DELAYED HARVEST TIME AFFECTS STRENGTH AND COLOR PARAMETERS IN COTTON FIBER

Gonzalo J. Scarpin [a,#], Antonela E. Cereijo [a,b,c,#], Pablo N. Dileo[a], H. Martin Winkler[a,b], Robertino J. Muchut[a,b,c], Fernando G. Lorenzini[a,b], Roxana A. Roeschlin[a,b,c], Marcelo Paytas[a,*]

[a]Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental de Reconquista, Ruta Nacional Nº 11, km 773 (3560) Reconquista, Santa Fe, Argentina.

[b]Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET).

[c]Universidad Católica de Santa Fe (UCSF), Facultad de Ciencias Agropecuarias, Ludueña 612 S3560DYR, Reconquista, Santa Fe, Argentina

[#]Both authors contribute equally

[*]Corresponding author

Marcelo J. Paytas

paytas.marcelo@inta.gob.ar

Abbreviations: S, season; HT, harvest time; SCY, seed cotton yield; LP, lint percentage; LY, lint yield; HVI, high volume instrument; UHML: upper-half mean length, UI: uniformity index, Mic: micronaire, Str: strength, Rd, reflectance; +b, yellowness; C, cultivar; DDA, days from defoliant application

ABSTRACT

Cotton (*Gossypium hirsutum* L.) is the most widely used natural fiber worldwide in the textile industry, thus maintaining or even improving fiber quality is essential to produce the best quality yarn and uniform fabrics. Final fiber quality properties are determined not only by genotypes or environmental conditions during crop development but can also be affected by other post-maturity factors, such as harvesting and ginning methods, and harvest time. The aim of this study is to associate the different environmental factors that affect specific lint quality traits produced by a delay

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/agj2.21295.

in harvest time, also assessing cultivar effect. This field study included 4 cotton cultivars evaluated at 7 different harvest times (manual harvested) for different quality parameters. Results indicate that prolonged exposure of cotton fiber to the environment affects lint percentage (LP), strength (Str), reflectance (Rd) and yellowness (+b). Str showed a decrease of 0.02 g tex^{-1} per day from defoliant application, while LP, Rd and +b presented different rates according to the season. No differences were obtained neither for length nor for fineness and maturity (micronaire) traits. In addition, the analysis of the results together with the climatic data recorded during the experiments indicated a negative correlation between Str, Rd, and +b with the number of rainy days, accumulated precipitation, and frost temperatures. Overall, this study establishes specific relationships between certain fiber characteristics and environmental conditions, being an important tool for crop management with regards to climate predictions that could help to make estimates of economic losses when the harvest is delayed.

1. INTRODUCTION

Upland cotton (*Gossypiuym hirsutum* L.) is the world's largest natural textile fiber crop, with a great economic impact and contribution to sustainable development in fiber producing and consuming countries (Khan et al., 2022; Paytas and Ploschuk, 2013; Scarpin et al., 2022). It is a perennial crop that is cultivated as annual in more than 80 countries. In 2019/20, natural fiber production worldwide reached 34 million tons of which 80% came from cotton, producing about 26 million tons of fiber in 2020 (ICAC, 2022). In the same period, the industry consumed more than 103 million tons of textile fibers, 24% of which were cotton (Constable and Bange, 2015; Wang et al., 2020).

Today, most of the apparel and home textiles traded worldwide are made from cotton fiber more than from any other natural fiber. Continuous demands and advances in the textile industry encourage cotton farmers and researchers worldwide to maintain or even improve cotton fiber quality (Siddiqui et al., 2020; Wang et al., 2020). Cotton fiber consists in a long and thick seed epidermal cell with cellulose deposition whose development involves four stages: *i.* initiation; *ii.* fiber elongation; *iii.* Secondary cell wall biosynthesis, cellulose deposition, and cell wall thickening; and *iv.* maturation

(Stewart et al., 2009). Once the mature bolls open, the fibers dehydrate, the cylindrical shape of the cell wall collapses causing a twisted ribbon shape to the fiber. This particular feature allows cotton fiber to be spun and used in industry to obtain diverse textile products (Kloth and Turley, 2010; Wang et al., 2020).

To produce the best quality yarn and uniform fabrics, it is essential to have high fiber quality. Therefore, for industry purposes it is important to know, measure, and control each quality parameter of cotton fiber. Those parameters can be grouped in different modules according to High Volume Instrument (HVI) measurements (Siddiqui et al., 2020). Fiber length directly influences the quality of yarn and affects its unevenness: with longer fibers, higher yarn tenacity can be achieved. The fiber length module is determined by the Upper Half Mean Length (UHML), that is the mean among the 50% of the longer fibers; the mean length of all fibers, designated Medium Length (ML); Uniformity Index (UI) which expresses the ratio between ML and UHML; and the Short Fiber Index (SFI), an indication of the percentage of fibers that are less than 12.7 mm. Besides, by means of the HVI, Strength (Str) and Elongation (Elg) determinations are made that indicate the force required to break the fibers, and their elastic behavior, respectively. Cotton fiber with higher fiber strength and elongation would avoid breakage during the spinning process (Haigler, 2010; Sarwar and Iqbal, 2020; Siddiqui et al., 2020). The micronaire (Mic) is an indirect measure of fineness and maturity and is the most widely used instrumental test of fiber quality (Bradow and Davidonis, 2010; Sarwar and Iqbal, 2020). Both, fiber fineness and maturity, are important properties of cotton fiber, since they determine the number of fibers required to be spun to achieve a specific linear density of a yarn. Unlike the above-mentioned parameters, for which higher values are better, for Mic there is an accepted (3.5-5.0) and premium (3.7-4.2) range of values (Haigler, 2010; Siddiqui et al., 2020). On the other hand, fiber color is established by Reflectance (Rd) and Yellowness (+b) parameters. The first one is a value expressing the whiteness of the light that is reflected by the cotton fibers, while +b indicates the yellowness of the light reflected by the fibers. These two parameters are represented together in the Nickerson/Hunter color chart to determine the color grade of cotton. The Rd and the +b of cotton affect its ability to absorb dye and, together with trash content, they have always played an essential role in the evaluation of fiber value. The fiber quality, as well as yield, is determined by a complex interaction among genotypes, environmental fluctuations during plant growth and development, and the genetic response controlled by genotypes to those environmental conditions (Oosterhuis, 1990). Nevertheless, the quality properties of the fiber entering the industry can also be affected by other post-maturity factors such as harvest and ginning methods, and harvest time (Bednarz et al., 2002; Bradow and Davidonis, 2010; Cevheri and Şahin, 2021; Dadgar, 2020; Siddiqui et al., 2020).

The term “weathering” could be defined as the reduction or modification of yield and quality parameters of crops as the result of different environmental conditions from the time of physiological maturation to harvest. It has been used for a long time and its impact has been evaluated in many crops such as wheat (McCaig et al., 2006), soybean (Forti et al., 2010), corn (Thomison et al., 2011), rice (Tavakkoli et al., 2011) and sorghum (Dykes et al., 2011). These studies have reported effects of weathering on grain color, internal fracturing, seed germination quality, grain yield, seed oil, and protein content, among others. In cotton, the term *´boll weathering´* has been previously used to define all environmental effects influencing fiber yield and quality by exposure of the open (and mature) boll to different environmental conditions from the time of boll opening to the harvest. The environmental factors that could most affect fiber quality after boll opening are rain, relative humidity, wind, frost, hail, and UV radiation, as well as the occurrence of insects, fungi, bacteria, and fiber stained with plant debris (Bednarz et al., 2002; Kelly, 2006). These factors can negatively affect different fiber quality parameters such as strength, color, and trash content, thus reducing the market value of cotton (Bradow and Davidonis, 2010; Dadgar, 2020; Duckett et al., 1999; Hake et al., 1992).

A delay in cotton harvest due to ecological, environmental, or planning factors, causes a prolonged exposure of the mature bolls that would result in a loss of fiber quality and even a decrease in yields. Therefore, it is important to analyze the impact of this excessive exposure of mature and open capsules to different environmental conditions in order to identify specific relationships between affected quality parameters and the occurring environmental factors. In this context, the aims of the present work were: (i) to compare the seed cotton yield (SCY), lint percentage (LP), and lint quality traits in different commercial varieties from Argentina at optimal harvest time; (ii) to evaluate the effect of different harvest times (HT) on fiber quality traits; and (iii) to associate the different environmental factors and their effects on lint quality parameters produced by a delay in harvest time.

2. MATERIALS AND METHODS

2.1 Experimental site and conditions

Experiments were conducted under field conditions during the summer growing season of 2016/17 (S1) and 2020/21 (S2) at INTA Reconquista (29°15' S; 59°44 W), located in Santa Fe province, Argentina. The study region presents a subtropical-subhumid dry transition climate, whose rainfall distribution concentrates 70% of precipitations from October to March (Zuil, 2011). The experimental site presented a silt loam Aquertic Argiudoll belonging to the Reconquista series, with the following properties: soil organic matter 1.74%, available P 25.1 mg kg^{-1}, inorganic nitrogen 64.2 mg kg^{-1} and available K 226.78 mg kg^{-1}.

2.2 Experimental design

In each season, four cultivars were grown in a randomized-complete block with four replications for each cultivar. The genotypes used were DP 1238, DP 402, Guazuncho 2000 and NuOpal. These cultivars are the most used by farmers in Argentina and they contain transgenic traits for resistance to both glyphosate herbicide and to certain lepidopteran insects. All cultivars were planted with a population density of 15 plants m^{-2}, being the usual population used by farmers in Argentina. Plots consisted of 12 rows that were 10 m long with 0.52 m spacing between rows.

The study was sown on 3 November and 30 October for the 2016/17 and 2020/21 seasons, respectively. Each year plots were fertilized with two applications: one at sowing time and the other at the early vegetative stage (4th expanded leaf) with 100 kg ha^{-1} of diammonium phosphate (18-46-0) and 100 kg ha^{-1} of urea (46-0-0), respectively. Recommended insect and weed control were employed each growing season as needed. Meteorological data from sowing to maturity was monitored with the INTA Reconquista weather station located 250 m from field experiments.

2.3 Harvest, yield, and fiber quality analysis

When approximately 70% of the bolls on the latest maturing genotype had opened (March 8th for both 2017 and 2021) defoliation application in each plot was performed. At that time, a mixture of thidiazuron and diuron (500 ml ha^{-1}) was applied with a handheld sprayer to defoliate the crop. Only one application was needed because the regrowth was negligible since the temperatures recorded from defoliant application in both seasons. Subsequently, at seven different harvest times (HT) from the defoliant application (7, 14, 21, 28, 49, 70, and 84 days from defoliant application), all bolls along 3 m of two rows (randomly selected in each plot) were manually harvested, and seed cotton yield (SCY) was determined at each moment. It is important to clarify that at each HT cotton was taken from plants not previously harvested to assess the effect of weathering on lint quality parameters. The harvest timing was a subsample within the cultivar experimental unit (not its own as a subplot). Then, the collected samples were ginned on a ten-saw laboratory gin (Termo Eletro, Brazil) and lint percentage (LP) was determined. Lint yield (LY) was calculated by multiplying LP by SCY. In addition, lint samples were sent to a testing laboratory at the Association for the Promotion of Cotton Production in Santa Fe (APPA, Reconquista, Santa Fe) for quality determination by high volume instrument (HVI). HVI was used to quantify staple length (UHML), length uniformity (UI), fiber strength (Str), fiber micronaire (Mic), and fiber color parameters: reflectance (Rd) and yellowness (+b) on each HT fiber sample. It is important to mention that LY and SCY were evaluated only at HT1.

2.4 Statistical analysis

The results were subjected to an analysis of variance (ANOVA) for repeated measures using InfoStat software (Di Rienzo et al., 2010). Differences between cultivars and environmental conditions were assessed at 95% confidence level ($p \leq 0.05$) according to the least significant difference (LSD) test, considering cultivars (C), season (S), harvest time (HT) and their interactions (C*S, C*HT, S*HT and C*S*HT) as fixed effects. As a random effect the model nested plot in C, C in blocks and block in S

(1|season/block/cultivar/plot). Afterwards, simple linear regression analysis was conducted to evaluate associations between fiber quality parameters and days from defoliant application (DDA). When interactions were detected in the above mentioned ANOVA, regression analysis was split and two independent regressions were obtained. Furthermore, a principal component analysis (PCA) was carried out on all cultivars' lint quality parameters and meteorological data using InfoStat software (Di Rienzo et al., 2010). Meteorological data selected according to their contribution to variability explanation were: average maximum temperature (Avg. MaxT), average minimum temperature (Avg. MinT), number of rainy days (NRD) defined as any day with > 0 mm, accumulated rainfall (AcuRain), number of days with minimum temperature less than 5 °C (NDMinT<5), number of days with minimum temperature less than 10 °C (NDMinT<10) and, average daily sunshine hours (Avg. DSh). In this sense, it is worth mentioning that the meteorological data was averaged (temperature and daily sunshine) or counted (number of days and rainfall) between defoliant application and each HT.

3. RESULTS

3.1 Environmental data

The environmental conditions presented during each season and their comparison with historical data are presented in Table 1. Overall, minimum monthly mean temperature was higher in S1 than S2, whereas, maximum mean temperature was higher in S2 than S1. In terms of rainfall, S1 recorded higher precipitations and days with precipitations than S2. Nonetheless, S2 registered higher precipitations during crop growth (November – March). By contrast, solar radiation levels were similar across seasons (Table 1).

3.2 Cultivars and season differences

The length of the cotton growth cycle, using 12°C as a base threshold, did not significatively differ between cultivars (Figure 1). Nevertheless, DP 402 and DP 1238 were the cultivars which presented the shortest and longest cycle, respectively (Figure 1). Growth cycle values (mean of both years, all cultivars) were 1513 °C day, with averages of 444, 783, 1053, and 1350 °C day to reach 1st square, 1st white flower opened, cutout, and 1st boll opened, respectively. These values indicated that the different cultivars were exposed to the same temperature conditions in both seasons.

The ANOVA showed significant differences for LY, LP, SCY, UHML, UI, Mic and Rd between the explored environments (S), whereas LP, Mic and Rd showed differences between cultivars (Table 2). Also, the analysis exhibited significant interaction (C*S) for LP. The mean values among cultivars, considering the optimal moment for harvest were LY: 1193 kg ha^{-1}; LP: 41.2%; SCY: 3124 kg ha^{-1}; UHML: 28.3 mm; UI: 82.4%; Mic: 4.3; Str: 31.8 g tex^{-1}; Rd: 77.3; and +b: 7.8 (Table 2). In terms of S, S2 showed the highest value in LY, SCY and Rd, whereas S1 exhibited the highest value in LP, UHML, UI and Mic. Regarding the interaction C*S, DP 1238 in S1 presented the highest LP (43.0%) and NuOpal in S1 showed the lowest LP (38.9%). The significant interaction found was mainly driven by the fact that LP obtained in S1 was higher than in S2 for the different cultivars, except for NuOpal that presented higher LP in S2 than in S1.

3.3 Effect of harvest time on lint quality parameters

Table 2 shows that LP, Str, Rd and +b were significantly affected by HT, while UHML, UI and Mic did not present differences along the evaluated HT. Str, Rd and +b showed a reduction of 6.4%, 8.4% and 9%, respectively, from HT1 (7 DDA) to HT7 (84 DDA), while a significant increase was recorded for LP in the two final HT evaluated (Table 2). However, significant interactions between S*HT were detected for LP, Rd and +b, showing differences according to the season.

The lint quality parameters Str, Rd, and +b presented a significant linear decrease in response to the days since defoliant application (DDA). Figure 2 shows that Str exhibited a daily reduction rate of 0.02 g tex^{-1} per day from defoliant application, regardless of cultivar or season. On the hand, since LP, Rd and +b presented significant interactions S*HT, the reduction rates were calculated depending on season (Figure 2). LP increased 0.03% per day from defoliant application for the first season (S1), while no significant variations were detected for S2 (Figure 2).

3.4 Relationship between meteorological data and lint quality parameters

Figure 3 shows the biplot analysis of lint quality parameters and their relationship with harvest time and meteorological data from the study conducted with four upland cotton genotypes in two seasons. The evaluation of the main components allowed us to understand the complex relationship between the lint quality parameters and the harvest times. Two eigenvalues were used that explained 79.5% of the variability in the original data set (Table 3). The interpretation of the results from the principal components was based on the assumption that PC1 was represented on the abscissa axis while PC2 was represented on the coordinate axis (Figure 3). The correlations between the variables and the main components are shown in Table 3. Avg. MinT, Rd, Avg. MaxT, Str, Avg. DSh, +b, UI, and LP presented positive correlation with PC1 whereas, NRD, AcuRain, NDMinT<10, NDMinT<5, and Mic showed negative correlation with PC1.

PC and correlation analysis confirmed that Rd, +b, Str, and UI were lower when NRD, AcuRain, NDMinT<10, and NDMinT<5 were higher. Furthermore, at PC2, UI, UHML, and LP registered positive correlation, while NDMinT<5, Str, +b, NDMinT<10, and Avg. DSh presented negative correlation, indicating that the longer and more uniform the fiber, the less the days with temperatures below 5 °C and the less the values of Str, and +b. To sum up, the different HT were horizontally aligned with HT1 to HT4 being on the right side of the PC analysis and close to the highest values of Rd, +b, and Str, while HT5 to HT7 were located on the left side of the PC analysis and close to highest values of NRD, AcuRain, NDMinT<5, and NDMinT<10.

4. DISCUSSION

4.1 Comparative behavior of analyzed cultivars in both season

Unlike other crops such as wheat and soybean, where photoperiod and vernalization, along with temperature, have an effect on the rate of development of cultivars (Miralles and Slafer, 1999; Nico et al., 2016), temperature is the only environmental factor affecting the developmental rate of cotton. In this context, the concept of day degree is an important tool to estimate the cycle length of each cotton genotype (Stewart et al., 2009).

Our experiments indicated that differences in thermal time among cultivars were not significant for any of the four developmental moments evaluated. In addition, the requirement of day degree to reach the different stages of development in cultivars from Argentina was lower than cultivars from Australia, Brazil, or the United States (Constable and Shaw, 1988; Robertson et al., 2007; Rosolem, 2001). The use of shorter-season cultivars in Argentina is explained by the shorter growing season (lower temperatures and rate of solar radiation) compared to the abovementioned countries, along with the narrow furrow planting system widely used in this region, which could contribute to increasing the earliness of the cultivars used (Brodrick et al., 2010).

Significant differences for LP were found among cultivars, while no variations were detected for lint yield and lint quality parameters (except for Mic and Rd). On the other hand, the analysis between seasons showed differences in LY, LP, SCY, UHML, UI, Mic and Rd. Altogether, average LY recorded in this study is similar to previous works conducted under experimental conditions in Argentina (Paytas and Tarrago, 2011; Scarpin et al., 2022) and it is also worth mentioning that it was above the national average of approximately 850 kg ha^{-1} (ICAC, 2022). The differences found in terms of lint yield between seasons and not among cultivars could be associated with the larger dependence of yield on environmental conditions (Meredith Jr et al., 2012; Snider et al., 2013). Recently, Scarpin et al. (2022) have demonstrated that the variation among environments explained close to 80% of the variation in LY and SCY in a similar environment (Scarpin et al., 2022). In addition, these and other authors have established a high genotypic dependence for LP variation (Campbell et al., 2012; Campbell and Jones, 2005) that could explain the differences among cultivars and, therefore, the minor changes of this character observed in the different environments. Considering the climatic differences between seasons, the higher SCY and LY obtained in S2 than in S1 could be associated with higher rates of solar radiation during the main growing months (December to February), proper minimum and maximum temperatures, and balanced rainfall distribution in S2 compared to S1. In agreement, several authors have associated larger yields with higher rates of solar radiation, rainfall, or temperature regimen during the growing periods (Conaty and Constable, 2020; Iqbal et al., 2020; Pettigrew et al., 2013). On the other hand, among all the quality parameters assessed, the statistical analysis showed significant differences in UHML, UI, Mic and Rd between seasons, while Mic and Rd also presented differences among cultivars. Higher Mic variation between seasons, in comparison to other lint quality parameters, has already been reported by many researchers (Campbell et al., 2012; Meredith Jr et al., 2012; Snider et al., 2013). This feature is associated with the fact that Mic value depends mainly on the cellulose deposition in the secondary wall of the fiber's cell, a process directly influenced by crop growing conditions during this period.

4.2 Weathering effect on cotton production

To the best of our knowledge, this is the first work that quantifies the weathering effects on cotton lint quality parameters over time produced by delayed harvest. Previously, several researchers have reported about this subject, but with different approaches or lack of statistical references. Hake et al. (1992) informed about the effects of weathering on yield and some fiber quality traits, but with an educational approach and without scientific or statistical evidence. Also, Kelly (2006) did a three-year work where the author evaluated the effects of harvest timing and field cleaning on yield and quality parameters of fiber. However, the author only evaluated the differences using one cultivar and the trials were harvested with stripper machines. Furthermore, Cevheri and Şahin (2021) studied the effects of HT on lint and yarn quality parameters, nonetheless they explained differences between years rather than harvest times. In addition, Bednarz et al. (2002) stated differences between lint quality at different moments, although their main objective was to evaluate the effect of defoliant application at different times rather than the weathering effects. Therefore, this reinforces the importance of the results submitted in this work, where we quantify and statistically compare the effects of weathering on fiber quality.

When evaluating weathering effects on cotton production, several authors have stated that a late harvest will not reduce lint yield if cotton does not fall to the ground before harvest (Buxton et al., 1973; Kelly, 2006). Nevertheless, several authors have reported significant yield reductions associated with delayed HT (Bednarz et al., 2002; Parvin, 2005; Ray and Minton, 1973). Coincidentally, these studies also recorded significant rainfall events after boll opening in addition to losses in LY with delayed harvest, so the observed reduction in LY could be related to these climatic events. Also, the boll type of cotton cultivars used in each experiment could be significantly related with pre-harvest losses of SCY. There are some genotypes that present a more open capsule, mostly adapted to a picker type of harvest, while others, that produce less open capsules, are preferable for a stripper harvesting system. The former are considered to be more susceptible to physical pre-harvest seed cotton losses than the latter (Kelly, 2006). In this context, one limitation of this work is that LY and SCY were not evaluated for the different HT, so there is not available data to make a discussion related to the results of the above mentioned authors. However, the main objective from our work was to evaluate the weathering effect on lint quality parameters, this being the reason for having data of LY and SCY only for HT1 (the optimal harvest time).

On the other hand, our outcomes about LP agree with several researchers who demonstrated increases in LP with a delayed harvest (Kelly, 2006). They associated the increase in LP to the fact that immature bolls that had not yet opened for the first HT were already opened for late HT, providing less trash or bur, which leads to higher LP. In our work, an interaction S*HT was detected, showing a significant increase in S1, while no variations were detected for S2. These differences between seasons could be related to the higher average maximum temperatures in March, April and May in S2 compared to S1. This higher temperature could generate more open bolls in less time for S2, probably generating less trash which could result in a high LP at the latest HT evaluated.

When considering the effects of weathering on lint quality parameters, our results indicated significant differences among the evaluated HT in Str and lint color parameters (Rd and +b), while no differences were found in UHML, Mic, and UI. Our study also aligns with the findings of several authors who have also observed lower values for Str, Rd, and +b in late HT (Buxton et al., 1973; Hake et al., 1992; Kelly, 2006). Regarding fiber strength, they suggest that the observed reductions resulting from prolonged exposure of cotton in the field might be more associated with UV radiation and fungi than with precipitation amounts. This effect is explained by the fact that the absorption of UV light by certain minerals in the fiber could break down some cellulose molecules and weaken fiber strength.

At the same time, as it is widely known, fungi can feed on the fiber's cellulose, leading to the same effect on cotton fiber Str (Hake et al., 1992; Kelly, 2006).

Moreover, the reduction in reflectance (Rd) is one of the most consistent quality losses due to weathering on cotton (Hake et al., 1992). Our findings are in line with those of Silvertooth (2001) who stated that, if open bolls are exposed to long-term or heavy rains, the cotton will be spotted and the graying and yellowness values will increase, which means lower values of Rd and +b, respectively. Our results also indicate an interaction S*HT for Rd and +b, with different decrease rates between seasons. For Rd the decrease rate was about 4 times higher in S1 than in S2. This could be related to higher rainfall, number of days with precipitation and less cumulative global radiation recorded between march and may for S1. Regarding +b, S2 showed no significant decrease in this parameter, being probably associated with the same above-mentioned weather conditions recorded for S2 compared to S1.

On the other hand, our research did not show differences in terms of UHML, UI, and Mic. In contrast to our study, Kelly (2006) observed significant reductions in UHML over the 3 years of the study due to weathering. The decrease in UHML could be explained by cellulose chain damage and oxidation as reported by Hessler and Upton (1955). In this regard, the absence of significant differences in UHML presented here could be attributed to a shorter exposure time or more favorable environmental conditions compared to those of the works mentioned above. Furthermore, previous studies have observed dissimilar results in terms of micronaire reductions due to different HT, presenting a small decrease in most cases (Buxton et al., 1973; Kelly, 2006) or being non-existent in other cases (Bednarz et al., 2002; Hake et al., 1992). Further studies have also investigated the UI parameter in different HT. However, differences have rarely been reported, being coincident with our results (Bednarz et al., 2002; Kelly, 2006).

As mentioned above, changes in Str and color parameters have been previously reported by several authors. Still, this is the first study to report a rate of decrease in each parameter per day since defoliant application. Although this is a two site-years study, the obtained values, which were determined by the evaluation of these two different environments as well as cultivars, could help to make estimates of economic losses according to the commercial parameters of each region when the harvest is delayed. These economic assessments of losses have been previously carried out, albeit presumably by approximation, as specific rates of decrease were not reported (Kelly, 2006; Parvin, 2005).

4.3 Weathering effect and its association with meteorological data

Almost all reports about weathering on cotton link its effect to the meteorological data, especially rain, temperature, relative humidity, and UV radiation (Buxton et al., 1973; Hake et al., 1992; Kelly, 2006; Parvin, 2005). However, none of them establishes specific relationships between individual quality parameters and certain environmental conditions. In this regard, multivariate statistical analysis is an important tool used to analyze the information that would be otherwise difficult to interpret. According to the collected data from this work, the multivariate analysis was the best statistical option to perform the analysis, since all the variables are interrelated with each other, and the information obtained is generated in groups and not individually (Alberto Moldes et al., 2013). In this context, the PC analysis revealed that the first 2 PCs are significant contributors to the total variation covering 79.6% of HT, LP, fiber quality, and meteorological data. The variables NRD, AcuRain, NDMinT<5, NDMinT<10, Avg. DSh, Avg MaxT, Avg MinT, Rd, Str, and +b contributed to the first PC which explained the largest proportion of the total variation. Besides, it is worth recalling that the results from the PCA in the current study are congruent with previous findings on cotton crops by other researchers (Jamil et al., 2020; Zafar et al., 2022).

In our experiments, this analysis indicated that Str and color parameters (Rd and +b) were negatively correlated with the number of rainy days, accumulated precipitation, and frost temperatures. These results imply that when the number of rainfall events increases and temperature decreases, fibers will have lower Str, Rd, and +b values as the harvest date is delayed. On the other hand, different results were obtained for UHML, UI and Mic for which the environmental conditions recorded did not present an association with these variables, suggesting that these parameters would not be affected as the harvest date is delayed.

Although many of the published studies did not establish a specific relationship between weathering and environmental data, most of them suggest associations between changes in fiber quality and meteorological data recorded during the experiments. Parvin (2005) informed a yield decrease of 1.01 kg of lint per millimeter of accumulative rainfall, Kelly (2006) associated increases in LP with later dates of first frost, decreases in LY with increases in rainfall events, and reductions in Str and color parameters with prolonged fiber exposure to UV radiation and rain. Furthermore, Cevheri and Şahin (2021) related lower UHML, Str, and Rd with higher rainfall events, and Hake et al. (1992) directly linked the effects of rain, wind, and UV radiation to fiber damage.

Altogether, this is the first study reporting lint quality parameters of Argentine cultivars, being similar to those reported in the main cotton-producing countries in terms of length, strength, uniformity, color, and micronaire (Abdelraheem et al., 2020; Ballester et al., 2021; Gao et al., 2020; McClanahan et al., 2020; Zeng et al., 2021). Results from our experiments have confirmed significant differences on lint yield and quality that depended on the cultivar, environment, or harvest time. Nevertheless, future studies may be carried out to complement or expand the current findings. The number of environments should be incremented, testing other cotton production areas in Argentina, with different temperature amplitudes and/or precipitation rates. Besides, other agronomic practices could be evaluated, such as plant density, row spacing, harvest methods, fertilization and growth regulators, to establish a possible relationship between these agronomic practices and fiber quality parameters.

5. CONCLUSIONS

Significant variations were obtained for LP among the cultivars analyzed, while no differences were detected for LY and SCY in these different commercial varieties from Argentina, with the LY recorded in this study (1193 kg ha^{-1}) above the national average (850 kg ha^{-1}). A delayed HT produces a weathering effect, which generates variations in the values of LP, Str, Rd, and +b. Str showed a decrease of 0.02 g tex^{-1} per day from defoliant application, while LP, Rd and +b presented different rates according to the season. Finally, the present study established different relationships between certain quality parameters and the meteorological data recorded during the experiments. These analyzes indicated negative correlations between Str, Rd, and +b on the one hand, and the number of rainy days, accumulated precipitation, and frost temperatures on the other.

6. ACKNOWLEDGMENTS

This research was financed by the National Institute of Agricultural Technology (INTA) and the Association for the Promotion of Cotton Production in Santa Fe (APPA). We thank them for supporting this research. Also, we are grateful to the technical staff at INTA for their assistance in field experiments, and to Pedro Alchourron and Julieta Agretti for their advice on language and grammar. GJS, PND are doctoral fellows from INTA and MJP is a research member from the same Institution. HMW is doctoral fellow from INTA-CONICET. AEC and RJM are postdoctoral fellows, FGL doctoral fellow and RAR is a research member from CONICET.

7. CONFLICT OF INTEREST

The authors declare no conflict of interest

8. REFERENCES LIST

Abdelraheem, A., Fang, D. D., Dever, J., & Zhang, J. (2020). QTL analysis of agronomic, fiber quality, and abiotic stress tolerance traits in a recombinant inbred population of pima cotton. Crop Science, 60(4), 1823-1843. doi:10.1002/csc2.20153

Alberto Moldes, C., Fontão de Lima Filho, O., Manuel Camiña, J., Gabriela Kiriachek, S., Lia Molas, M., & Mui Tsai, S. (2013). Assessment of the Effect of Silicon on Antioxidant Enzymes in Cotton Plants by Multivariate Analysis. Journal of agricultural and food chemistry, 61(47), 11243-11249. doi:10.1021/jf4039088

Ballester, C., Hornbuckle, J., Brinkhoff, J., & Quayle, W. C. (2021). Effects of three frequencies of irrigation and nitrogen rates on lint yield, nitrogen use efficiency and fibre quality of cotton under furrow irrigation. Agricultural Water Management, 248, 106783. doi:10.1016/j.agwat.2021.106783

Bednarz, C. W., Shurley, W. D., & Anthony, W. S. (2002). Losses in Yield, Quality, and Profitability of Cotton from Improper Harvest Timing. Agronomy Journal, 94(5), 1004-1011. doi:10.2134/agronj2002.1004

Bradow, J. M., & Davidonis, G. H. (2010). Effects of Environment on Fiber Quality. In J. M. Stewart, D. M. Oosterhuis, J. J. Heitholt, & J. R. Mauney (Eds.), Physiology of Cotton (pp. 229-245). Dordrecht: Springer Netherlands.

Brodrick, R., Bange, M. P., Milroy, S. P., & Hammer, G. L. (2010). Yield and maturity of ultra-narrow row cotton in high input production systems. Agronomy Journal, 102(3), 843-848.

Buxton, D. R., Stapleton, H. N., Makki, Y., & Briggs, R. E. (1973). Some Effects of Field Weathering of Seed Cotton in a Desert Environment1. Agronomy Journal, 65(1), 14-17. doi:10.2134/agronj1973.00021962006500010005x

Campbell, B. T., Chee, P. W., Lubbers, E., Bowman, D. T., Meredith, W. R., Johnson, J., . . . Jones, D. C. (2012). Dissecting Genotype × Environment Interactions and Trait Correlations Present in the Pee Dee Cotton Germplasm Collection following Seventy Years of Plant Breeding. Crop Science, 52(2), 690-699. doi:10.2135/cropsci2011.07.0380

Campbell, B. T., & Jones, M. A. (2005). Assessment of genotype × environment interactions for yield and fiber quality in cotton performance trials. Euphytica, 144(1-2), 69-78. doi:10.1007/s10681-005-4336-7

Cevheri, C. İ., & Şahin, M. (2021). Effect of Conditioning on Fiber Quality Characteristics (Afis) and Yarn Values of Cotton (Gossypium hirsutum L.). Journal of Natural Fibers, 1-13. doi:10.1080/15440478.2021.1993473

Conaty, W. C., & Constable, G. A. (2020). Factors responsible for yield improvement in new Gossypium hirsutum L. cotton cultivars. Field Crops Research, 250. doi:10.1016/j.fcr.2020.107780

Constable, G. A., & Bange, M. P. (2015). The yield potential of cotton (Gossypium hirsutum L.). Field Crops Research, 182, 98-106. doi:10.1016/j.fcr.2015.07.017

Constable, G. A., & Shaw, A. J. (1988). Temperature requirements for cotton. Agfact P5, 3(5).

Dadgar, M. (2020). The Harvesting and Ginning of Cotton. In H. Wang & H. Memon (Eds.), Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling (pp. 61-78). Singapore: Springer Singapore.

Di Rienzo, J., Balzarini, M., Gonzalez, L., Casanoves, F., Tablada, M., & Robledo, W. C. (2010). Infostat: sofware estadístico. Retrieved from https://www.infostat.com.ar/

Duckett, K., Zapletalova, T., Cheng, L., Ghorashi, H., & Watson, M. (1999). Color Grading of Cotton Part I: Spectral and Color Image Analysis. Textile Research Journal, 69(11), 876-886. doi:10.1177/004051759906901112

Dykes, L., Peterson, G. C., Rooney, W. L., & Rooney, L. W. (2011). Flavonoid composition of lemon-yellow sorghum genotypes. Food Chemistry, 128(1), 173-179. doi:10.1016/j.foodchem.2011.03.020

Forti, V. A., Cicero, S. M., & Pinto, T. L. F. (2010). Evaluation of the evolution of "weathering" damage and reduction in vigor of soybean seeds, TMG 113-RR cultivar, during storage, using X-ray images and physiological potential tests. Revista Brasileira de Sementes, 32(3), 123-133. doi:10.1590/s0101-31222010000300014

Gao, M., Xu, B., Wang, Y., Zhou, Z., & Hu, W. (2020). Quantifying individual and interactive effects of elevated temperature and drought stress on cotton yield and fibre quality. Journal of Agronomy and Crop Science, 207(3), 422-436. doi:10.1111/jac.12462

Haigler, C. H. (2010). Physiological and Anatomical Factors Determining Fiber Structure and Utility. In J. M. Stewart, D. M. Oosterhuis, J. J. Heitholt, & J. R. Mauney (Eds.), Physiology of Cotton (pp. 33-47). Dordrecht: Springer Netherlands.

Hake, K. D., Banks, J. C., Bourland, F. M., Sasser, P., Tugwell, N. P., & Williford, R. (1992). Boll Weathering. Retrieved from https://www.cotton.org/tech/physiology/cpt/fiberquality/upload/CPT-Nov92-REPOP.pdf

Hessler, L. E., & Upton, D. J. (1955). Chemical Properties of Field-Weathered Cotton. Textile Research Journal, 25(12), 1029-1034. doi:10.1177/004051755502501211

ICAC. (2022). Data portal. Retrieved from https://www.icac.org/DataPortal/DataPortal?MenuId=23

Iqbal, M., Khan, M. A., & Chattha, W. S. (2020). Developing short-season cotton genotypes with high harvest index might be an advantageous option under late duration plantings. Plant Genetic Resources: Characterization and Utilization, 18(3), 190-195. doi:10.1017/s1479262120000106

Jamil, A., Khan, S. J., & Ullah, K. (2020). Genetic diversity for cell membrane thermostability, yield and quality attributes in cotton (Gossypium hirsutum L.). Genetic Resources and Crop Evolution, 67(6), 1405-1414. doi:10.1007/s10722-020-00911-w

Kelly, M. S. (2006). Field weathering effects on stripper harvested cotton in the texas high plains. (Doctor of Philosophy). Texas Tech University, Retrieved from https://ttu-ir.tdl.org/handle/2346/1282

Khan, Z., Ali, Z., & Khan, A. A. (2022). Cotton Breeding and Biotechnology, Challenges and Opportunities (Z. Khan, Z. Ali, & A. A. Khan Eds.).

Kloth, R. H., & Turley, R. B. (2010). Physiology of Seed and Fiber Development. In J. M. Stewart, D. M. Oosterhuis, J. J. Heitholt, & J. R. Mauney (Eds.), Physiology of Cotton (pp. 111-122). Dordrecht: Springer Netherlands.

Majumdar, A., Sarkar, B., & Majumdar, P. K. (2004). Application of analytic hierarchy process for the selection of cotton fibers. Fibers and Polymers, 5(4), 297-302. doi:10.1007/BF02875528

McCaig, T. N., Gan, Y. T., Clarke, P., Clarke, J. M., & DePauw, R. M. (2006). Kernel colour changes associated with field weathering of spring wheat. Canadian Journal of Plant Science, 86(2), 371-377. doi:10.4141/P05-033

McClanahan, S., Frame, W. H., Stewart, R. D., & Thomason, W. E. (2020). Cotton yield and lint quality responses to nitrogen rate and placement in the humid southeast. Agronomy Journal, 112(5), 4276-4286. doi:10.1002/agj2.20290

Meredith Jr, W. R., Boykin, D. L., Bourland, F. M., Caldwell, W. D., Campbell, B. T., Gannaway, J. R., . . . Zhang, J. F. (2012). Genotype X environment interactions over seven years for yield, yield components, fiber quality and hgossypol traits in the regional high quality test. Journal of cotton science, 16, 160-169.

Miralles, D. J., & Slafer, G. A. (1999). Wheat development. Wheat: ecology and physiology of yield determination, 13-43.

Nico, M., Mantese, A. I., Miralles, D. J., & Kantolic, A. G. (2016). Soybean fruit development and set at the node level under combined photoperiod and radiation conditions. Journal of experimental botany, 67(1), 365-377.

Oosterhuis, D. M. (1990). Growth and development of a cotton plant. In W. N. Miley & D. M. Oosterhuis (Eds.), Nitrogen Nutrition of Cotton: Practical Issues.

Parvin, D. W. (2005). Effect of harvest season rainfall on cotton yield. Journal of cotton science, v. 9(no. 3), pp. 1408-1417-2005 v.1409 no.1403. Retrieved from https://handle.nal.usda.gov/10113/1793

Paytas, M., & Ploschuk, E. L. (2013). Cultivos Industriales. Algodón. In E. B. de la Fuente, A. Gil, P. I. Gimenez, A. G. Kantolic, M. Lopez Pereira, E. L. Ploschuk, D. M. Sorlino, P. Vilariño, D. F. Wassner, & L. B. Windauer (Eds.), Cultivos industriales (3 ed., pp. 835): Facultad de Agronomía, Universidad de Buenos Aires. Buenos Aires. AR.

Paytas, M., & Tarrago, J. (2011). Cotton genotypes performance under rainfed and irrigated conditions in two regions of northern Argentina, Mumbai, India.

Pettigrew, W. T., Meredith Jr, W. R., & Zeng, L. H. (2013). Reponse of obsolete and modern cotton genotypes to varying plant densities. Journal of cotton science, 17(4), 253-262.

Ray, L., & Minton, E. B. (1973). Effects of field weathering on cotton, lint yield, seed quality, fiber quality. Texas Agricultural Experiment Station, 1118, 8.

Robertson, B., Bednarz, C., & Burmester, C. (2007). Growth and development: first 60 days. Cotton Physiology Today, 13(2), 1-5.

Rosolem, C. A. (2001). Ecofisiologia e manejo da cultura do algodoeiro. Informações Agronômicas, 95, 1-9.

Sarwar, M. I., & Iqbal, D. (2020). Quality Aspects of Cotton Lint. In S. Ahmad & M. Hasanuzzaman (Eds.), Cotton Production and Uses: Agronomy, Crop Protection, and Postharvest Technologies (pp. 571-588). Singapore: Springer Singapore.

Scarpin, G. J., Dileo, P. N., Winkler, H. M., Cereijo, A. E., Lorenzini, F. G., Roeschlin, R.A., Muchut, R.J., Acuña, C., Paytas, M. (2022). Genetic progress in cotton lint and yield components in Argentina. Field Crops Research, 275. doi:10.1016/j.fcr.2021.108322

Siddiqui, M. Q., Wang, H., & Memon, H. (2020). Cotton Fiber Testing. In H. Wang & H. Memon (Eds.), Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling (pp. 99-119). Singapore: Springer Singapore.

Silvertooth, J. C. (2001). Crop management for optimum fiber quality and yield. Retrieved from ag.arizona.edu/pubs/crops/az1219.pdf

Snider, J. L., Collins, G. D., Whitaker, J., & Davis, J. W. (2013). Quantifying genotypic and environmental contributions to yield and fiber quality in Georgia. Data from seven commercial cultivars and 33 yield environments. The Journal of Cotton Science, 17, 285-292.

Stewart, J. M., Oosterhuis, D., Heitholt, J. J., & Mauney, J. R. (2009). Physiology of cotton: Springer Science & Business Media.

Tavakkoli, E., Lyons, G., English, P., & Guppy, C. N. (2011). Silicon nutrition of rice is affected by soil pH, weathering and silicon fertilisation. Journal of Plant Nutrition and Soil Science, 174(3), 437-446. doi:10.1002/jpln.201000023

Thomison, P. R., Mullen, R. W., Lipps, P. E., Doerge, T., & Geyer, A. B. (2011). Corn response to harvest date as affected by plant population and hybrid. Agronomy Journal, 103(6), 1765-1772. doi:10.2134/agronj2011.0147

Wang, H., Siddiqui, M. Q., & Memon, H. (2020). Physical Structure, Properties and Quality of Cotton. In H. Wang & H. Memon (Eds.), Cotton Science and Processing Technology: Gene, Ginning, Garment and Green Recycling (pp. 79-97). Singapore: Springer Singapore.

Zafar, M. M., Jia, X., Shakeel, A., Sarfraz, Z., Manan, A., Imran, A., . . . Ren, M. (2022). Unraveling Heat Tolerance in Upland Cotton (Gossypium hirsutum L.) Using Univariate and Multivariate Analysis. Frontiers in Plant Science, 12. doi:10.3389/fpls.2021.727835

Zeng, L., Wu, J., Bourland, F. M., Campbell, B. T., Dever, J. K., Hague, S., . . . Zhang, J. (2021). Comparative study of transgenic and nontransgenic cotton. Crop Science, 61(4), 2467-2477. doi:10.1002/csc2.20522

Zuil, S. (2011). Comportamiento de soja en tres campañas contrastantes en el norte de Santa Fe. Paper presented at the V Congreso de Soja del Mercosur/I Foro de la Soja ASIA–Mercosur. E.

FIGURE LEGENDS

Figure 1. Average thermal time requirements for each developmental phase for four cultivars. Bars indicate the mean of both seasons with their respective standard error (n=2).

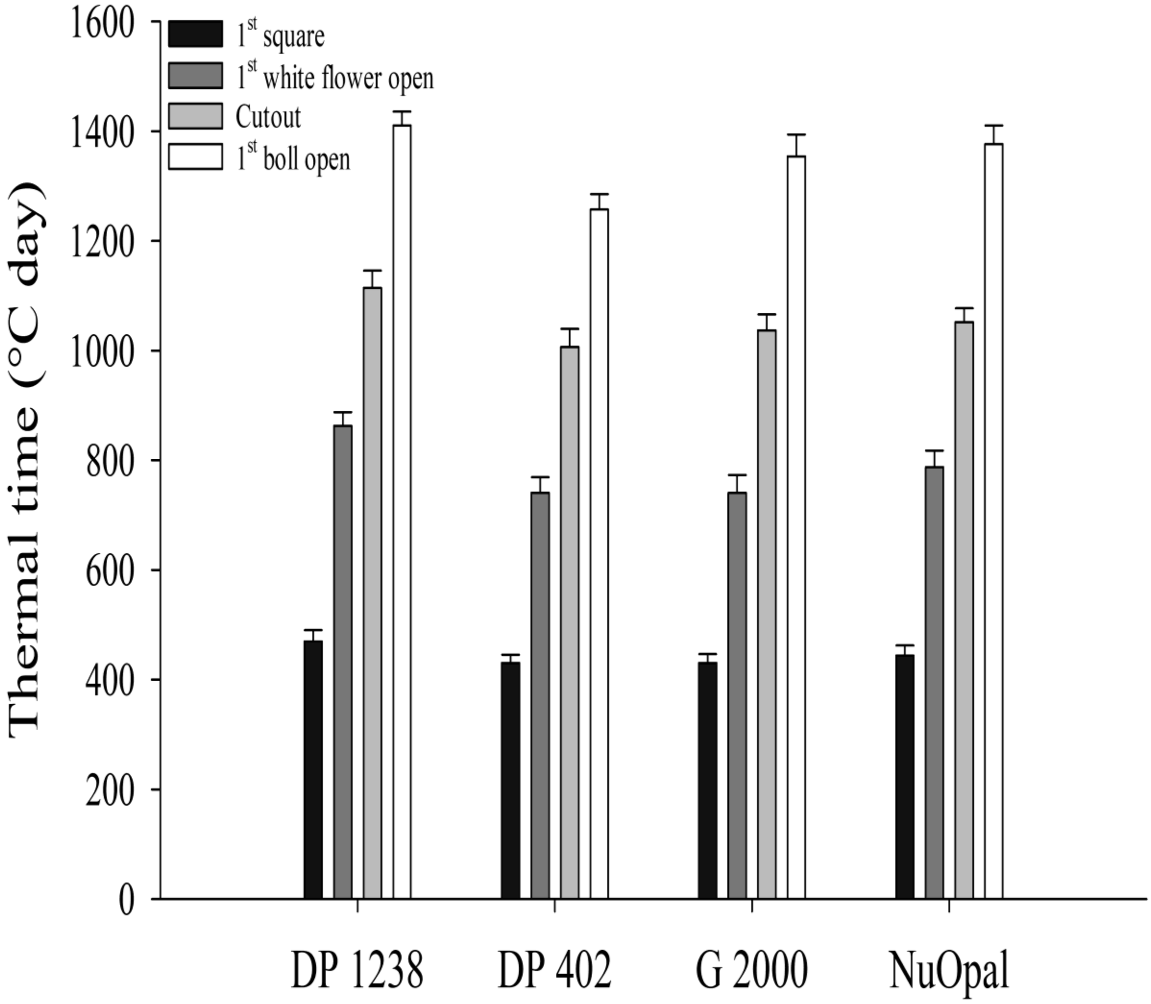


Figure 2. Linear regression of strength (Str, **A**), lint percentage (LP, **B**), reflectance (Rd, **C**) and yellowness (+b, **D**) on the days from defoliant application in four cultivars and two seasons. Open symbols belong to S1 and filled symbols to S2. DP 1238 (circle), DP 402 (triangle), G 2000 (square) and NuOpal (diamond). Dashed and doted lines represent regressions for S1 and S2, respectively. Str

parameter did not present significative interaction S*HT (see Table 2), hence regression was not split by S.

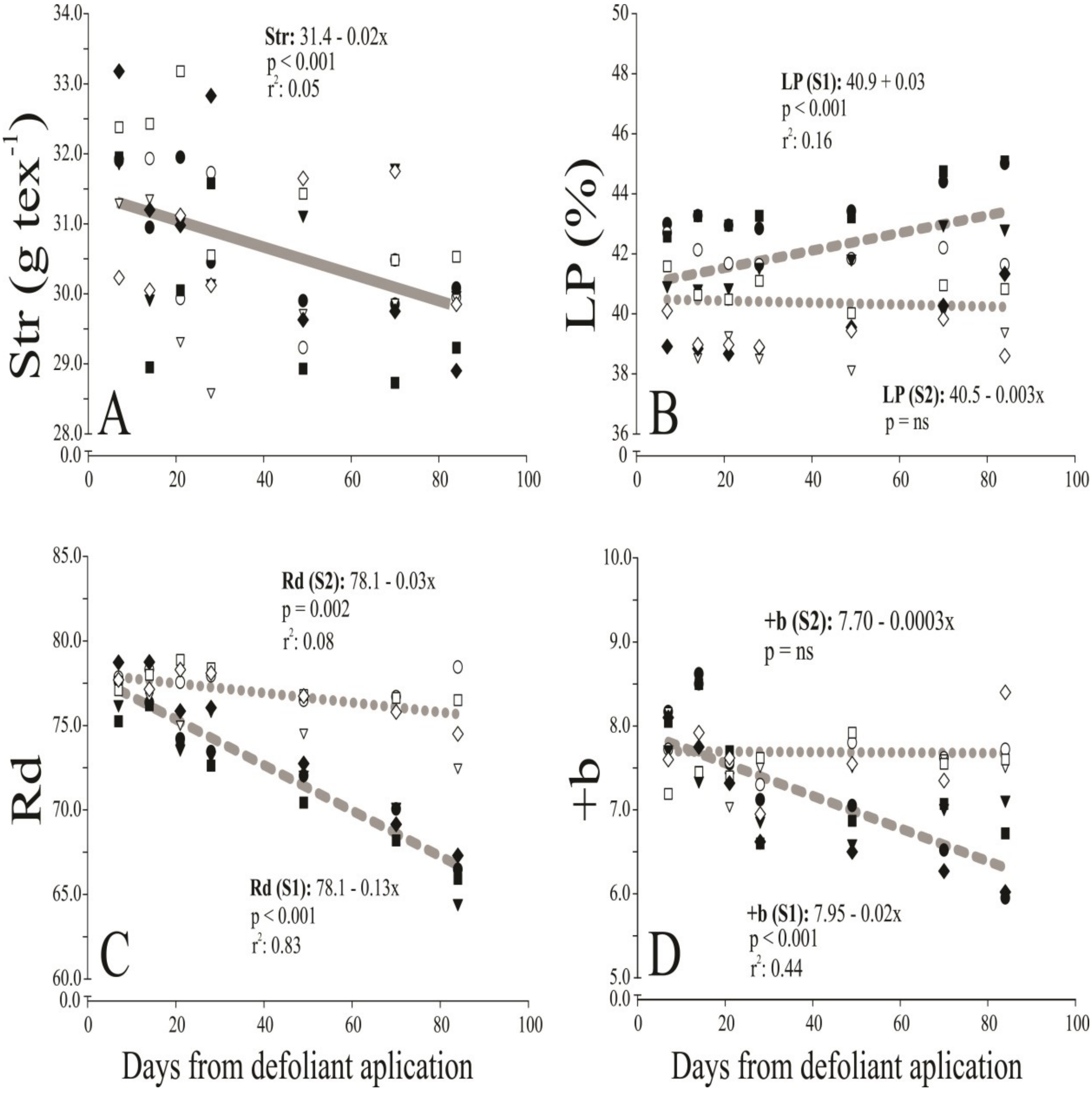
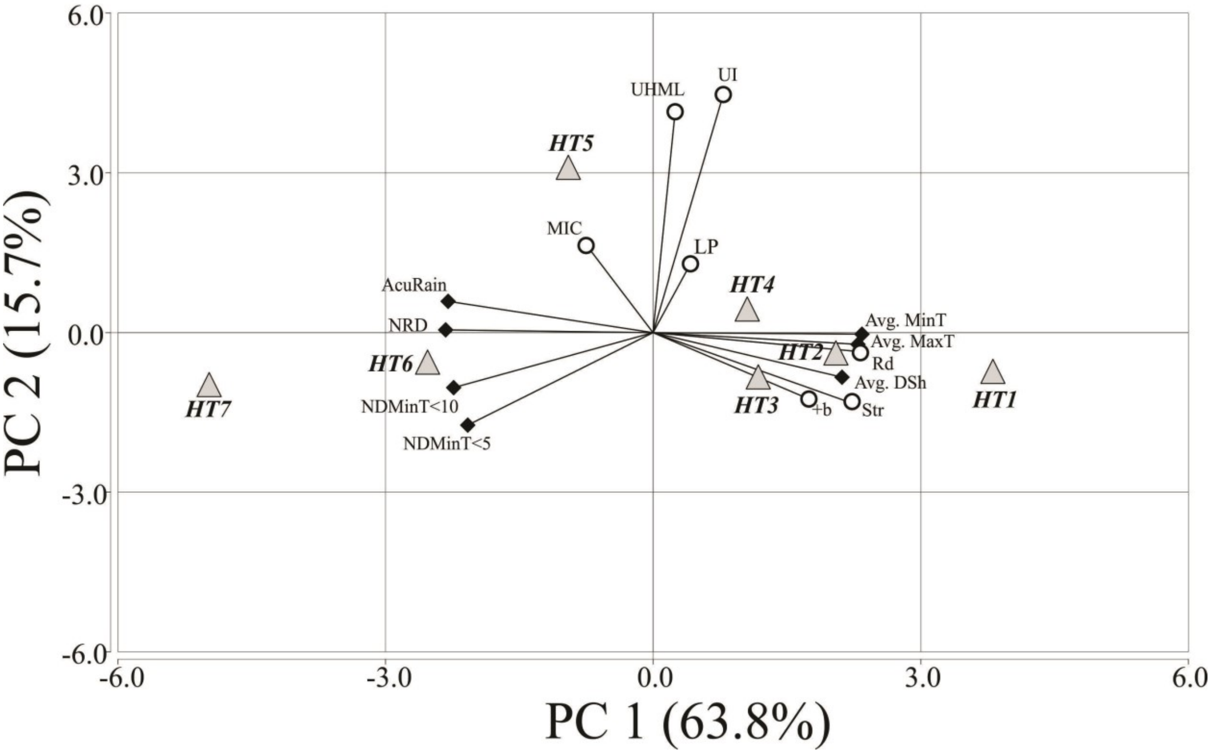


Figure 3. Biplot graph using mean data of four cotton cultivars, seven lint quality traits and seven meteorological parameters from the experiment. References: PC: principal component. LP: lint percentage (%), UHML: upper-half mean length (mm), UI: uniformity index (%), Mic: micronaire, Str: strength (g tex-1), reflectance (Rd), yellowness (+b), Avg. MaxT: average maximum temperature, Avg. MinT: average minimum temperature, NRD: number of rainy days, AcuRain: accumulated

rainfall from defoliant application, NDMinT: number of days with minimum temperature less than 5 or 10°C, Avg. DSh: average daily sunshine hours.



TABLES

Table 1. Environmental data recorded between sowing and harvest moment in the 2016/17 (S1), 2020/21 (S2) and the average of historical data.

Month	Avg. minimum Temp (°C)			Avg. maximum Temp (°C)			Rainfall (mm)			Days with precipitations (d)			Cumulative global radiation (MJ m^{-2})		
	S1	S2	Avg. 1970-2021	S1	S2	Avg. 1970-2021	S1	S2	Avg. 1960-2021	S1	S2	Avg. 1960-2021	S1	S2	Avg. 1970-2021
Oct	14.4	14.4	14.5	24.8	27.9	26.4	261.0	71.0	127.2	13	6	9	586.9	580.0	585.2
Nov	16.1	16.3	16.7	28.8	30.6	28.5	113.1	118.9	147.9	7	5	9	738.9	728.5	674.0
Dec	19.8	17.6	19.1	31.1	30.2	30.9	129.3	250.2	153.8	8	4	8	774.6	776.6	737.4
Jan	20.7	19.4	20.6	32.3	31.6	32.1	114.3	138.5	147.0	8	11	8	761.6	746.1	722.2
Feb	20.6	19.2	19.9	30.2	30.1	30.8	196.6	133.1	151.5	10	9	8	568.7	619.0	599.4
Mar	18.9	17.9	18.3	29.0	29.5	28.9	64.2	117.1	157.6	7	5	8	561.9	525.7	545.1
Apr	15.1	15.2	15.2	24.9	27.3	25.6	144.4	121.9	147.6	9	8	8	392.5	446.1	402.0
May	14.0	9.9	12.2	21.7	22.3	22.3	135.0	72.2	64.3	15	8	6	268.0	344.6	330.3
Jun	10.5	8.3	9.3	21.0	19.5	19.4	33.4	76.4	42.8	5	7	5	273.6	256.6	263.0

Table 2. Statistical analysis (ANOVA) and mean values for lint yield, its main components and fiber parameters in the cultivars (C), seasons (S) and harvest time (HT) evaluated in the experiment. LY: lint yield (kg ha^{-1}), LP: lint percentage (%), SCY: seed cotton yield (kg ha^{-1}), UHML: upper-half mean length (mm), UI: uniformity index (%), Mic: micronaire,

Str: strength (g tex^{-1}), reflectance (Rd) and yellowness (+b). *, ** and *** represent significance at $p<0.05$, $p<0.01$ and $p<0.001$, respectively. n.s. represents non-significant results. Values not sharing a common letter within a column are significantly different (LSD, $p<0.05$).

	LY (kg ha^{-1})	LP (%)	SCY (kg ha^{-1})	UHML (mm)	UI (%)	Mic	Str (g tex^{-1})	Rd	+b
DP 1238	1217.89	42.76 a	2843.13	28.42	82.81	4.42 a	30.73	75.24 a	7.52
DP 402	1163.13	40.43 c	2883.76	28.22	82.12	4.06 b	30.43	74.00 b	7.36
G 2000	1311.35	42.19 b	3123.9	28.18	82.24	4.39 a	30.74	74.64 ab	7.45
NuOpal	1199.33	39.37 d	3024.76	28.07	82.40	4.40 a	30.80	75.49 a	7.28
S1	917.68 b	42.08 a	2219,16 b	28.67 a	82.73 a	4.55 a	30.60	72.79 a	7.19
S2	1528.17 a	40.30 b	3718,63 a	27.78 b	82.05 b	4.09 b	30.75	76.89 b	7.62
HT1	-	41.23 b	-	28.38	82.40	4.26	31.84 a	77.27 a	7.84 a
HT2	-	40.81 c	-	28.13	82.31	4.34	30.85 ab	77.31 a	7.95 a
HT3	-	40.73 c	-	28.00	82.31	4.33	30.94 ab	75.94 b	7.45 b
HT4	-	40.84 bc	-	28.30	82.55	4.24	30.75 abc	75.70 b	7.08 c
HT5	-	40.93 bc	-	28.48	82.93	4.39	30.20 bc	73.99 c	7.23 bc
HT6	-	41.94 a	-	28.08	82.17	4.31	30.34 bc	72.93 d	7.13 c
HT7	-	41.84 a	-	28.18	82.09	4.36	29.81 c	70.77 e	7.13 c
Cultivar	ns	***	ns	ns	ns	**	ns	*	ns
S	***	***	***	***	*	***	ns	***	ns
HT	-	***	-	ns	ns	ns	*	***	***
Cultivar * S	ns	***	ns	ns	ns	ns	ns	ns	ns
Cultivar * HT	-	ns	-	ns	ns	ns	ns	ns	ns
S * HT	-	***	-	ns	ns	ns	ns	***	***
Cultivar * S * HT	-	ns	-	ns	ns	ns	ns	ns	ns

Table 3. Eigen values of the covariance matrix of the PC analysis and correlation values between each main component. References: PC: principal component. LP: lint percentage (%), UHML: upper-half mean length (mm), UI: uniformity index (%), Mic: micronaire, Str: strength (g tex^{-1}), reflectance (Rd), yellowness (+b), Avg. MaxT: average maximum temperature, Avg. MinT: average minimum temperature, NRD: number of rainy days, AcuRain: accumulated rainfall from defoliant application, NDMinT: number of days with minimum temperature less than 5 or 10°C, Avg. DSh: average daily sunshine hours. Equal signs indicate a direct relationship, whereas opposite signs indicate an indirect relationship.

Principal component	Eigenvalue	Total variance (%)	Cumulative (%)	Variable	PC1	PC2
1	8.78	63.8	63.8	LP	0.059	0.182
2	2.21	15.7	79.6	UHML	0.035	0.585
3	1.36	9.6	89.2	UI	0.111	0.632
4	0.81	5.7	94.8	Mic	-0.104	0.229
5	0.73	4.4	99.2	Str	0.316	-0.188
6	0.11	0.8	100.0	Rd	0.328	-0.051
7	0.0	0.0	100.0	+b	0.246	-0.177
8	0.0	0.0	100.0	Avg. MaxT	0.324	-0.031

9	0.0	0.0	100.0	Avg. MinT	0.330	-0.004
10	0.0	0.0	100.0	NRD	-0.329	0.007
11	0.0	0.0	100.0	AcuRain	-0.325	0.083
12	0.0	0.0	100.0	NDMinT<5	-0.294	-0.246
13	0.0	0.0	100.0	NDMinT<10	-0.316	-0.146
14	0.0	0.0	100.0	Avg. DSh	0.299	-0.118