant genotypes. Evaluating 23 cotton genotypes under ten days of water suppression, they reported relative water content reductions of 6-22 %, with smaller decreases in tolerant plants. Abdel-Kader et al. (2015) further emphasized that tolerant genotypes maintain a lower electrolyte leakage under stress.

By contrast, FMT 705, FM 966 and FMT 701 displayed severe physiological impairments under drought, with up to 92 % of reduction in the CO_2 assimilation, increased electrolyte leakage and decreased relative water content (Figure 4), all reflected in reduced growth (Figures 1-3). CNPA ITA 90 showed a 69 % reduction in the CO_2 assimilation (Figure 4B), but remained relatively stable in other traits (Figures 4A, 4C and 4D), suggesting an intermediate sensitivity. Thus, CNPA ITA 90 may perform somewhat better than FMT 705, FM 966 and FMT 701 in water-limited environments, although further studies are required to confirm this. Consistent with these findings, Tsonev et al. (2011) reported photosynthetic declines of > 60 % in drought-sensitive cotton genotypes, whereas Tang et al. (2022) noted that sensitive plants exhibit faster reductions and slower recovery in photosynthesis under stress.

Severe drought also had the strongest impact on production traits in cultivars adapted to the Cerrado biome. The number of bolls (Figure 5A), boll mass (Figure 5B) and lint mass (Figure 5C) decreased by 64 % in FMT 705, 56 % in FMT 701, 53 % in CNPA ITA 90 and 52 % in FM 966. In contrast, other cultivars exhibited reductions of approximately 30 %, confirming their greater resilience under water deficit (Vasconcelos et al. 2018, Carvalho et al. 2019, Thomaz et al. 2024).

Regarding fiber quality, CNPA 7MH and CNPA 5M were the least affected by drought, maintaining the most favorable attributes (Table 2), particularly for fiber length, strength and micronaire

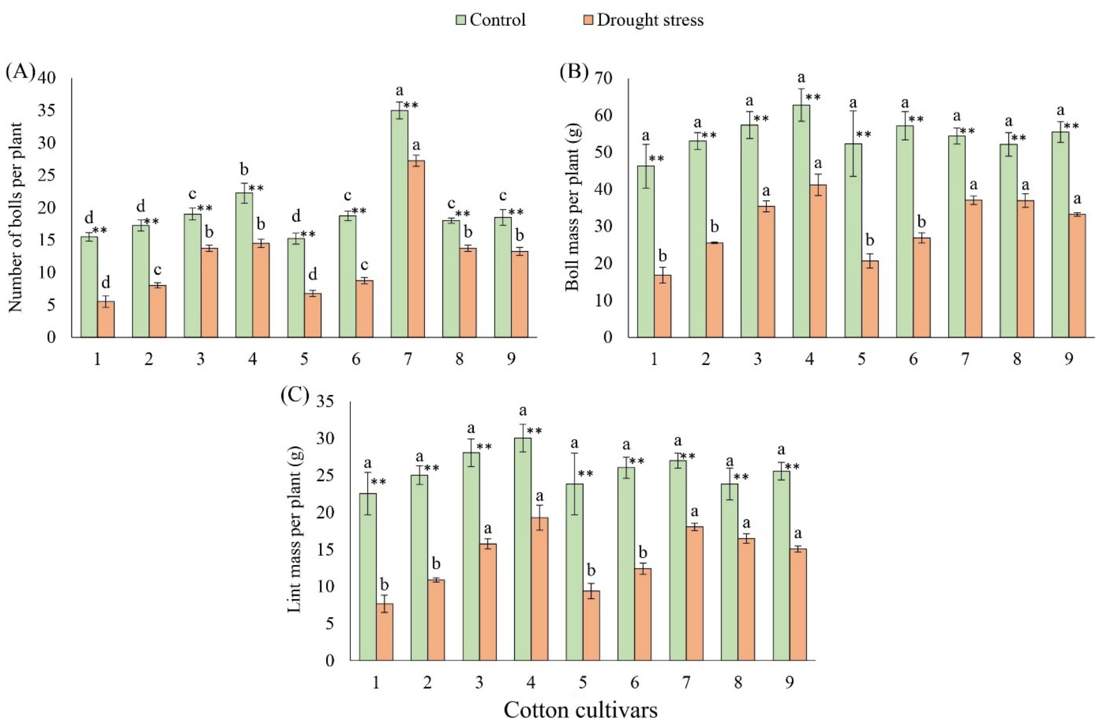

Figure 5. Number of bolls (A), boll mass (B) and lint mass (C) of cotton cultivars subjected to 21 days of water suppression. 1 - FMT 705; 2 - FM 966; 3 - BRS Rubi; 4 - BRS 286; 5 - FMT 701; 6 - CNPA ITA 90; 7 - CNPA 5M; 8 - CNPA 7MH; 9 - BRS Seridó. ** Statistical differences between water regimes at p ≤ 0.01 by the F-test. Uppercase and lowercase letters compare cultivars for the control and drought-stress conditions, respectively (Scott-Knott test; p ≤ 0.05). Bars represent the standard error of the mean.

index. Along with BRS Seridó, these cultivars produced fibers longer than 30 mm, meeting industry standards (Carvalho et al. 2015, Vasconcelos et al. 2020). This germplasm thus represents a valuable resource for breeding programs aimed at improving cotton performance under water limitation.

Fiber uniformity also remained stable in most cultivars (Table 2). Only CNPA 7MH and CNPA 5M showed slight increases (2.7 and 1.7 %, respectively) under drought, suggesting structural adjustments that preserved uniformity (Hussein et al. 2011, Vasconcelos et al. 2020). Short fiber index, yarn elongation and spinnability index were unaffected by water regime, indicating a strong genetic control.

Conversely, under drought stress, fiber strength declined by 12 % in FMT 705, 16 % in FMT 701 and 13 % in CNPA ITA 90 (Table 2), dropping their strength values below the 29 gf tex^{-1} industry minimum (Carvalho et al. 2015). In contrast, CNPA 7MH and CNPA 5M increased it by 7.6 and 6 %, respectively, maintaining values above this benchmark.

The micronaire index, a key indicator of fiber fineness and maturity, increased under stress in FMT 705 (+21 %), FM 966 (+18 %), FMT 701 (+30 %), CNPA 7MH (+21 %) and BRS Seridó (+8 %), while remaining stable in other cultivars (Table 2). Most values remained within the optimal range of 3.6-4.2 (Kasama et al. 2016). Because increases occurred in both drought-sensitive and drought-tolerant cultivars, the micronaire index alone is insufficient to discriminate drought tolerance.

Fiber maturity showed no significant changes in most cultivars, except for FMT 705, FM 966, FMT 701 (+2 % under stress) and BRS Seridó (+3.5 %). All cultivars maintained fiber maturity values above 0.80, the minimum required by the textile industry (Carvalho et al. 2015). According to Kijun et al. (2014), fibers below this threshold are prone to defects and uneven dye uptake.

To integrate plant traits, canonical variables (CV) analysis was performed using the mean matrices and the residual variance-covariance matrix. The first two canonical variables explained 89.09 % of the total variation (CV1 = 71.76 %; CV2 = 17.33 %), enabling the representation in a two-dimensional plane.

This analysis revealed four groups (Figure 6). Group 1, composed of CNPA 5M and CNPA 7MH, showed a superior drought tolerance, likely due to traits inherited from perennial cotton genotypes (Mocó), which are adapted to semiarid conditions. Group 2, including BRS Rubi, BRS 286 and BRS

Table 2. Fiber quality traits of cotton cultivars subjected to drought stress.

Cultivar	Length (mm)		Uniformity (%)		Short fiber index		Strength (g tex^{-1})	
	C	DS	C	DS	C	DS	C	DS
FMT 705	27.83 c	26.70 c	85.63 aA	83.34 dB	6.66 b	7.45 b	32.89 aA	28.83 cB
FM 966	28.97 c	29.86 b	86.24 a	86.51 a	6.60 b	6.43 c	33.97 a	33.64 a
BRS Rubi	19.16 dB	23.23 dA	80.20 c	81.15 d	9.76 a	9.42 a	26.32 c	26.26 c
BRS 286	28.96 c	29.96 b	84.26 b	85.42 b	6.82 b	6.75 c	30.91 b	31.14 b
FMT 701	28.01 c	29.04 b	85.03 b	84.43 c	7.28 b	7.18 b	33.21 aA	28.03 bB
CNPA ITA 90	29.40 b	29.07 b	84.90 b	84.39 d	7.29 b	7.78 b	32.18 aA	27.95 cB
CNPA 5M	32.21 a	33.41 a	83.69 bB	85.12 bA	6.81 b	6.28 c	30.57 bB	32.92 aA
CNPA 7MH	32.16 a	33.38 a	84.09 bB	86.44 aA	6.17 b	6.15 c	32.87 aB	34.83 aA
BRS Seridó	30.13 b	30.69 b	86.20 a	85.94 c	6.31 b	6.76 c	32.43 a	32.20 b
Cultivar	Yarn elongation (%)		Micronaire index		Maturity		Spinnability index	
	C	DS	C	DS	C	DS	C	DS
FMT 705	5.48 a	5.08 a	4.29 bB	5.21 aA	0.87 bB	0.89 aA	2,996.53 a	2,350.02 d
FM 966	4.73 b	4.17 b	3.84 bB	4.52 bA	0.86 bB	0.88 aA	3,262.30 a	3,191.14 b
BRS Rubi	6.11 a	5.71 a	4.75 a	4.29 b	0.88 a	0.86 b	1,640.71 b	1,880.91 e
BRS 286	6.06 a	5.60 a	4.04 b	3.69 c	0.85 c	8.85 c	2,840.98 a	3,101.44 c
FMT 701	5.38 a	4.73 b	3.06 cB	3.99 cA	0.84 cB	0.86 bA	3,060.10 a	3,005.57 c
CNPA ITA 90	6.04 a	5.88 a	3.46 c	3.07 d	0.84 c	0.84 c	3,182.62 a	2,949.36 c
CNPA 5M	4.97 b	5.12 a	3.49 c	3.69 c	0.85 c	0.85 c	3,106.68 a	3,247.02 b
CNPA 7MH	4.39 b	4.79 b	3.12 cB	3.77 cA	0.84 c	0.86 b	3,339.67 a	3,589.48 a
BRS Seridó	5.57 a	5.32 a	3.85 bB	4.17 bA	0.85 cB	0.88 aA	3,233.65 a	2,958.60 c

C: control; DS: drought stress. Lowercase letters indicate comparisons among cultivars within the same water regime (Scott-Knott test; $p \leq 0.05$). Uppercase letters indicate significant differences between water regimes within each cultivar (F test; $p \leq 0.05$). Absence of uppercase letters indicates no significant differences.

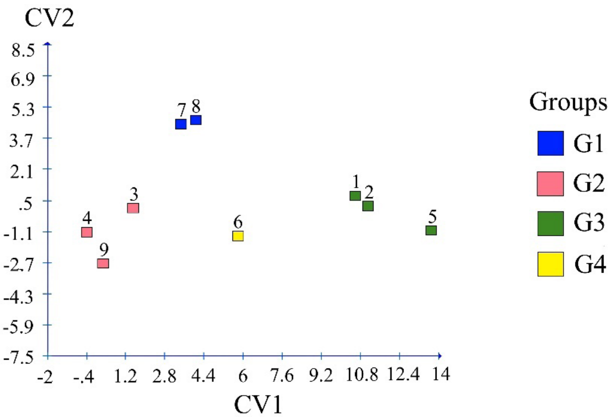

Figure 6. Dispersion of cotton cultivars subjected to water suppression, based on canonical variables. 1 - FMT 705; 2 - FM 966; 3 - BRS Rubi; 4 - BRS 286; 5 - FMT 701; 6 - CNPA ITA 90; 7 - CNPA 5M; 8 - CNPA 7MH; 9 - BRS Seridó. CV: canonical variable. G1: CNPA 5M and CNPA 7MH; G2: BRS Rubi, BRS 286 and BRS Seridó; G3: FMT 701, FM 966 and FMT 705; G4: CNPA ITA 90.

Seridó, consisted of early-maturing cultivars with broad adaptation to the Brazilian Northeast region. Group 3 comprised the most drought-sensitive cultivars: FMT 701, FM 966 and FMT 705. Despite their high fiber yield potential, their performance under stress was strongly impaired, limiting competitiveness in water-limited environments. Group 4 included only CNPA ITA 90, a long-cycle cultivar derived from Deltapine Acala 90. Although developed for the Cerrado, it shows potential for dual adaptation due to its excellent fiber quality.

These findings caution against relying solely on gas exchange parameters to discriminate drought tolerance. While informative and widely used as early stress indicators, they provide only a partial view of the complex responses involved in drought adaptation. In this study, cultivars with similar reductions in gas exchange displayed contrasting responses in growth, cellular hydration, integrity and production traits. This highlights the need to integrate multiple traits for a more accurate assessment of genotype adaptation to water-limited conditions.

CONCLUSIONS

1. BRS Rubi, BRS 286, BRS Seridó, CNPA 5M and CNPA 7MH exhibited distinct drought-tolerance strategies. BRS Rubi and BRS 286 (upland cultivars) maintained gas exchange rates close to control levels, whereas CNPA 5M (perennial) and CNPA 7MH (hybrid upland × perennial) reduced gas exchange to conserve water while sustaining a high relative water content, low electrolyte leakage and satisfactory growth;
2. BRS 286, BRS Seridó, CNPA 5M and CNPA 7MH combined superior physiological performance, higher boll production and better fiber quality, making them promising candidates for diallel crosses aimed at combining yield and drought tolerance.

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