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Fiber quality in upland cotton cultivars under water deficit strategies

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An evaluation was made of upland cotton cultivar fiber quality, when subjected to water deficit periods, on the phenological stages. The experiment was carried out at the Campina Grande Federal University, Pombal county Campus, Paraíba State, Brazil, between June and December 2015. Treatments were formed using a split-plot arrangement, in which the plots were 6 water deficit periods (P) (P1 = No deficit; P2 = Deficit in the initial growth stage; P3 = Deficit in the flower bud stage; P4 = Deficit in the flower stage; P5 = Deficit in the boll stage; and P6 = Deficit in the open boll stage) and the subplots, 2 upland cotton cultivars (C) (C1 = Brazil Seeds 286 and C2 = BRS 336), in randomized block design, with 4 replicates. The water deficits applied affected cultivars fiber quality, except maturity, reflectance and yellowness. The treatment without water deficit promoted the best fiber values, except of short fiber index, elongation and micronaire. Tested upland cotton cultivars were more tolerant to water deficit in the initial growth and boll stages. In general, BRS 336 was more tolerant to water deficits than BRS 286.

Key words: *Gossypium hirsutum* L. r. *latifolium* H., stress, cotton lint industry technological characteristics.

INTRODUCTION

Upland cotton (*Gossypium hirsutum* L. r. *latifolium* H.) is a dicotyledon of high economic and social importance that is cultivated in more than 100 countries of the world and its fiber, its main product, dresses almost half of humanity (43%). It is the only plant that economically produces fiber (41% on average in relation to the cotton seed dry weight - CSDW), oil (14 to 28% in relation to the CSDW) and protein (mean of 26% in relation to the CSDW), with high biological value (Beltrão, 2006).

In the semiarid region, irrigated cotton crops can be an excellent opportunity for the cotton sector, since the climatic characteristics of this region are able to produce fibers of excellent quality (Brito et al., 2011). However, according to Zonta et al. (2015a) research should seek to improve the irrigation management of cotton for high quality fibers.

In the semiarid region of the Brazilian Northeast, this plant has always stood out as one of the main subsistence crops (Sousa, 1994) and although it is considered a relatively drought-tolerant crop, its yield can

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be considerably reduced when water deficits occur during its development cycle (Bezerra et al., 2003).

Cotton requires, for its growth and development, an adequate amount of water defined according to the soil and climate. Lack of water at critical times of the cycle compromises crop growth, development and yield (Hussein et al., 2011; Luo et al., 2013). Beltrão et al. (2001) and Almeida et al. (2016) stated that water scarcity affects the growth of cotton and it most critically affects the phenological stages of flowering and formation and development of fruits.

Yazar et al. (2002) stated that final yield can be affected when water stress occurs during the cotton growing season, since it depends on the production and retention of open bolls, which can decrease with water stress. According to Pettigrew (2004), when water stress occurs in the early development stages, fibers are the most affected because they involve several physiological mechanisms of cell expansion.

In the initial stage of fiber elongation, up to 15 days after anthesis, water stress inhibits fiber elongation, length and uniformity (Lokhande and Reddy, 2014). Beltrão et al. (2008) stated that water deficit in the period of fiber elongation causes a decrease in its length.

Because of the presence of the genotype and environment interaction in cotton, a single cultivar cannot adapt to all cultivation regions of Brazil and it is important to identify the most appropriate cultivars for each region. Therefore, the success of a good agronomic performance of upland cotton will depend on the correct choice of the cultivar to be planted, as well as the environment and the cultural management (Araújo et al., 2013).

For Zonta et al. (2017), the value of the cotton fiber and the economic return obtained with the cotton crop depends on both yield and fiber quality, which depend on the interaction of several factors, such as management, environment and plant genetics. Santana et al. (2008) stated that the technological characteristics of cotton fiber, although conditioned by hereditary factors, are influenced by environmental factors and depend on the conditions of cultivation.

The objective of this study was to evaluate the fiber technological characteristics of upland cotton cultivars cultivated in the semiarid region of the Brazilian Northeast, subject to water deficit periods, on the phenological stages, in order to relate the rational use of water for sustainable crop production in the semiarid region of Paraíba State, Brazil, identifying the most appropriate management.

MATERIALS AND METHODS

The experiment was conducted under field conditions between June and December 2015 in the experimental area of the Center for Agricultural Science and Technology, of the Campina Grande Federal University, Pombal County Campus, Paraíba State, Brazil, located in the following geographic coordinates: 06° 47' 52" S, 37° 48' 10" W and 175 m above mean sea level. The predominant climate of the region is hot semiarid (the BSh type), according to Köppen climate classification. The soil of the experimental area was classified as Fluvic Neo-soil (Santos et al., 2013), loamy sand texture (80% sand, 5.96% clay and 14.51% silt) and water tension curve of 15.49% (at 0.1 atm. Field Capacity - FC), 4.63% (at 15.0 atm. Permanent Wilting Point - PWP) with available water content (AWC) of 6.63% at the depth of 0 to 40 cm.

Fertilization was carried out according to the technical recommendations for the crop (Cavalcanti, 2008), based on the analysis of soil fertility (Table 1), in the foundation, by the application of 30 kg ha^{-1} of N, 40 kg ha^{-1} of P_2O_5 and 10 kg ha^{-1} of K_2O and in 2 covers, with the application of 30 kg ha^{-1} of N and 5 kg ha^{-1} of K_2O. Liming was not needed.

Upland cotton cultivars were planted in single rows, spaced 1.0 m between rows × 0.10 m among plants.

The water used in the irrigation presented C_2S_1 salinity (low alkali and medium salinity hazard, an electric conductivity - EC of 0.315 dSm^{-1}) and low sodium adsorption ratio (SAR = 1.78). Such water can be used for irrigation whenever there is a moderate degree of leaching and special care in the preparation of the soil.

Water was applied by a localized irrigation system, with drip tapes and emitters spaced 0.10 m apart. Each treatment consisted of a lateral line, spaced from the other lines by 1 m, with 6 m of length, each.

Subsequently, after installation of the irrigation system and beginning of the experiment, a water distribution test was carried out in the field. Through this, the mean precipitation applied was determined as 8.86 mm h^{-1} and application efficiency (Ae) as 91%, according to Bernardo et al. (2008).

Irrigations were carried out daily, always in the morning, based on the availability of soil water (AWC) to plants. The replacement water volume was calculated considering the water lost by the crop evapotranspiration, which is represented as the difference between the soil water content in the field capacity (FC) and the current mean soil water content (SWC) measured in the depths of 0.10, 0.20, 0.30 and 0.40 m, which were measured before irrigations.

The current SWC was determined by the time-domain reflectometry (TDR) method, using a Delta-T-PR2 probe introduced through access pipes installed in each treatment.

With the data of the current SWC, using an Excel spreadsheet, in which the daily values of the SWC and the AWC to plants were recorded, the depth for the replacement of water and the time of irrigation were calculated for the treatments, which were the basis for the determination of the Net and Gross Irrigation Depth (NID and GID), according to Mantovani et al. (2009).

Treatments were formed from a split-plot arrangement, in which the plots were 6 water deficit periods (P) (P1 = No deficit; P2 = Deficit in the initial growth stage; P3 = Deficit in the flower bud stage; P4 = Deficit in the flower stage; P5 = Deficit in the boll stage; and P6 = Deficit in the open boll stage) and the subplots, 2 upland cotton cultivars (C) (C1 = Brazil Seeds 286 and C2 = BRS 336), in randomized block design, with 4 replicates, amounting to 48 experimental subplots (Figure 1).

Each period of water deficit consisted of 14 days without irrigation in the predetermined phenological stage shown in Table 2. After this period, the plants had normal irrigation until the end of the cycle. The total irrigation depth applied for each treatment is also shown in Table 2.

The necessary phytosanitary treatments were carried out when the first injuries and symptoms of pests and diseases appeared, as well as crop treatments for weed control.

For each cotton cultivar, the technological characteristics of the fiber were determined in a standard sample of 20 open bolls, collected in the middle third of the plants in the useful area of each subplot, before harvest, using a High Volume Instrument (HVI) of the Laboratory of Fibers and Yarns of Embrapa Cotton in Campina Grande county, Paraíba State, Brazil.

The fiber technological characteristics evaluated were Length

Table 1. Chemical characteristics of the soil of the experimental area at different depths (Pombal county, Paraíba State, Brazil, 2015).

Depth (cm)	pH Water	OM (%)	P (mg $100g^{-1}$)	Na^+	K^+	Ca^{2+}	Mg^{2+}
0-20	6.79	1.16	51.5	0.14	0.42	4.28	1.40
20-40	6.94	0.78	49.0	0.15	0.27	4.03	1.89

pH = Hidrogenionic potential; OM = organic matter.
Source: Irrigation and Salinity Laboratory, UFCG, Campina Grande County, Paraíba State, Brazil.

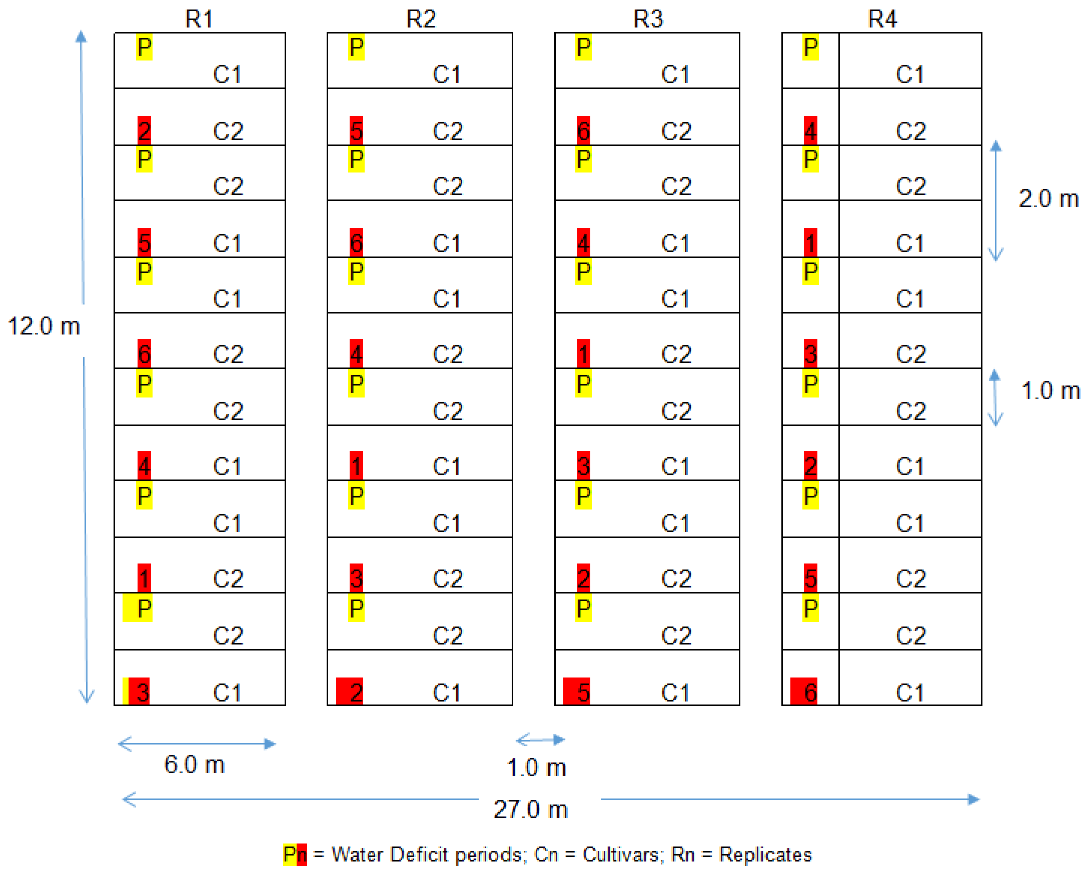

Figure 1. Design of the experimental area.
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

Table 2. Detail of the deficit treatments (Pombal County, Paraíba State, Brazil, 2015).

Treatment	Period of application of the deficit	Beginning of the deficit	Ending of the deficit	Total irrigation depth applied (La - mm)
No deficit (P1)	-	-	-	732.41
Deficit in the initial growth stage (P2)	22/Jul to 04/Aug	29 DAG	43 DAG	686.65
Deficit in the flower bud stage (P3)	03/Aug to 16/Aug	40 DAG	54 DAG	608.39
Deficit in the flower stage (P4)	18/Aug to 31/Aug	54 DAG	68 DAG	603.53
Deficit in the boll stage (P5)	26/Aug to 08/Sep	62 DAG	76 DAG	610.85
Deficit in the open boll stage (P6)	03/Oct to 16/Oct	100 DAG	114 DAG	649.67

(P1), …, (P6) = Treatments designation; DAG = days after germination.

(UHM_mm), Uniformity (UNF_%), Short Fiber Index (SFI_%), Resistance (STR_gf tex^{-1}), Elongation (ELG_%), Micronaire index (MIC_ μg inch^{-1}), Maturity (MAT_%), Reflectance (Rd_%), Yellowness (+b_dimensioless) and Count Strength Product (CSP_dimensionless).

The obtained data were subjected to analysis of variance through the F-test and the means of the factor levels or treatments, both qualitative, were compared by the Tukey test at 5% of probability using the statistical program SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

Because the higher concentration of cotton roots is in the 0.0 to 0.40 m depth layer, according to Amaral and Silva (2008), the soil moisture profiles were evaluated in this layer, during 126 days, in all treatments of water deficit periods (P1, …, P6) (Figure 2), comparing them to the water content in the FC and PWP averages of soil of the experimental area.

It can be observed that soil moisture in all treatments of each water deficit period was very close to the PWP, which increased during the period of application of the deficit and remained in approximately 50% of the AWC after this application. The deficit treatment applied in the open boll stage presented the same behavior of the irrigated treatment until a little before the application of the deficit period (Figure 2).

According to Sun et al. (2015), tolerance to water stress depends on the plant growth stage and when water deficit occurs at critical stages, such as the reproductive stage, plant growth and development may be affected. Thus, it is very likely that the metabolic and physiological functions of the plants have been severely affected in this study.

Significant effect of the deficit periods (P) for almost all studied fiber variables at 1% probability level, except for maturity, reflectance and yellowness, was detected. Regarding cultivar (C), there was a significant effect for all the variables of fiber at 1% of probability. In relation to the interaction (P × C), there was no significant effect for any of the variables studied, which means that the effect of the periods of water deficit tested did not depend on the cultivars studied and vice and versa (Table 3).

Other research studies corroborate all the evaluated variables, such as Zonta et al. (2015b), who have studied the effect of irrigation on yield and fiber quality in upland cotton cultivars; Zonta et al. (2017), who have studied the influence of sampling on the analysis of the fiber quality of irrigated and water stressed cotton; and Almeida et al. (2016), who have studied the effect of periods of water deficit in different phenological stages for cotton fiber quality, who have also found significant differences between treatments and cultivars studied for fiber variables at 1% probability level.

In relation to UHM, the lowest value was found in the P6 water deficit period, which differs from all other deficit treatments; and these, are not differentiated among each other (Figure 3A).

In this variable, the cultivars also differed between each other, with emphasis on cultivar BRS 336, classified as very long fiber cotton, with a mean of 32.31 mm, which is higher than value to cultivar BRS 286 with 29.04 mm, classified as long fiber cotton (Figure 3B), according to the industrial classification (Santana et al., 2008).

Both cultivars presented mean values within the cultivar standard, which is from 29.1 to 31.3% for BRS 286 and from 32.0 to 34.0% for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively.

The P6 water deficit decreased the UHM when compared to the other treatments and accentuated water deficits produce inferior fibers when compared to the other deficit treatments in the phenological stages (Figure 3A). This behavior has also been observed by other authors, such as Wen et al. (2013), who have stated that many fiber quality characteristics are directly influenced by the water deficits applied to the soil in different phenological stages.

In addition, according to Abidi et al. (2010), when the fiber growth period occurs within 3 weeks after anthesis, it may compromise UHM formed in these open bolls. Kim (2015) stated that the open bolls generally develop rapidly up to 16 days after anthesis and reach their maximum size approximately 24 days after it; the open bolls reach maturity between 40 and 60 days after anthesis.

The values of UHM vary according to the position of the open boll in the plant, being it higher in the middle and lower third and lower in the upper positions on the plant. Thus, when only samples from the middle third are harvested, the values tend to be overestimated in relation to the representative sample collection of the whole plant, which may have occurred in this assay (Kelly et al., 2015).

The results were similar to those found by Almeida et al. (2016) who, when studying fiber quality under water deficit in all phenological stages, except for the open boll stage, have found no significant effect of the water deficit on UHM.

The results obtained also confirm those of Pettigrew (2004), who stated that the occurrence of water stress soon after flowering and during the fiber elongation stage reduced UHM because of the direct connection with the physiological mechanisms of cell expansion. Similarly, Beltrão et al. (2008) have observed that the occurrence of water deficit in the fiber elongation period significantly decreased UHM.

Similarly to UHM, the lowest value of UNF (Figure 4A) was found in the P6 water deficit, which differs from the other deficit treatments, and these, do not differ among each other. The cultivars also differed between each other, with emphasis on BRS 336 (86.56%), classified as very uniform fiber cotton, with a higher mean than BRS 286 (85.06%), classified as uniform fiber cotton (Figure 4B), according to the industrial classification (Santana et al., 2008).

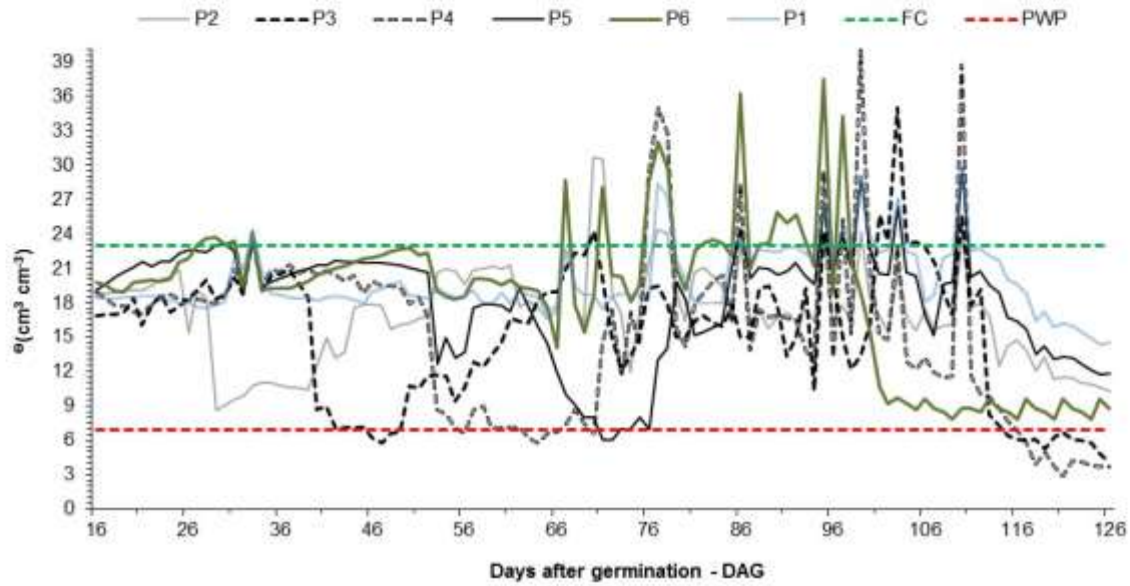

Figure 2. Variation of soil water content on the different water deficit treatments along experimental period. Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

Table 3. Summary of the analysis of variance of fiber technological characteristics variables of two upland cotton cultivars under water deficit strategies in phenological stages (Pombal county, Paraíba State, Brazil, 2015).

SV	DF	UHM	UNF	SFI	STR	ELG	MIC	MAT	Rd	+b	CSP
		Mean squares									
Block	3	0.32	1.96	0.13	1.27	0.0047	0.01	0.000017	0.87	0.07	36258.57
Deficit periods (P)	5	26.28**	17.76**	5.02**	20.60**	1.0103**	0.58**	0.000158^{ns}	2.51^{ns}	0.58^{ns}	1272342.47**
Error 1	15	2.20	0.98	0.29	3.15	0.2315	0.07	0.000055	0.78	0.42	72402.59
Cultivar (C)	1	128.38**	27.00**	8.41**	127.72**	17.2800**	0.46**	0.002408**	7.36**	17.16**	2697534.18**
(P × C)	5	0.33^{ns}	0.53^{ns}	0.13^{ns}	0.78^{ns}	0.1115^{ns}	0.06^{ns}	0.000033^{ns}	0.11^{ns}	0.30^{ns}	7875.73^{ns}
Error 2	18	1.48	1.11	0.61	2.90	0.1756	0.04	0.000040	0.34	0.30	59672.81
Total	47										
General Mean		30.67	85.81	6.51	33.67	4.44	5.01	0.89	83.67	9.70	3039.89
CV 1 (%)		4.85	1.16	8.38	5.27	10.82	5.38	0.83	1.06	6.72	8.85
CV 2 (%)		3.97	1.23	12.06	5.06	9.43	4.20	0.71	0.70	5.72	8.04

^{ns}, **, *: not significant and significant at p ≤ 0.01 and p ≤ 0.05, respectively (F-Test). MS = Mean squares; CV = coefficient of variation.

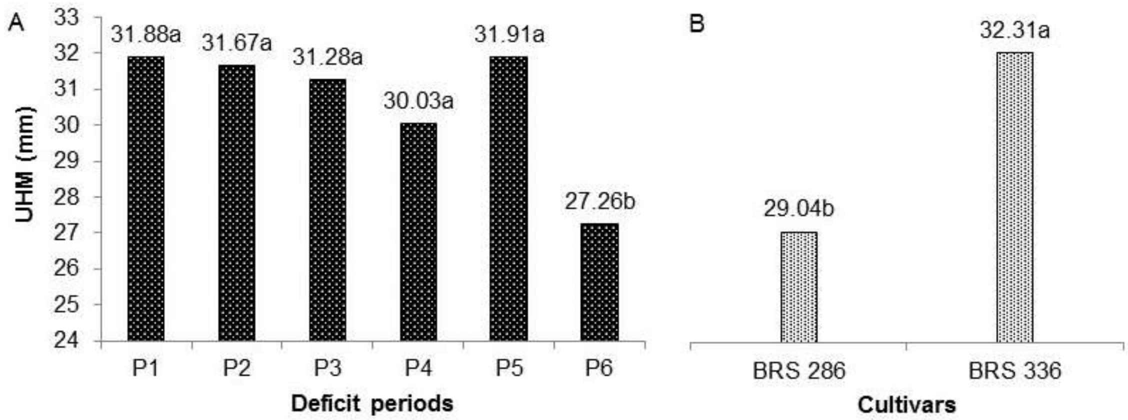

Figure 3. Means of fiber length of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

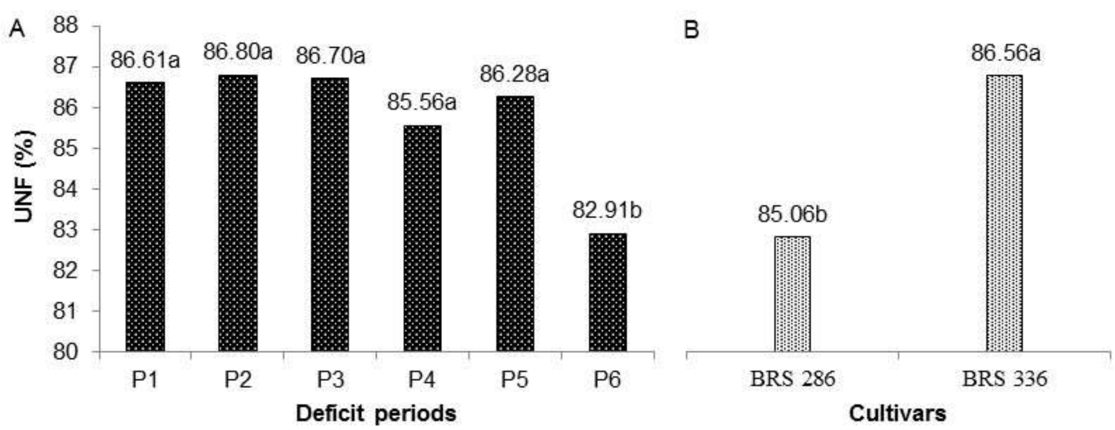

Figure 4. Means of fiber uniformity of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

Both cultivars presented mean values within the cultivar standard, from 83.5 to 85.5% for BRS 286 and from 82.6 to 86.3% for BRS 336 (Figure 4B), according to Silva Filho et al. (2008) and Morello et al. (2011), respectively.

The other water deficit treatments, both for UHM and UNF, probably recovered, in this research, from the irrigation return at the end of their deficit periods. The same did not occurred in P6, when, after the deficit period, irrigation was definitively suspended as it was the end of the cotton cycle. Thus, only P6 was affected, which reduced the cotton UHM and UNF produced on it.

Wen et al. (2013) stated same results when stating that environmental conditions such as water deficit may decrease the elongation rate or shorten the elongation period of the fibers, thus decreasing their UHM and UNF.

Considering the variable of SFI, the highest index (worst index) was obtained when the water deficit was applied in the open boll stage (P6), which is significantly higher to those obtained in the other treatments, and these, do not differ among each other (Figure 5A). Bradow and Davidonis (2000) that, although UHM is a primarily genetic trait, the SFI depends, in addition to genotype, on the cultivation conditions, among them water availability; the result in this work was similar to these authors only for cultivar factor.

SFI was also affected by the cultivars, especially BRS 336 (shorter, but better index) with mean of 6.09%, lower than the 6.92% value of BRS 286 (Figure 5B); however both were classified as short fiber cotton, according to the industrial classification (Santana et al., 2008). Only

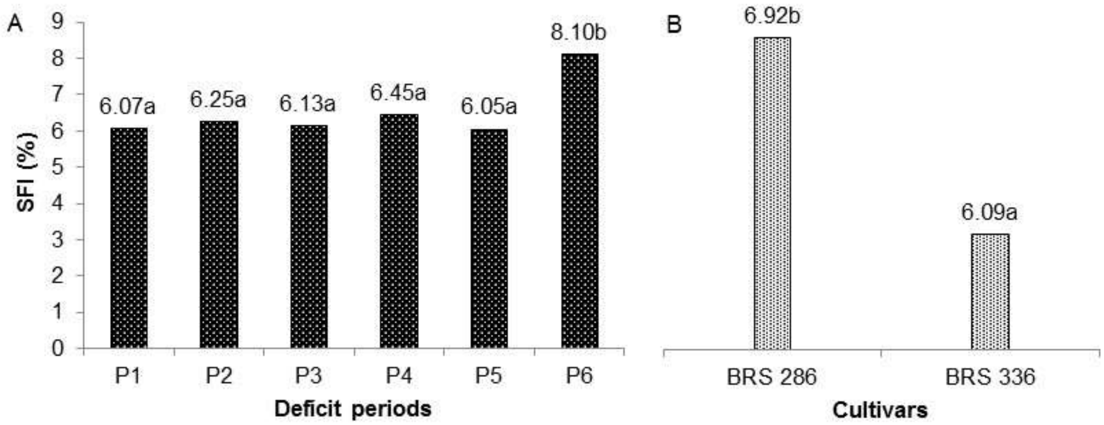

Figure 5. Means of short fiber index of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

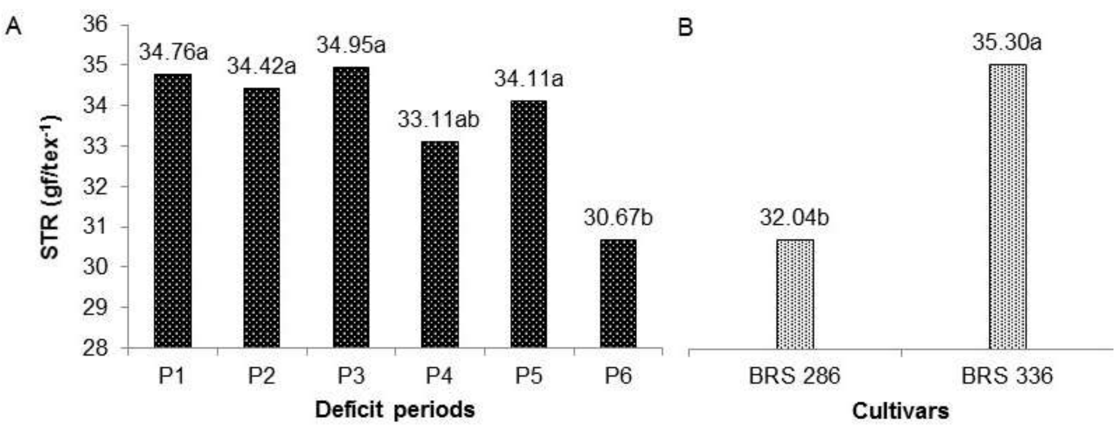

Figure 6. Means of fiber resistance of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

cultivar BRS 336 showed a mean value within the variety standard, which is 4.6 to 7.3%, according to Morello et al. (2011) (Figure 5B).

The results found in this study were satisfactory because, according to Cordão Sobrinho et al. (2015), the lower the SFI, the better the performance in the yarn manufacturing process and the greater the market interest in the product.

For STR, the lowest value was found in the open boll stage (P6) as well, except for the value of the treatment applied in the flower stage (P4) that did not differ from either P6 or the other treatments (Figure 6A).

Mean STR for BRS 286 was 32.04 and for BRS 336 was 35.30 gf tex^{-1} (which is more resistant than BRS 286) (Figure 6B), are classified as strong and very strong resistance, respectively, according to the industrial classification (Santana et al., 2008).

Both cultivars presented mean values above the cultivar standard, which is from 27.8 to 31.5 for cultivar BRS 286 and from 31.0 to 34.2% gf tex^{-1} for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively.

The cultivars studied in this study presented mean STR that fit the characteristics desirable by the industry. According to Cordão Sobrinho et al. (2015) and Zhao et al. (2012), the higher the STR, the greater its commercial value, quality gain and yield in the textile market.

BRS 336 had greater STR than BRS 286, which is interesting, as according to Zhao et al. (2012), UHM and STR are significant determinants of fiber quality. Bradow and Davidonis (2000) have concluded that STR has a negative correlation with yield.

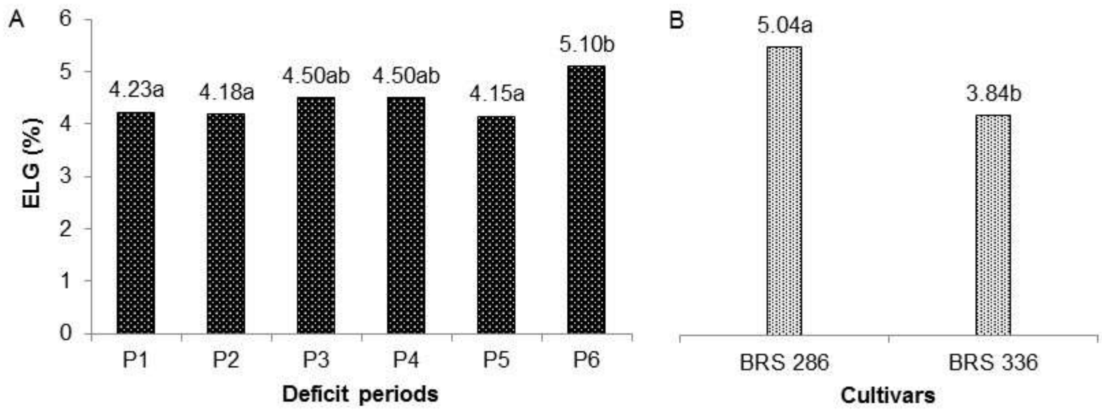

Figure 7. Means of fiber Elongation of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

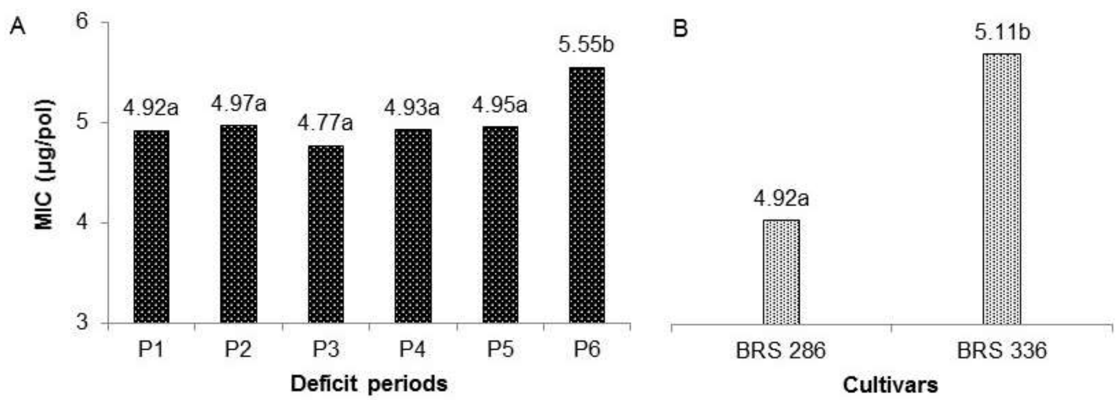

Figure 8. Means of fiber micronaire index of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, p<0.05).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

As for ELG, the best values were found in the treatments without deficit (P1) and with water deficits applied in the initial growth (P2) and boll (P5) stages, which did not differ from the other treatments, except for P6, or between each other. Water deficits applied in these two stages (P2 and P5) decreased ELG (Figure 7A), as, according to Cordão Sobrinho et al. (2015), the lower the ELG, the greater the resistance of the yarn.

On the other hand, the water deficit applied in the stages of flower bud (P3), flower (P4) and open boll (P6) negatively affected the ELG. According to Freire (2015), the process of fiber formation occurs from the fertilization of the flower, thus, water deficit at this stage can negatively affect fiber quality.

For the cultivars, the mean obtained for ELG was 5.04% for BRS 286 and 3.84% for BRS 336 (Figure 7B), which classify them as low and very low elongation, respectively, according to the industrial classification (Santana et al., 2008).

Both cultivars presented mean values below the cultivar standard, which is from 7.5 to 9.5% for BRS 286 and from 4.6 to 7.1% for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively.

Regarding the MIC, the highest (and worst) can be observed in the water deficit applied in the open boll stage (P6), which is significantly higher than in the other deficit treatments, and these, did not differ among each other (Figure 8A). The studied cultivars behaved differently with water deficits in different phenological stages, with a mean value of 4.92 and 5.11 µg pol^{-1} for BRS 286 and BRS 336, respectively (Figure 8B).

Both cultivars presented mean values above the

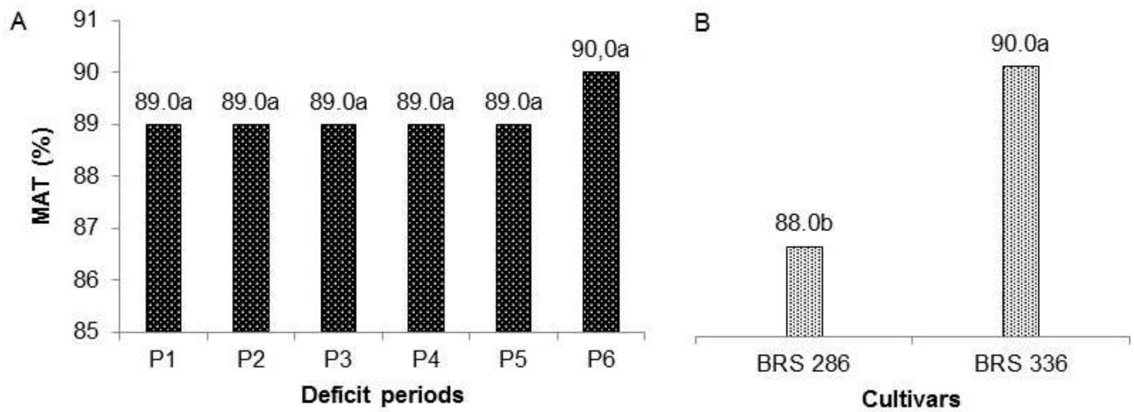

Figure 9. Means of fiber maturity of upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

cultivar standard, which is from 3.9 to 4.5 for BRS 286 and from 4.0 to 4.9 µg pol^{-1} for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively.

Regarding the industrial classification, the fibers of BRS 286 and BRS 336 are classified as medium and thick for the MIC, respectively, according to Santana et al. (2008) and Kljun et al. (2014).

According to Ge (2007), cotton fibers with MIC greater than 5.0 µg pol^{-1} are very thick fibers and subject to more irregularities and imperfections because of fiber reduction in the cross section of the yarn. Fibers with micronaire up to 3.80 µg pol^{-1} are classified as thin and are recommended for the manufacture of fine yarns, with higher commercial value in the textile industry. Lower micronaire values (<3.5) suggest that the fiber is immature and may cause neps and, consequently, low dye affinity (Kljun et al., 2014).

According to Cordão Sobrinho et al. (2015), it is important to keep a constant micronaire value, since a flow of thick fibers can cause loss of yarn resistance and decreased efficiency in the process, while thin fibers increase the number of neps in carding and ruptures in the process, besides negatively affecting the dyeing. Zhao et al. (2013) claim that fiber micronaire and maturity are important commercial quality parameters that guide management in fiber production.

According to Zonta et al. (2017), the results found in this study have a high micronaire index and may be associated with the collection of the fiber samples, in which mainly first position open bolls are collected.

Several authors such as Cordão Sobrinho et al. (2015) and Zonta et al. (2015a) have reported micronaire values above 5.0 µg pol^{-1} in experiments with irrigated cotton, considered thick and above the market tolerance. Similarly, Belot and Dutra (2015), presented higher values for this characteristic, which micronaire were close to or above 5.0 µg pol^{-1}.

The treatment periods of water deficit did not affect the MAT, with a mean value of 89% (Figure 9A). BRS 336 had a mean value of 90%, which is significantly higher than the BRS 286 value, which was 88% (Figure 9B), and they are classified as high and very high maturity, according to Santana et al. (2008). The same authors stated that the mean values found in the treatment periods of water deficits are classified as very mature fiber cotton.

MAT is a very important characteristic for the textile industry, since its variability has a negative impact on the final product, mainly in the dyeing, as immature fibers have lower absorptive capacity, making the fabric uneven (Kelly et al., 2015; Kim, 2015).

In relation to Rd and +b, which are related to the color of the fiber, both had the same behavior as MAT and were not affected by the water deficit periods, with mean value of 83.66% (Rd) (Figure 10A) and 9.70 (+b) (Figure 11A).

BRS 336 had a reflectance of 84.06%, which is significantly higher than that for BRS 286 (83.27%) (Figure 10B). Both cultivars presented mean values above the cultivar standard, which is from 75 to 80% for cultivar BRS 286 and from 68.4 to 82.8% for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively. Regarding industrial classification, Rd was classified as white cotton fiber for both cultivars (Santana et al. 2008).

These results, according to Cordão Sobrinho et al. (2015), are satisfactory, since the higher the Rd, the lower its graying and, consequently, the greater the interest of the cotton and textile industry chain as it adds a higher value to the product. Santana et al. (2001) have found similar results in a test assessing intrinsic

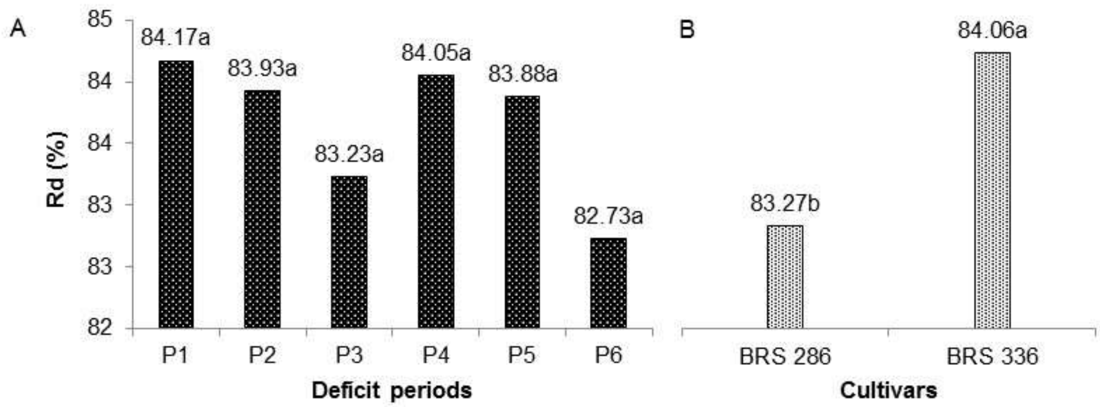

Figure 10. Means of fiber reflectance of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

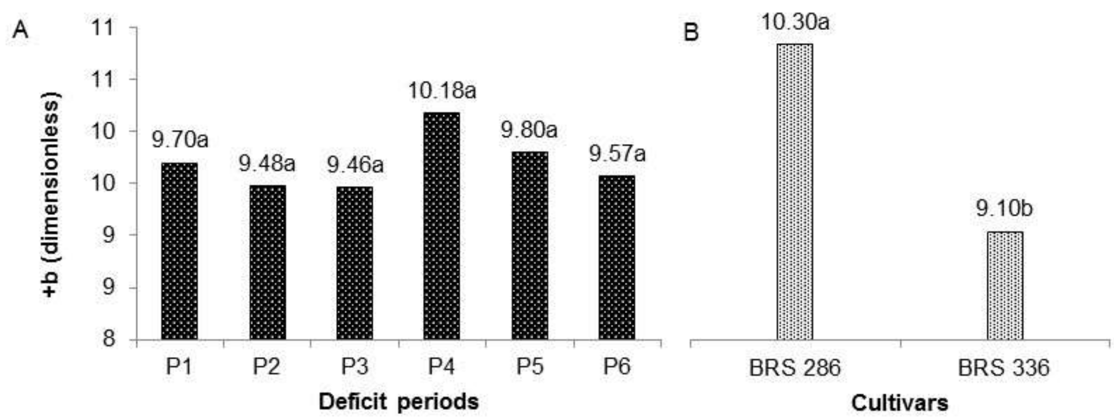

Figure 11. Means of fiber yellowness of two upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

characteristics of cotton fiber in Northeast Brazil.

Regarding +b, both cultivars presented mean values above the variety standard, which is from 7.0 to 9.0 for BRS 286 and from 4.9 to 8.6 for BRS 336, according to Silva Filho et al. (2008) and Morello et al. (2011), respectively. Yellowness also differed among cultivars, in which BRS 286 had the highest yellowness (10.60) and BRS 336 the lowest yellowness (9.23) (Figure 11B), both classified as white (Santana et al., 2008).

According to Bradow and Davidonis (2000), fiber color is directly linked to environmental factors during the growing season, which in this work was the water stress in different phenological stages. Zonta et al. (2015b) state that factors such as the application of defoliants and desiccants, pest attack, among others, can also influence fiber color.

According to Cordão Sobrinho et al. (2015), knowledge about fiber color is important, as it cannot always be seen with the naked eye and only in ultraviolet light and, if yellowness in the mixture is not controlled, problems such as differences in shades after dyeing can happen in the yarn and fabric.

Regarding CSP, it was lower when the water deficit was applied in the open boll stage (P6), which differs significantly from the other deficit treatments, and these, did not differ among each other (Figure 12A).

The mean value obtained for CSP by BRS 286 was 2802.83 and for BRS 336 was 3276.95 (best index), both classified as very high (Santana et al., 2008). Regarding cultivar standard, the values found in this study (Figure 12B) were higher than those found by Silva Filho et al. (2008) and Morello et al. (2011), respectively.

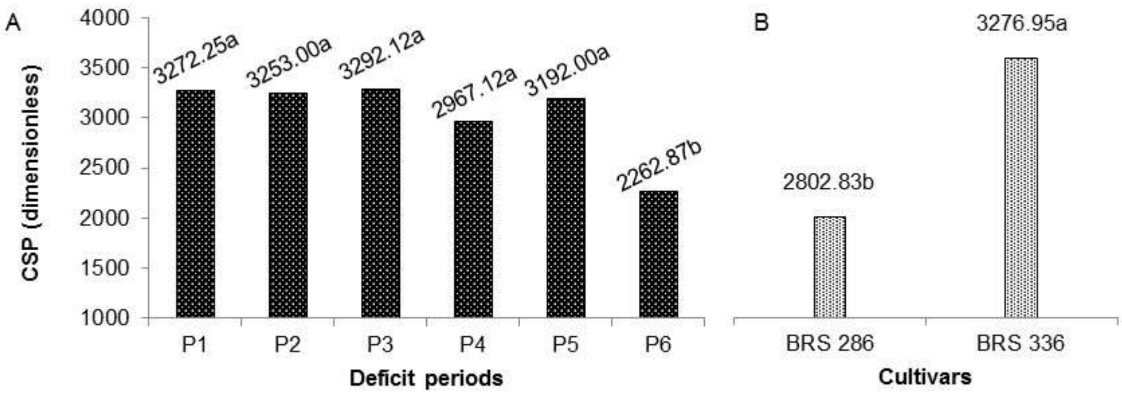

Figure 12. Means of fiber Count Strength Product of upland cotton cultivars under water deficit strategies in phenological stages (A. Deficit periods; B. Cultivars). Same letters in the factors (A and B) indicate no significant difference among means (Tukey, $p<0.05$).
Source: UFCG, Pombal County Campus, Paraíba State, Brazil (2015).

These results are satisfactory as, according to Cordão Sobrinho et al. (2015), the values found for CSP (greater than the variety mean) reflect the characteristic of yarn resistance that depends especially on individual fibers.

In summary, treatment without deficit (P1, irrigated throughout the cycle) promoted the best values in all analyzed variables, which indicates that treatments with deficit periods applied in different phenological stages of upland cotton cultivars BRS 286 and BRS 336 made possible fiber standards currently demanded by the market and cotton industry, except when the water deficit was applied in the flower bud (P3), flower (P4) and open boll (P6) stages, which negatively affected the cotton fiber quality.

BRS 336 presented the best results for almost all fiber characteristics evaluated, except micronaire. On the other hand, despite presenting lower values, BRS 286 presented values within the cultivar standard and thus it also meets most technological characteristics required for fibers by the modern textile industry. Finally, the cultivars tested have fiber quality in accordance with the cultivar and commercial standards of medium (BRS 286) and long (BRS 336) fibers.

The results obtained in this work demonstrate that the two cultivars evaluated have potential for irrigated cultivation in the semiarid region, provided that the correct management of irrigation and other cultural treatments is carried out. The differences found between the cultivars were expected as, according to Bradow and Davidonis (2000), there are always differences in fiber quality characteristics among different genotypes.

Santana et al. (2008) stated that the most important fiber characteristics in the current and modern textile processes are micronaire and resistance. It is important to note that even for micronaire, it was within an acceptable quality range by the brazilian textile industry (Zonta et al., 2015b).

Authors such as Bradow and Davidonis (2000), Bauer et al. (2009) and Feng et al. (2011) mentioned in their work that variation in fiber components can occur within a single plant and, when working with standard samples, as in this research, in which the middle third of the plants are collected, the result of these fiber analysis can be masked, not representing the actual condition of the plot or block, especially when working with experiments in which abiotic stresses, such as water stress, are applied.

The same authors also mentioned that the environmental variation that occurs within the plant canopy, between plants, or between plots, causes the fiber characteristics to present great variability as to open boll, plant and plot. In this way, the more uniform and representative is the sampling about the conditions of the plant and plot as a whole, the more representative the results of the fiber analysis (Zonta et al., 2017).

In order not to underestimate or overestimate the results, Zonta et al. (2017) indicate, for the determination of fiber quality in water stress tests, the collection of samples representing all open boll positions of the plant, in order to avoid erroneous estimates of the results. The same authors stated that when water stress is applied at different stages of the phenological crop cycle, this stress will affect the open bolls at different stages of growth and maturation, influencing them differently, which highlights a fact that may have happened in this study.

For cotton, several authors such as Wen et al. (2013), Brito et al. (2011), De Tar (2008) and Pettigrew (2004) have shown that fiber yield, percentage and quality in the crop are influenced when subjected to water deficit irrigation. Santana et al. (2008) and Zonta et al. (2017) stated that, although they are conditioned by hereditary factors, the technological characteristics of the cotton fiber undergo decisive influence of environmental factors (temperature, luminosity, water availability) and depend on the conditions of cultivation.

Conclusion

The water deficits applied in the different phenological stages of the upland cotton cultivars affected fiber quality, except maturity, reflectance and yellowness; treatment without water deficit promoted the best fiber values, except of short fiber index, elongation and micronaire; tested upland cotton cultivars was more tolerant to water deficit in the initial growth and boll stages; in general, BRS 336 was more tolerant to water deficits than BRS 286.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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