Global Journal of Engineering and Technology Advances
eISSN: 2582-5003
Cross Ref DOI: 10.30574/gjeta
Journal homepage: https://gjeta.com/

(Research Article)

Check for updates

Quality of cotton fiber and its relationship with meteorological conditions

Isabella Theresa de Almeida Martins [1,*], Paulo Cesar Sentelhas [2] and José Helvécio Martins [3]

[1] *Applied Meteorology, Agricultural Engineering Department, Federal University of Viçosa (UFV), Viçosa, MG, Brazil.*
[2] *Agricultural Systems Engineering, Luiz de Queiroz Agriculture College, São Paulo University (USP), Piracicaba, SP, Brazil.*
[3] *Agricultural Engineering, Agricultural Engineering Department, Federal University of Viçosa, Viçosa (UFV), MG, Brazil.*

Global Journal of Engineering and Technology Advances, 2023, 15(02), 033–051

Publication history: Received on 23 March 2023; revised on 03 May 2023; accepted on 06 May 2023

Article DOI: https://doi.org/10.30574/gjeta.2023.15.2.0082

Abstract

Cotton (*Gossypium hirsutum* L., variety *latifolium Hutch*) is produced by more than 60 countries and, despite the quality and multiplicity of its seeds use it is grown mainly for the production of fibers. The quality of the fiber can differ between different production environments, being a key factor in determining the price and quality of cotton destined for textile products. These differences in quality are mainly associated with cultivars and meteorological conditions, which influence the indicative parameters of fiber quality. The knowledge of the factors that condition the quality of the cotton fiber is important for the definition of the regions with potential for the production of superior quality fibers. Thus, as a way to subsidize the production of better quality cotton fibers, this work aimed to identify and classify the factors that interfere with the quality of the cotton fiber. Data from meteorological variables and cotton fiber quality indices of 32 Brazilian cultivars were submitted to Pearson's correlation and cluster analyses. These analyses were performed considering three phases of the cotton cycle: total cycle; last 100 days of the cycle; and last 50 days of the cycle. Finally, the results of correlation and clustering analysis were compared. In general, considering the total cotton cycle, it was possible to obtain better statistical correlations between the meteorological variables and the quality of the cotton fiber.

Keywords: *Gossypium hirsutum* L.; Micronaire index; Pearson´s correlation; Clustering

1. Introduction

Cotton (*Gossypium hirsutum* L. variety *latifolium Hutch*) is one of the most cultivated plants in the world, due to the wide use and applicability of its fiber in the textile industry. In addition to being the most important source of natural fiber as a raw material for the textile industry, cotton is a product of extreme socioeconomic importance for Brazil, since its entire production chain (textiles, animal and human food, fashion, among others) is an important source of income and jobs.

According to the Brazilian Association of Cotton Producers [1], the world production of feathers for the 2020/2021 harvest was estimated at 25.6 million tons, and consumption at 24.6 million tons. In addition, the ranking of the largest cotton producers in the world places Brazil in fourth place in the world, behind only India, China and the United States. Brazil produced, approximately, 2.85 million tons of plumes in the 2019/2020 harvest in a planted area of 1.603 million hectares, resulting in an average productivity of 1778 kg/ha. For the 2020/2021 harvest, the forecast for cotton lint production in the country was estimated at 2.65 million tons, in a planted area of 1.52 million hectares, with a productivity of 1,746 kg/ha [1].

The cotton culture is sensitive to variations in environmental conditions, such as air temperature, solar radiation and water availability in the soil, with each stage of its development presenting a specific climatic requirement. Therefore, adverse conditions at any stage of the crop cycle can lead the cotton plant to suffer stress (momentary or prolonged),

* Corresponding author: Isabella Theresa de Almeida Martins

affecting the development, growth, productivity and quality of fibers. Through genetic improvement, cotton plants became more tolerant to environmental stresses, which gave them greater feather production capacity [21].

The quality of cotton fiber is a character that depends on a number of factors, including those related to cultivars, soil, climate, sowing time, pest control, disease and weed plants, plant nutrition, the type of harvester and the processing, and storage process. Thus, each cultivar has an intrinsic quality of fiber, genetically controlled, but which can be altered by environmental and management conditions [9].

The technological characters of the cotton fiber, such as fiber percentage, short fiber index, length, length uniformity, resistance and fineness (micronaire index) are important for the genetic improvement of cotton, as they are characters that determine the quality of this product, which influences its price [20].

In the commercial cultivation of cotton, the aim is to achieve the highest possible amount of fiber per unit area in a given time interval (harvest). To enhance fiber production, it is necessary to optimize production per plant, which in turn depends on the quantity of fruit and fiber quality, which depend on the accumulation of stresses that occur in the different stages of crop development. Each of these phases has specific climatic needs, and their variations can affect both productivity and cotton fiber quality [21].

Knowledge of the factors that determine the quality of cotton fiber is important for defining regions with potential for the production of superior quality fibers. Thus, aiming to maximize the quality of the cotton fiber produced, the objective of this work was to identify the meteorological variables that affect the quality of the cotton fiber.

2. Material and methods

2.1. Experimental data

The experimental data used in this study come from competition tests of cotton cultivars carried out by the company Tropical Melhoramento & Genética-TMG (Tropical Breeding & Genetics). The experiments were conducted at five sites in the state of Mato Grosso, Brazil: Campo Novo do Parecis (14°15'55” S; 58°00'17” W; altitude 664 m); Campo Verde (15°26'15” S; 54°25'26” W, altitude 625 m); Pedra Preta (16°50'23” S; 54°02'39” W; altitude 740 m); Sapezal (13°28'58” S; 58°54'34” W; altitude 570 m); and Sorriso (12°26'33” S; 55°39'20”W; altitude 414 m), between 2011 and 2019, totaling eight harvests, as shown in Figure 1.

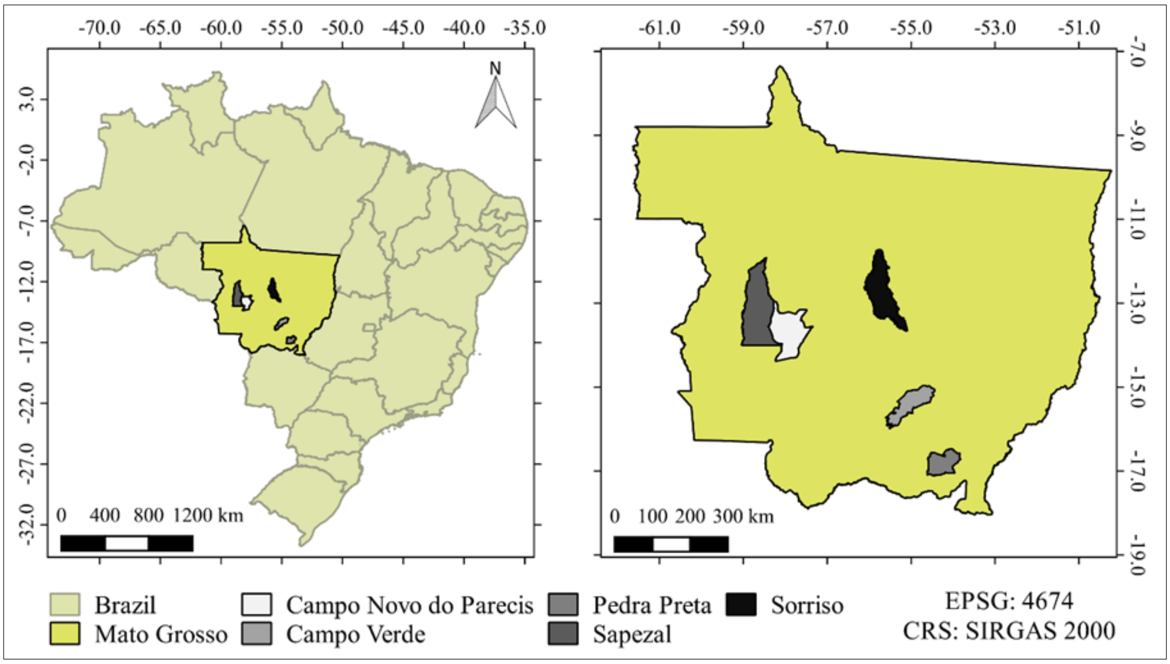

Figure 1 Geographic location of competition tests of cotton cultivars carried out by the company Tropical Melhoramento & Genética-TMG, in the state of Mato Grosso, Brazil

2.2. Edaphoclimatic description of the study areas

According to the Brazilian Soil Classification System - SIBCS [22], the soils in the study area were classified as Red Yellow Latosol. The climates of these areas are classified, according to Köppen, as Aw for the locations of Campo Verde and Pedra Preta, and of transition between Aw and Am for the other locations [2].

2.3. Cultivars

Data on technological characters of cotton fiber quality of thirty-two Brazilian cultivars were used, referring to eight harvests: 2011-2012; 2012-2013; 2013-2014; 2014-2015; 2015-2016; 2016-2017; 2017-2018; and 2018-2019. In addition, for all locations and crops, three sowing dates and four replications were considered. The total number of data evaluated was 1085, considering data from all cultivars and the relationship between the numbers of data per cultivar, as shown in Table 1.

In all locations and years of cultivation, sowing dates were not identical, in order to obtain variability for comparisons. In this case, approximately, the first sowing took place from December 3 to 28, the second from December 29 to January 22, and the third from January 23 to February 13.

Table 1 Brazilian cotton cultivars and number of data per cultivar analyzed

Cultivar	No. of Data	Cultivar	No. of Data	Cultivar	No. of Data	Cultivar	No. of Data
DP1240B2RF	15	FM951LL	24	FMT705	39	TMG44B2RF	62
DP1243B2RF	35	FM954GLT	20	FMT707	24	TMG45B2RF	47
DP1536B2RF	35	FM975WS	83	FMT709	39	TMG46B2RF	15
DP1648B2RF	35	FM980GLT	15	IMA8405GLT	32	TMG47B2RF	47
DP1746B2RF	28	FM983GLT	20	TMG11WS	21	TMG61RF	26
FM910	11	FM993	11	TMG41WS	15	TMG62RF	29
FM940GLT	30	FMT523	13	TMG42WS	65	TMG81WS	74
FM944GL	47	FMT701	39	TMG43WS	59	TMG82WS	30
Subtotal:	236		225		294		330
Total of data: 1085							

2.4. Variables analyzed

The experimental data used in this work refer to the cotton fiber quality indexes measured by the High-Volume Instrument-HVI equipment. The technological characters used were: micronaire index ($dimensionless$); length (mm); resistance (gf/tex)[tex: is a unit equivalent to the mass in grams of a thousand meters of textile material in the form of fiber, ribbon blanket, wick and thread][15]; uniformity (%); elongation (%); and short fiber index - SFI (%).

2.5. Evaluated phenological stages

The cotton cycle has been subdivided into two major phases [4]: (i) vegetative, which begins with the emergence of seedlings and ends with the formation of the first fruitful branch; and (ii) reproductive, which begins with the appearance of the first flower bud and ends when the boll fibers reach the point of physiological maturity for harvesting.

According to data provided by the company TMG, the average cotton cycle was 170 days, and the time when the first apple is visible is approximately in the last 100 days of the cycle. Thus, considering these aspects, the following periods were considered for the correlation analysis between meteorological variables and cotton fiber quality characters: total cycle (170 days); last 100 days of the cycle; and last 50 days of the cycle.

2.6. Meteorological data

The meteorological data used in this study were: precipitation ($Prec$), maximum air temperature ($Tmax$), minimum air temperature ($Tmin$), global solar radiation or insolation (Qg), relative humidity (RH), and wind speed at 2 m high ($U2$), all on a daily scale for the places where the experiments were carried out. Meteorological data were obtained from automatic meteorological stations (Model HOBO U-30 NRC) installed in the experimental areas of the TMG company. In addition to these meteorological variables, others were also determined, as described below: Mean air temperature ($Tmed$, °C)*;* Thermal amplitude (TA, °C)*;* Number of days with $Tmax \geq 30$ °C ($Tmax30$); Number of days with $Tmax \geq$ 32 °C ($Tmax32$); Number of days with $Tmin \leq 18$°C ($Tmin18$); Number of days with $Tmin \leq 20$ °C ($Tmin20$); Number of days with $TA \geq 10$ °C ($TA10$); Number of days with $TA \geq 12$ °C ($TA12$); Number of days with $TA \geq 13$°C ($TA13$); and Number of days with rain (NDR, mm), or number of days with $Prec > 0\ mm$.

These data were used to compose the correlation matrix and determine the relationship between the meteorological variables and the cotton fiber quality indices, evaluated in all periods of the cotton cycle mentioned above. The temperature limits were defined based on the literature, considering the optimal range for cotton cultivation between 20°C and 30°C [4].

2.7. Crop water balance

Meteorological variables were also used to prepare the sequential water balance of the crop, considering all sowing times, using the method proposed by Thornthwaite and Mather in 1955 [23], and considering the conditions of the cotton crop, in order to determine the following variables: water deficit (DEF, mm); total water deficit of the cycle ($TDEF, mm$); number of days with $DEF > 0$ ($DEF0, mm$); water excess (EXC, mm); total water excess of the cycle ($TEXC, mm$); number of days with $EXC > 0$ ($EXC0$)*;* and number of days with the ratio between water storage capacity (WSC) and available water capacity (AWC), ($WCR = WSC/AWC \geq 0.5$).

The water balance of the crop was calculated for each of the evaluated sowing dates, and the balance extract was determined for each of the evaluated cotton cycle phases: total cycle (170 days); last 100 days of the cycle; and last 50 days of the cycle. To determine the water balance of the cotton crop, an available water capacity (AWC) representative of the soils where the experiments were conducted was considered. With the WSC and AWC values, the relative soil water storage (WSC/AWC) was determined.

As described in Ordinance No. 131, of August 13, 2019, regarding the Agricultural Climate Risk Zoning for the cultivation of herbaceous cotton in the State of Mato Grosso (harvest year 2019/2020), the available water capacity (AWC) was estimated based on the effective depth of the roots and the useful reserve of the soils, for three types of soils. Soils Type 1 (sandy texture), Type 2 (medium texture) and Type 3 (clay texture) were considered, respectively, with AWC of 42, 66 and 90 mm [18]. Given this information, it was decided to adopt the AWC of 90 mm, since the soils in the experimental areas of the TMG were classified as Red Yellow Latosols, with clayey texture.

2.8. Correlation and cluster analysis

A Pearson correlation matrix was created between cotton fiber quality characters and all meteorological variables, and those generated from them, considering data from all cultivars and sowing dates (general approach) for each of the three evaluated cotton cycle phases (total cycle, last 100 days and last 50 days). Defining two variables (vectors) X and Y, such that $\bar{X}$ and $\bar{Y}$ are, respectively, their averages, the formula for determining the Pearson correlation coefficient (r) is given by:

$$r = \frac{\sum_{i=1}^{p}(X_i-\bar{X})\cdot(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{p}(X_i-\bar{X})^2 \cdot \sum(Y_i-\bar{Y})^2}} \quad (1)$$

Cluster analyzes aim to use variable values to devise a scheme for grouping objects into classes so that similar objects are in the same class. As in this study there are many objects (in this case, the cultivars) and variables (the fiber quality indices), a cluster analysis was performed to group the objects in the same group (cultivars) closest to the evaluated quality parameters. Thus, a cluster analysis was carried out considering the data of all the quality indices of all evaluated cultivars, and after defining the groups and which cultivars were included in each of them, a correlation matrix, per group, was created between the indices of quality evaluated (group approach), and the meteorological variables corresponding to the data of the cultivars of each group. In the group approach, the three phases of the cotton cycle mentioned above were also considered.

There are several methods of cluster analysis, but the most used is the Ward method, as it, unlike the others, provides a demonstrative dendrogram of the clusters formed. For this reason, it was decided to use it, although this method has the disadvantage that the number of groups must be indicated by the user. This is often unfeasible and takes a lot of computational time, as the choice of the number of groups would have to be done through trials, until the best result is found. To solve this problem, along with Ward's method, the K-means algorithm was used to choose the number of groups.

The K-means algorithm divides the data into K groups by minimizing the sum of squared distances in each record to the mean of its assigned group. This is called the sum of squares (SS) within the group. K-means does not guarantee that the groups are the same size, but it finds groups that are better when separated [3].

To exemplify, according to Bruce and Bruce [3], consider a data set of n records and only two variables, for example, x and y. Suppose it is wanted to divide the data into $K = 4$ groups. This means assigning each record of the variables (x_i, y_i) to a group K. Thus, given an assignment of n_k records to a group K, the center of the group $(\bar{x}_k, \bar{y}_k)$ is the average of the points in the group:

$$\bar{x}_k = \frac{1}{n_{k_i}} \in \sum_{Cluster\ k} x_i \tag{2}$$

$$\bar{y}_k = \frac{1}{n_{k_i}} \in \sum_{Cluster\ k} y_i \tag{3}$$

In grouping records with multiple variables, the term group mean does not refer to a single number, but to the vector of variable means. Thus, the sum of squares within a group is given by:

$$SS_k = i \in \sum_{Cluster\ k} (x_i - \bar{x}_k)^2 + (y_i - \bar{y}_k)^2 \tag{4}$$

The K-means thus find the assignment of records that minimize the sum of squares within the grouping across all four groups, $SS_1 + SS_2 + SS_3 + SS_4$, that is:

$$SS_4 = \sum_{k=1}^{4} SS_i \tag{5}$$

Clustering by K-means can be performed through the R software using the *kmean*s function, and can be applied to a dataset with p variables $X_1, X_2, \cdots, X_p$. The algorithm starts with a user-specified K and an initial set of group means and iterates through the following steps: (1) assigns each record to the closest group mean measured by distance squared; (2) calculates the mean of the new group based on record assignment.

The algorithm converges when the assignment of records to groups does not change. For the first iteration, it is necessary to specify an initial set of group means, which is usually done by randomly assigning each record to one of the K groups and then finding the mean of those groups. When using more than one set of iterations, the K-means results are given by the iteration that has the smallest sum of squares within the group [3].

In this study, the K-means method was used only to choose the number of groups to be used in Ward's method, as this procedure allows the visualization of the number of groups that will generate the smallest sum of squares within the group, which can contribute to a better result of the cluster analysis. For this, the number of iterations was defined by creating a vector so that K varied from 1 to 10 groups. The variables used were the cotton fiber quality indices (micronaire, length, resistance, uniformity, elongation and short fiber index), and the records were data from the 32 cotton cultivars. Thus, the algorithm generated a graph with the ratio between the sum of squares within the groups and the number of groups.

Both the correlation matrix and the cluster analysis were performed using algorithms executed in the R software (http://www.r-project.org/). For the correlation matrix, the *corrplot* package was used, for K-means, the *kmeans* function was used, and for the Ward's method, a script was generated following the steps described below:

- Data reading;
- Standardization of the data, so that p variables are equally important in determining the distances between objects. This was done by coding the variables so that the means were all equal to zero and the variances were equal to one;
- Application of the *kmeans* function as a way of obtaining the number of groups;

- Generation of the graph that shows the ratio of the sum of squares within the groups and the number of groups, and based on this, the number of groupings to be used was defined;
- Cluster analysis by Ward's method (non-hierarchical clustering), using Euclidean distance to determine distances between objects;
- Dendrogram generation.

3. Results and discussion

3.1. Correlation and cluster analysis

3.1.1. Correlation analysis (general approach)

The result of Pearson's correlation matrix elaborated for each technological characters of cotton fiber quality, considering the data of all cultivars (general approach), for each of the three phases of the cotton cycle evaluated (total cycle, last 100 days and last 50 days) are shown in Table 2. Each parameter in this table is discussed in detail below.

3.1.2. Micronaire index

Pearson correlation coefficients (r) for the relationship between cotton fiber quality characters with meteorological and water balance variables ($AWC = 90\ mm$) are presented in Table 2 (general approach), for three periods of the cotton cycle: total cycle; last 100 days of the cycle; and last 50 days of the cycle).

Table 2 Pearson correlation coefficients ($\boldsymbol{r}$) for the relationship between cotton fiber quality characters and meteorological and water balance variables ($\boldsymbol{AWC = 90\ mm}$), for three periods of the cotton cycle: total cycle; last 100 days of the cycle; and last 50 days of the cycle)

Pearson's correlation (r)- Fiber quality characters and meteorological variables and water balance			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Micronaire index**		
$Tmin20$	− 0.34 **	− 0.27 **	− 0.28 **
$Tmin$	0.24 **	0.18 **	0.15 **
$Tmed$	0.23 **	0.21 **	0.15 **
$Tmax32$	0.22 **	0.21 **	0.13 **
Variables	**Fiber length**		
RH	0.54 **	0.47 **	0.40 **
Qg	− 0.29 **	− 0.18 **	− 0.29 **
U2	0.25 **	0.28 **	0.25 **
Tmed	− 0.25 **	− 0.18 **	− 0.16 **
TDEF	− 0.24 **	− 0.27 **	− 0.42 **
Tmax30	− 0.29 **	− 0.25 **	− 0.28 **
TA13	− 0.22 **	− 0.24 **	− 0.29 **
SWC/AWC	0.21 **	0.22 **	0.29 **
Variables	**Fiber resistance**		
Qg	− 0.25 **	− 0.19 **	− 0.15 **
NDR	− 0.23 **	− 0.20 **	−0.24 **
EXC0	− 0.26 **	− 0.13 **	− 0.15 **
DEF0	0.27 **	0.16 **	0.19 **
SWC/AWC	− 0.20 **	− 0.19 **	− 0.15 **
Variables	**Fiber uniformity**		

Prec	0.21 **	0.17 **	0.26 **
U2	0.29 **	0.28 **	0.22 **
TEXC	0.22 **	0.15 **	0.20 **
Variables	**Fiber elongation**		
Qg	−0.40 **	− 0.41 **	− 0.41 **
Tmax	− 0.26 **	− 0.29 **	−0.29 **
Tmin	− 0.22 **	− 0.14 **	−0.13 **
Prec	−0.27 **	− 0.12 **	−0.16 **
Tmed	− 0.28 **	− 0.27 **	−0.27 **
Tmax30	− 0.29 **	− 0.29 **	−0.27 **
NDR	− 0.37 **	− 0.29 **	−0.28 **
EXC0	− 0.40 **	− 0.17 **	−0.19 **
DEF0	0.35 **	0.16 **	0.15 **
Variables	**Short fiber index (SFI)**		
RH	−0.22 **	−0.20 **	−0.17 **
Prec	−0.23 **	−0.19 **	−0.15 **
TEXC	−0.23 **	−0.18 **	−0.13 **

** Significant correlation at 1% probability by the t-test.

In Table 2, it can be seen that the micronaire index presented a negative and greater correlation, when considering the total cycle, in the three periods of the cotton cycle evaluated, in relation to the other periods of the cycle, with the meteorological variable Tmin20. The correlation between the meteorological variables $Tmin$, $Tmed$, and $Tmax32$ with the micronaire index were positive and, as well as for $Tmin20$, higher when considering the total cotton cycle.

The influence of the minimum air temperature on the micronaire index was more significant than that caused by the maximum temperature. This became more evident when considering the minimum temperature below 20°C, which corroborates results in the literature that also verified that the increase in the minimum temperature promotes an increase in the micronaire index [6, 10, 19]. A possible explanation, according to Hake et al. [11], is that the increase in the minimum temperature can improve the respiration of photoassimilates and promote better deposition of cellulose to form the fiber, since warmer nights increase respiration and, after a certain amount, decrease liquid photosynthesis.

3.1.3. Fiber Length

Cotton fiber length was positively correlated with RH, SWC/AWC and $U2$ ($P < 0.01$), and negatively correlated with Qg, $Tmed$, $TDEF$, $Tmax30$ and $TA13$ ($P < 0.01$), as shown in Table 2. Among of these variables, the one that presented the best correlation with length was the RH, being more representative when considering the total cycle of the cotton plant. After RH, the variables with the greatest effect on cotton fiber length were $TDEF$ (in the last 50 days of the cotton cycle) and Qg ($P < 0.01$). In the case of Qg, for the total cycle and in the last 50 days of the cycle, the correlations with length were identical, while for the last 100 days of the cycle this correlation was lower. Regarding the other meteorological and water balance variables, although they presented significant correlations ($P < 0.01$) with length, the results for each development phase were very similar.

According to the results presented above, the effects of environmental conditions on the length of the cotton fiber are not consistent and vary. Studies have shown that the fiber length was not affected by shading [8, 24]. However, increases in length have been observed in China, in environments of higher temperatures [7, 17], which is associated with the longer duration of the closure of the plasmodesms of the fiber cells, generating greater internal osmotic turgor for elongation. On the other hand, under lower temperatures, the reduction of enzyme activity and carbohydrate flow led to a decrease in the elongation rate, reducing the final length [7]. Although some studies have shown a correlation between increased minimum temperature and fiber length, in this study, it was not found that temperature variations consistently influence the response to fiber length (Table 2).

The $TDEF$ variable was the second variable most correlated with length, especially in the last 50 days of the cycle (Table 2). This result agrees with that obtained by Lokhande and Reddy [16], who also observed a linear reduction in fiber length with increased water deficit. One of the explanations for the high correlation between $TDEF$ in the last 50 days of the cotton cycle and fiber length is that the water needs of the cotton plant vary according to the phenological phases, with the highest water demand being the reproductive phase, which includes the flowering and fruit formation [5]. Thus, the water stress in this phase, which corresponds approximately to the last 50 days of the cotton cycle, can affect the development of the crop and, consequently, the fiber length of the cotton plant.

3.1.4. Fiber Resistance

It was also observed in Table 2 that resistance presented a positive correlation ($P < 0.01$) with $DEF0$ and a significant negative correlation ($P < 0.01$) with the variables Qg, NDR, $EXC0$ and SWC/AWC. In this study, fiber resistance was not greatly influenced by temperature increase, but by rainfall variations. Lokhande and Reddy [16] found similar results, in which there was influence of rain on cotton fiber resistance. These authors observed a linear reduction in fiber resistance in response to water deficit, with this character of cotton fiber quality being the most responsive to water stress.

Regarding the water surplus, in a study carried out by Wang et al. [25] in a controlled environment, they observed that soaking the soil during the flowering and boll formation phases reduced the resistance of the cotton fiber. Fiber resistance was inversely proportional to the amount of bolls retained in the plant, which is justified by the change in the source-drain ratio [14] and may explain the negative correlation found between $EXC0$ and resistance in this study.

3.1.5. Fiber uniformity

Uniformity showed a positive correlation ($P < 0.01$) with variables $Prec$, $U2$ and $TEXC$ (Table 2). Uniformity is the relationship between the average length of 100% of the fibers (Mean Length-ML) and the average length of the 50% of the longest fibers (Upper Half Mean Length - UHML), expressed as a percentage [15]. Thus, because it is a character of homogeneity in the length of the bale fibers, and because it is an indirect measure (dependent on the length), there are few studies on the effect of meteorological variables and water balance on uniformity. Although Lokhande and Reddy [16] observed a linear reduction in uniformity in response to the increase in the water deficit, which partly explains the correlation found with $Prec$, there is nothing in the study of the referred authors that mentions the influence of the water surplus and the wind speed in the uniformity of cotton fibers.

3.1.6. Fiber Elongation

Elongation at fiber breakage is when a bundle of fibers yields in the longitudinal direction until the moment of breakage, in relation to the initial length of the specimen. Just like uniformity, it is an intrinsic character of the fiber associated with another character, in this case, resistance. Thus, the best way to analyze the results of correlations between elongation and meteorological and water balance variables is to compare them with the results found for resistance. In this study, elongation presented a negative correlation ($P < 0.01$) with eight variables, which are: Qg, $Tmax$, $Tmin$, $Prec$, $Tmed$, $Tmax30$, NDR and $EXC0$. On the other hand, it showed a positive correlation ($P < 0.01$) only with the $DEF0$ variable. For the variables Qg, $Tmax$, $Tmed$ and $Tmax30$, the values of the correlation coefficients were approximately equal in all analyzed periods of the crop. For $Tmin$, $Prec$, NDR, $EXC0$ and DEF0, the correlation coefficients were different between the periods of the cotton crop, with the total period always showing the highest correlations (Table 2).

Regarding the evaluated cotton development stages, there were considerable differences between the correlations with the variables $Prec$, NDR, $EXC0$ and $DEF0$, and for all of them the correlation coefficients were higher when considering the total cycle of the cotton plant. For the other variables, the results for all periods considered were very similar (Table 2).

Comparing the resistance with the elongation of the eight meteorological variables with which the elongation presented significant correlations, four of them were common with the correlations found for the resistance. Both elongation and resistance showed negative correlations ($P < 0.01$) with Qg, NDR and $EXC0$, and positive correlations ($P < 0.01$) with $DEF0$. Thus, it can be said that there is a relationship between elongation and resistance and that both are more sensitive to variations in solar radiation and water stress.

3.1.7. Short fiber index (SFI)

The short fiber index (SFI) is the percentage of fibers smaller than 12.7 mm present in the specimens. In addition, the SFI works together with the uniformity index, in the sense that a high content of short fibers combined with a low uniformity index can cause the fluctuation of fibrils and impurities in the dry zones of different machines in the spinning process, generating accumulation of dust and micropowder [13]. Thus, it is possible that there are common and opposite correlations between these two cotton fiber quality indices and meteorological variables. In addition, as the SFI refers to the percentage of short fibers, there are also chances that this index presents correlations with environmental variables that have affected the cotton fiber length.

It is observed in Table 2 that the SFI presented correlations ($P < 0.01$) only with the variables Qg, $Prec$ and $TEXC$, all negative. Furthermore, for all these variables, the correlation values were higher when considering the total cotton cycle. Comparing the results of the SFI correlations with those of the uniformity index, each one of them presented three significant correlations. Among them, two were common: $Prec$ and $TEXC$. However, as previously mentioned, SFI and uniformity act together, but in an opposite way, since the low value of one, combined with the high value of the other, generates changes in fiber quality. Thus, it is expected that there are common but contrary correlations between them. In this sense, as expected, for the SFI, the correlations between $Prec$ and $TEXC$ were negative, while for the uniformity index they were positive (Table 2).

Regarding length, the only common correlation was with RH, while for SFI the correlation with RH was negative, while for length it was positive. Thus, it is evident that the SFI acts together with the uniformity index, but in an opposite way, as observed in the results of Table 2, and cited by Fonseca and Farias [13]. In addition, it was possible to observe that the SFI is more sensitive to precipitation ($Prec$) and its variations, and this sensitivity is more evident during the total cotton cycle (Table 2).

3.1.8. Cluster Analysis (grouping approach)

The cotton fiber quality indices (micronaire, length, resistance, uniformity, elongation and short fiber index) were submitted to cluster analysis, considering data from all evaluated cultivars. Once the groups were defined and which cultivars were included in each of them, a correlation matrix per group was established between the fiber quality index data and the meteorological and water balance variables. In addition, the three periods of the cotton cycle were also considered, that is, the total cycle, the last 100 days of the cycle and the last 50 days of the cycle.

First, the number of groups to be considered was defined using the K-means method, which provides a graph with the ratio of the sum of squares within the groups (sum of the squared distances of each record, divided by the average of their assigned groups) and the number of groups (Figure 2).

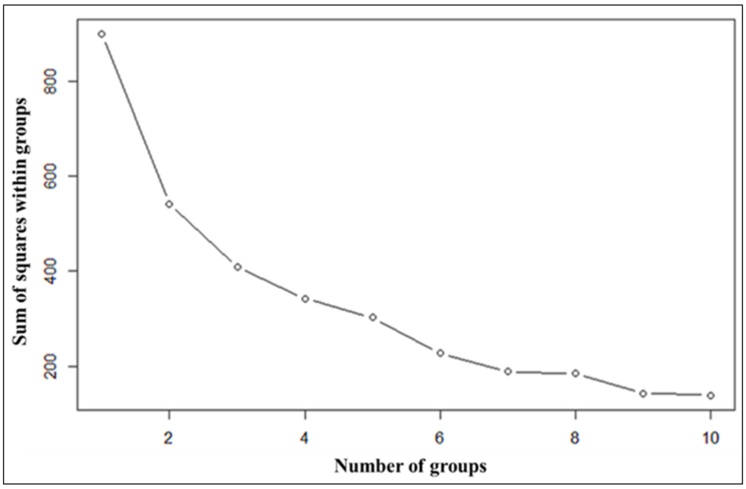

Figure 2 Relationship between the sum of squares within groups (sum of squared distances of each record in relation to the mean of the group to which it belongs) and the number of groups considered in the cluster analysis

The smaller the sum of squares within the groups, the better is the grouping. It is observed in Figure 2 that, from 1 to 10, the best number of groups would be 10. However, it is noted that for six groups the sum of squares within the groups was practically stable, around 200. Thus, for practicality and feasibility, it was decided to use six groups (intermediate value) to compose the cluster analysis.

Once the number of groups was defined, the cluster analysis itself was performed using the Ward's method, a non-hierarchical method in which the criterion used to determine the distances between the objects (cultivars) was the Euclidean distance, defined in Equation 6. Euclidean distance is the most frequently used distance measure when all variables are quantitative. The Euclidean distance (Ed) is used to calculate specific measures, as well as the simple

Euclidean distance, and the quadratic or absolute Euclidean distance, which is the sum of the squares of the differences, without calculating the square root. The quadratic Euclidean distance is given by:

$$Ed = \sum_{j=1}^{p} \left(x_{ij} - x_{kj}^{*}\right)^{2} \quad (6)$$

where x_{ij} is the jth characteristic of the ith individual, and x_{kj}^{*} is the jth characteristic of the kth individual. The closer the Euclidean distance is to zero, the more similar are the compared objects [12].

Hierarchical grouping serves for a natural graphical display, the dendrogram, as represented in Figure 3. The leaves of the trees correspond to the records (cultivars), and the length of the tree branches indicates the degree of similarity between the corresponding groups [3].

According to the dendrogram in Figure 3, it is possible to see that the cultivars are represented within each group by numbers and not by names. Thus, the identification of cultivars, as well as the composition of each group is shown in Table 3.

The results of the correlation matrices elaborated after the cluster analysis are presented in Tables 4 to 9, organized according to the cotton fiber quality index and the periods of the crop cycle, as described in the next topics.

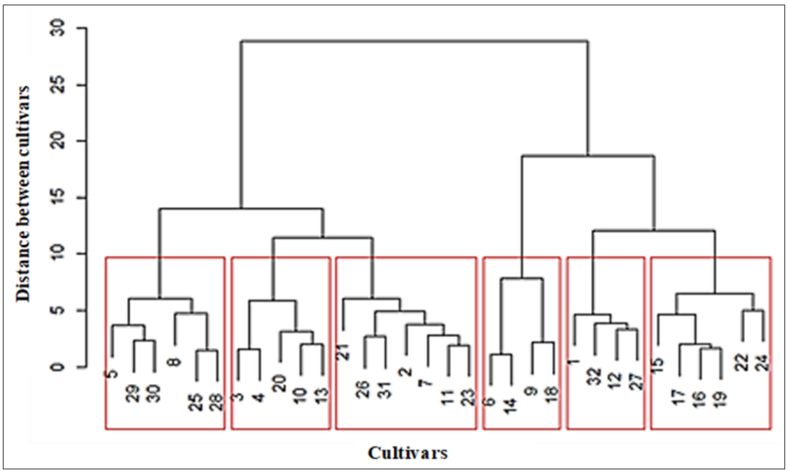

Figure 3 Dendrogram of cotton cultivar grouping in relation to fiber quality indices. The numbers correspond to the cultivars found in Table 3

Table 3 Cotton cultivar groups classified according to cluster analysis for cotton fiber quality indices. The numbers on the cultivars correspond to those shown in Figure 3

Groups	**Group 1**	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
Cultivars	5-DP1746B2RF	3-DP1536B2RF	2-DP1243B2RF	6-FM910	1-DP1240B2RF	15-FMT523
	8-FM944GL	4-DP1648B2RF	7-FM940GLT	9-FM951LL	12-FM980GLT	16-FMT701
	25-TMG44B2RF	10-FM954GLT	11-FM975WS	14-FM993	27-TMG46B2RF	17-FMT705
	28-TMG47B2RF	13-FM983GLT	21-TMG11WS	18-FMT707	32-TMG82WS	19-FMT709
	29-TMG61RF	20-IMA8405GLT	23-TMG42WS			22-TMG41WS
	30-TMG62RF		26-TMG45B2RF			24-TMG43WS
			31-TMG81WS			
Total of data	**239**	**142**	**355**	**70**	**75**	**204**

3.1.9. Pearson's correlation coefficient for the relationship to the micronaire index, and meteorological variables (Table 4).

Regarding the micronaire index, it can be seen that both for the cluster analysis (Table 4) and for the correlation analysis with the general approach (Table 2), there was agreement, in some groups, for correlations with the meteorological variables $Tmin20$, $Tmin$, $Tmed$ and $Tmax32$. Group 1 presented, in the same way as the general approach, a negative correlation with $Tmin20$ ($P < 0.01$) and a positive correlation with $Tmin$ ($P < 0.01$).

Group 2 showed correlation agreement in relation to $Tmin20$, and in both approaches the correlation with this variable was negative ($P < 0.01$) and better when considering the total cotton cycle. Group 3, in turn, showed agreement between the two approaches for the relationship between the micronaire index and the $Tmin20$ variable, with a negative correlation ($P < 0.01$), and $Tmax32$, with a positive correlation ($P < 0.01$). In addition, for both cases, the correlations for these two meteorological variables were greater, if considering the total cotton cycle. Group 4 did not show any significant correlation, while Group 5 showed a positive correlation only with $Tmin$ ($P < 0.01$), in the same way as the general approach (Table 2). Finally, Group 6 agreed with the general approach regarding the correlations between the micronaire index, more expressive for the whole cycle for variables Tmin20 with a negative correlation ($P < 0.01$), $Tmed$ with a positive correlation ($P < 0.01$), $Tmin$ with a positive correlation ($P < 0.01$), and better correlation occurring for the whole cycle and $Tmax32$, with a positive correlation ($P < 0.01$) (Table 4).

Thus, it can be observed that, for the two approaches (general and by grouping), there was agreement between the correlations of the micronaire index and the meteorological variables, the main ones being $Tmin$, $Tmin20$, $Tmed$ and $Tmax32$ (Table 4). Furthermore, for all correlations between the micronaire index and these variables, the total cycle was the period that demonstrated the greatest influence on cotton fiber quality, mainly in Groups 2, 3 and 6. These results show the importance of air temperature on the micronaire index of the cotton fiber, mainly when it comes to the minimum temperature.

Table 4 Pearson's correlation coefficient with respect to the micronaire index and meteorological variables, and water balance ($\boldsymbol{AWC = 90\ mm}$)

Pearson's correlation coefficients (r) – Fiber micronaire index			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Group 1**		
$Tmin$	0.25 **	0.28 **	0.29 **
RH	0.26 **	0.29 **	0.34 **
$Prec$	0.24 **	0.39 **	0.39 **
TA	− 0.19 **	− 0.24 **	− 0.26 **
$TDEF$	− 0.24 **	− 0.27 **	− 0.33 **
$TEXC$	0.22 **	0.39 **	0.35 **
SWC/AWC	0.25 **	0.26 **	0.34 **
$Tmin18$	− 0.29 **	− 0.31 **	− 0.32 **
$Tmin20$	− 0.31 **	− 0.35 **	− 0.42 *
$TA13$	− 0.18 **	− 0.22 **	− 0.22 **
Variables	**Group 2**		
TDEF	− 0.22 **	− 0.23 **	− 0.38 **
Tmin20	− 0.28 **	− 0.24 **	− 0.24 **
Variables	**Group 3**		
U2	− 0.18 **	− 0.20 **	− 0.23 **
Tmax30	0.32 **	0.28 **	0.18 **
Tmax32	0.30 **	0.28 **	0.17 **
Tmin18	− 0.17 **	− 0.14 **	− 0.16 **
Tmin20	− 0.43 **	− 0.30 **	− 0.25 **

Variables	Group 5		
Tmin	0.30 **	0.36 **	0.36 **
Tmin18	− 0.43 **	− 0.42 **	− 0.39 **
Variables	Group 6		
Qg	0.27 **	0.36 **	0.32 **
Tmax	0.37 **	0.37 **	0.32 **
Tmin	0.37 **	0.31 **	0.29 **
Tmed	0.40 **	0.40 **	0.37 **
Tmax30	0.36 **	0.36 **	0.31 **
Tmax32	0.39 **	0.38 **	0.34 **
Tmin18	− 0.28 **	− 0.26 **	− 0.29 **
Tmin20	− 0.40 **	− 0.31 **	− 0.30 **

** Significant correlation at 1%, probability by the t- test.

3.2. Pearson's correlation coefficient for the relationship between fiber length and meteorological variables, and water balance (Table 5).

It can be observed for the fiber length (Table 5) that there was a lot of variation in the correlation coefficients between the different groups. However, regardless of the group, there was agreement with the general approach for the correlations between length and the variables RH, Qg, $U2$, $Tmed$, $TDEF$, $Tmax30$, $TA13$ and SWC/WAC.

Table 5 Pearson's correlation coefficient with respect to the fiber length and meteorological variables, and with water balance ($AWC = 90\ mm$)

Pearson's correlation coefficients (r) – Fiber length			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Group 1**		
Qg	−0.61 **	−0.51 **	−0.63 **
$Tmax$	−0.37 **	−0.38 **	−0.49 **
RH	0.74 **	0.67 **	0.58 **
$U2$	0.28 **	0.33 **	0.28 **
TA	−0.21 **	−0.24 **	−0.36 **
$Tmed$	−0.37 **	−0.31 **	−0.32 **
$TDEF$	−0.31 **	−0.36 **	−0.60 **
$Tmax30$	−0.45 **	−0.45 **	−0.52 **
$Tmax32$	−0.35 **	−0.38 **	−0.48 **
$TA12$	−0.18 **	−0.24 **	−0.42 **
$TA13$	−0.31 **	−0.33 **	−0.43 **
NDR	−0.52 **	−0.42 **	−0.22 **
SWC/AWC	0.26 **	0.27 **	0.39 **
Variables	**Group 3**		
Qg	−0.23 **	−0.16 **	−0.22 **
$Tmax$	−0.18 **	−0.17 **	−0.19 **

RH	0.38 ∗∗	0.33 ∗∗	0.27 ∗∗
$U2$	0.18 ∗∗	0.20 ∗∗	0.17 ∗∗
$TDEF$	−0.15 ∗∗	−0.18 ∗∗	−0.29 ∗∗
$Tmax30$	−0.21 ∗∗	−0.18 ∗∗	−0.19 ∗∗
$Tmax32$	−0.18 ∗∗	−0.18 ∗∗	−0.20 ∗∗
$TA13$	−0.15 ∗∗	−0.16 ∗∗	−0.19 ∗∗
Variables	**Group 4**		
TA	−0.53 ∗∗	−0.47 ∗∗	−0.43 ∗∗
$Tmax30$	−0.42 ∗∗	−0.38 ∗∗	−0.44 ∗∗
$TA10$	−0.55 ∗∗	−0.47 ∗∗	−0.38 ∗∗
$TA12$	−0.54 ∗∗	−0.51 ∗∗	−0.46 ∗∗
$TA13$	−0.50 ∗∗	−0.49 ∗∗	−0.49 ∗∗
Variables	**Group 6**		
TA	0.20 ∗∗	0.21 ∗∗	0.19 ∗∗
$TA10$	−0.23 ∗∗	−0.21 ∗∗	−0.19 ∗∗
$TA12$	−0.24 ∗∗	−0.23 ∗∗	−0.19 ∗∗
$TA13$	−0.21 ∗∗	−0.22 ∗∗	−0.22 ∗∗

∗∗ Significant correlation at 1% probability by the t-test.

Group 1 presented, for both approaches, significant correlations ($P < 0.01$) between length and the following variables: RH (positive and greater for the total cycle); Qg (negative); $U2$ (positive); $Tmed$ (negative and greater for the total cycle); $TDEF$ (negative and higher in the last 50 days of the cotton cycle); Tmax30 (negative); $TA13$ (negative and highest in the last 50 days of the cycle); and SWC/AWC (positive and higher in the last 50 days of the cotton cycle).

Group 2 did not show significant correlation in the grouping approach and Group 3 showed significant correlations between length and Qg variables (negative); RH (positive); $U2$ (positive); $TDEF$ (negative and higher in the last 50 days of the cycle); $Tmax30$ (negative); and $TA13$ (negative).

Group 4 showed significant correlations between length and variables $Tmax30$ (negative) and $TA13$ (negative), while Group 5 did not show significant correlation. Group 6 showed a negative correlation ($P < 0.01$) only with $TA13$. Although there was considerably variation in correlations between groups, it can be seen that all correlations occurring in length with meteorological variables were consistent between both, general and grouping approaches (Tables 2 and 3).

3.3. Pearson's correlation coefficient for the relationship between resistance and meteorological variables, and water balance (Table 6).

For resistance, there were not many significant correlations in the cluster approach (Table 6), just as they did not occur in the general approach (Table 2). However, when there were correlations, they were corresponding in both approaches. In comparative terms, in the general approach, resistance showed a significant correlation ($P < 0.01$) with the following variables: Qg (negative and greater for the total cycle); NDR (negative); $EXC0$ (negative and better for the total cycle); $DEF0$ (positive and greater for the total cycle); and SWC/AWC (negative).

In the clustering approach, Group 1 showed correlation ($P < 0.01$) only with NDR (negative), while Groups 2, 3, 4 and 5 did not show significant correlation. Finally, Group 6 showed significant correlations ($P < 0.01$) between resistance and the following meteorological variables: Qg (negative and better for the total cycle); NDR (negative); $DEF0$ (positive and greater for the entire cycle); and SWC/AWC (negative).

Table 6 Pearson's correlation coefficient for the relationship between resistance and meteorological variables, and water balance ($AWC = 90\ mm$)

Pearson's correlation coefficients (r) – Fiber resistance			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Group 1**		
RH	0.37 **	0.31 **	0.27 **
NDR	−0.20 **	−0.19 **	−0.17 **
Variables	**Group 2**		
$U2$	0.32 **	0.32 **	0.27 **
Variables	**Group 6**		
Qg	−0.39 **	−0.30 **	−0.20 **
$TDEF$	0.25 **	0.22 **	0.23 **
NDR	−0.39 **	−0.31 **	−0.41 **
$DEF0$	0.40 **	0.23 **	0.33 **
SWC/AWC	−0.24 **	−0.22 **	−0.19 **

** Significant correlation at 1% probability by the t-test.

3.4. Results of Pearson's correlation coefficient for the relationship between uniformity and meteorological variables, and water balance (Table 7).

In the case of the uniformity index (Table 7), if the agreement between the general (Table 2) and grouping (Table 3) approaches is considered, it is possible to observe that Group 1 presented a correlation ($P < 0.01$) only with wind speed, $U2$ (positive), in both situations; Group 4 showed a positive correlation with precipitation, Prec, ($P < 0.01$); and Group 5 positive correlation ($P < 0.01$) with $Prec$ and $TEXC$.

Table 7 Pearson's correlation coefficient for the relationship between uniformity and meteorological variables, and water balance ($AWC = 90\ mm$)

Pearson's correlation coefficients (r) – Fiber uniformity			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Group 1**		
$U2$	0.19 **	0.23 **	0.19 **
Variables	**Group 4**		
$Tmax$	−0.37 **	−0.41 **	−0.46 **
$Prec$	0.30 **	0.40 **	0.40 **
TA	−0.53 **	−0.57 **	−0.52 **
$TDEF$	−0.34 **	−0.36 **	−0.30 **
$Tmax30$	−0.39 **	−0.46 **	−0.50 **
$Tmax32$	−0.32 **	−0.36 **	−0.37 **
$TA10$	−0.48 **	−0.56 **	−0.45 **
$TA12$	−0.56 **	−0.61 **	−0.55 **
$TA13$	−0.53 **	−0.58 **	−0.55 **
Variables	**Group 5**		

$Tmin$	0.36 **	0.37 **	0.34 **
RH	0.30 **	0.34 **	0.43 **
$Prec$	0.33 **	0.37 **	0.45 **
$TEXC$	0.30 **	0.31 **	0.40 **
$Tmin18$	−0.34 **	−0.38 **	−0.42 **
$Tmin20$	−0.36 **	−0.46 **	−0.41 **
Variables	**Group 6**		
$Tmax$	−0.21 **	−0.19 **	−0.19 **
TA	−0.24 **	−0.22 **	−0.22 **
$Tmax30$	−0.23 **	−0.23 **	−0.23 **
$TA12$	−0.22 **	−0.22 **	−0.23 **
$TA13$	−0.23 **	−0.23 **	−0.24 **

** Significant correlation at 1% probability by the t-test.

3.5. Results of Pearson's correlation coefficient for the relationship between elongation and meteorological variables, and water balance (Table 8).

In the general approach (Table 2), fiber elongation correlated with the following meteorological variables ($P < 0.01$): Qg (negative); Tmax (negative); $Tmin$ (negative and better in the total cycle); $Prec$ (negative and better in the total cycle); $Tmed$ (negative); $Tmax30$ (negative); NDR (negative and better in the total cycle); $EXC0$ (negative and better in the total cycle); and $DEF0$ (positive and greater in the total cycle).

In the grouping approach (Table 8), the results were variable between groups. Group 1 showed correlations of fiber elongation with the following meteorological variables ($P < 0.01$): Qg (negative); $Tmax$ (negative and better in the last 50 days); $Tmin$ (negative and better throughout the cycle); $Tmed$ (negative); $Tmax30$ (negative and best in the last 50 days); and NDR (negative and better throughout the cycle).

Table 8 Pearson's correlation coefficient for the relationship between elongation and meteorological variables, and water balance ($\boldsymbol{AWC = 90\ mm}$)

Pearson's correlation coefficients (r) – Fiber elongation			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variables	**Group 1**		
Qg	−0.57 **	−0.54 **	−0.60 **
$Tmax$	−0.46 **	−0.50 **	−0.56 **
$Tmin$	−0.36 **	−0.24 **	−0.18 **
RH	0.49 **	0.42 **	0.30 **
$U2$	0.25 **	0.28 **	0.26 **
TA	−0.21 **	−0.21 **	−0.29 **
$Tmed$	−0.49 **	−0.47 **	−0.48 **
$TDEF$	− 0.22 **	− 0.25 **	− 0.41 **
$Tmax30$	− 0.51 **	− 0.52 **	− 0.56 *
$Tmax32$	− 0.43 **	− 0.45 **	− 0.53 **
$TA12$	−0.24 **	−0.24 **	−0.36 **
$TA13$	−0.30 **	−0.30 **	−0.36 **
NDR	−0.40 **	−0.34 **	−0.22 **

Variables	**Group 2**		
Qg	$-$ 0.41 **	$-$ 0.41 **	$-$ 0.41 **
$Tmax$	$-$ 0.47 **	$-$ 0.51 **	$-$ 0.51 **
$U2$	0.34 **	0.32 **	0.30 **
TA	−0.28 **	−0.23 **	−0.26 **
$Tmed$	−0.44 **	−0.44 **	−0.42 **
$Tmax30$	−0.47 **	−0.52 **	−0.53 **
$Tmax32$	−0.38 **	−0.38 **	−0.44 **
$TA12$	−0.30 **	−0.23 **	−0.26 **
$TA13$	−0.31 **	−0.27 **	−0.29 **
Variables	**Group 3**		
Qg	−0.30 **	−0.30 **	−0.34 **
$Tmax$	−0.23 **	−0.26 **	−0.26 **
$U2$	0.16 **	0.16 **	0.16 **
$Tmed$	−0.24 **	−0.25 **	−0.23 **
$Tmax30$	−0.25 **	−0.29 **	−0.28 **
$Tmax32$	−0.22 **	−0.23 **	−0.24 **
$TA12$	−0.17 **	−0.14 **	−0.15 **
$TA13$	−0.19 **	−0.17 **	−0.17 **
NDR	−0.29 **	−0.23 **	−0.17 **
Variables	**Group 4**		
Qg	−0.42 **	−0.42 **	−0.32 **
SWC/AWC	−0.41 **	−0.41 **	−0.33 **
Variables	**Group 6**		
Qg	−0.24 **	−0.24 **	−0.23 **
$Prec$	−0.27 **	−0.21 **	−0.20 **
$TDEF$	0.27 **	0.25 **	0.20 **
NDR	−0.40 **	−0.30 **	−0.30 **
$EXC0$	−0.44 **	−0.25 **	−0.21 **
$DEF0$	0.41 **	0.26 **	0.23 **
SWC/AWC	−0.30 **	−0.27 **	−0.20 **

** Significant correlation at 1% probability by the t-test.

Group 2 showed correlations with Qg (negative); $Tmax$ (negative); $Tmed$ (negative); and $Tmax30$ (negative), all significant ($P < 0.01$). Group 3, in turn, showed correlations ($P < 0.01$) with the following variables: Qg (negative); $Tmax$ (negative); $Tmed$ (negative); $Tmax30$ (negative); and NDR (negative and best for the entire cycle).

Group 4 presented a correlation ($P < 0.01$) only with Qg (negative) and Group 5 did not present any significant correlation. Finally, Group 6 showed correlations with the following variables ($P < 0.01$) : Qg (negative); $Prec$ (negative and better for the total cycle); NDR (negative and better for the total cycle); $EXC0$ (negative and better for the total cycle); and $DEF0$ (positive and higher for the total cycle). Thus, it can be observed that there was a lot of variation between the groups in the grouping analysis for fiber elongation (Table 8), however, the values found were consistent with those found for the adopted approach in general (Table 3).

3.6. Results of Pearson's correlation coefficient for the relationship between Short Fiber Index (SFI) and meteorological variables, and water balance (Table 9).

The short fiber index (SFI) showed, in the general approach (Table 2), correlations ($P < 0.01$) with three meteorological variables: RH (negative and better for the entire cycle); $Prec$ (negative and better for the total cycle); and $TEXC$ (negative and better for the total cycle). With regard to the cluster analysis for the SFI (Table 9), there were not many significant correlations, but, like the other quality indices, those that occurred are in agreement with the general approach. In Group 1 there was correlation ($P < 0.01$) only with RH (negative and better for the total cycle). Group 4 showed correlation ($P < 0.01$) only with $Prec$ (negative); and Group 5 only with RH (negative and better for the total cycle), while Groups 2, 3 and 6 showed no significant correlation.

Table 9 Pearson's correlation coefficient for the relationship between short fiber index and meteorological variables, and water balance ($\boldsymbol{AWC = 90\ mm}$)

Pearson's correlation coefficients (r) – Short Fiber Index (SFI)			
Crop cycles	**Total cycle**	**Last 100 days**	**Last 50 days**
Variable	**Group 1**		
RH	-0.36 **	-0.34 **	-0.30 **
$Tmin20$	0.21 **	0.20 **	0.23 **
Variable	**Group 4**		
$Tmax$	-0.33 **	-0.34 **	-0.40 **
$Prec$	-0.30 **	-0.40 **	-0.36 **
TA	0.51 **	0.56 **	0.50 **
$TDEF$	0.38 **	0.39 **	0.31 **
$Tmax30$	0.37 **	0.41 **	0.46 **
$TA10$	0.48 **	0.55 **	0.43 **
$TA12$	0.56 **	0.59 **	0.52 **
$TA13$	0.51 **	0.57 **	0.54 **
Variable	**Group 5**		
$Tmax30$	-0.45 **	-0.40 **	-0.37 **
$Tmin$	-0.40 **	-0.37 **	-0.34 **
RH	-0.50 **	-0.44 **	-0.38 **
$U2$	0.43 **	0.43 **	0.46 **
$Tmed$	-0.46 **	-0.44 **	-0.44 **
$Tmax30$	-0.45 **	-0.39 **	-0.33 **
$Tmax32$	-0.43 **	-0.40 **	-0.39 **
$Tmin18$	0.33 **	0.32 **	0.35 **
$Tmin20$	0.48 **	0.49 **	0.49 **

** Significant correlation at 1% probability by the t-test.

4. Conclusion

It appears that, although there were variations in the correlation coefficients among the groups in the cluster analysis, for all fiber quality indices evaluated, the correlations were similar to those of the general approach. In addition, although the values of the correlation coefficients were not always high, they were all significant (P<0.01). Therefore, considering the number of data used for this study, there is an indication that the fiber quality indices are influenced by environmental conditions, some more and others less, and empirical models for estimating these quality indices, according to these conditions, can be developed.

The results obtained in the present study through classical statistical techniques led to the conclusion that, if the total cycle of the cotton crop is considered, it is possible to obtain better statistical correlations between the meteorological variables and the quality of the cotton fiber than considering the last 100 and 50 days of the cotton cycle.

There were no differences in the correlations between the cotton fiber quality variables and the meteorological variables, regardless of whether the analyses were performed for individual cultivars or in clusters. Therefore, it is interesting for future studies to consider more advanced data mining techniques to complement these results to obtain the meteorological variables that most affect cotton fiber quality, both at the individual level (considering the data of each individual cultivar) and at the grouping level (considering data by group of cultivars).

Compliance with ethical standards

Acknowledgments

The authors are grateful for the support received from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior-CAPES (Higher Education Personnel Improvement Coordination), the Luiz de Queiroz College of Agriculture-ESALQ, of the University of São Paulo-USP, the company Tropical Melhoramento & Genética-TMG and, in particular, Prof. doctor Paulo Cesar Sentelhas (in memoriam), from ESALQ/USP.

Disclosure of conflict of interest

There is no conflict of interest on this article.

References

[1] ABRAPA [internet]. Associação Brasileira dos Produtores de Algodão (Brazilian Association of Cotton Producers). Main indicators of cotton production in Brazil and worldwide, Paper from the Presidency of ABRAPA, Brasília, DF, Brazil, © 2020 [cited 2023 Apr 23]. Available from https://abapa.com.br/wp-content/uploads/2020/04/Paper-Presid%C3%AAncia-Principals-Indicadores-Cotonicultura-7abril2020vs final.pdf.

[2] Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift (Meteorological Journal), Stuttgart, Germany, v.22, n. 6, p.711-728, 2013.

[3] Bruce P, Bruce A. Practical Statistics for Data Scientists: 50 Essential Concepts, 1st ed. (1st ed.), Rio de Janeiro, RJ, Brazil: Alta Books, 2019.

[4] Camera, GMS; Chiavegato, EJ. Cotton: Origin, plants and perspectives for the crop (Cotton: Origin, plants and perspectives for the crop). In: The agribusiness of oilseed plants: cotton, peanuts, sunflower and castor bean, Piracicaba, SP, Brazil: ESALQ, 2001. p.51–73. Available from https://repositorio.usp.br/item/001206066.

[5] Chiavegato EJ, Salvatierra DK, Gottardo LCB. Cotton (Cotton). In: Agrometeorology of crops-The meteorological factor in agricultural production, Chapter 2, p.50-64 (In: Agrometeorology of crops-The meteorological factor in agricultural production, Chapter 2, p.50-64), 1st ed. (1st ed.). Instituto Nacional de Meteorologia-INMET (National Institute of Meteorology-INMET), Brasília, DF, Brazil, 2009. Available from https://www.bibliotecaagptea.org.br/agricultura/agricultura_geral/livros/AGROMETEOROLOGIA%20DOS%20CULTIVOS%20O %20FATOR%20METEOROLOGICO%20NA%20PRODUCAO%20AGRICOLA.pdf.

[6] Bange MP, Constable GA, Johnston DB, Kelly D. Molecular Biology and Physiology-A method to estimate the effects of temperature on cotton micronaire. Journal of Cotton Science, v.14, n.14, p. 164-172, 2010.

[7] Chen J, Lv F, Liu J, Ma Y, Wang Y, Chen B, Meng Y, Zhou Z. Effects of different planting dates and low light on cotton fiber length formation. Acta Physiologiae Plantarum, v.36, p. 2581-2595, 2014.

[8] Echer FR, Rosolem CA. Cotton yield and fiber quality affected by row spacing and shading at different growth stages. European Journal of Agronomy, v.65, p.18-26, 2015.

[9] Freire EC. Cotton in the Cerrado of Brazil (Cotton in the Cerrado of Brazil). In: Brazilian Association of Cotton Producers - ABRAPA (In: Brazilian Association of Cotton Producers - ABRAPA), 3rd ed. (3rd ed.), Brasília, DF, Brazil: Gráfica e Editora Positiva, p.301–332, 2015.

[10] Gipson JR, Johan HE. Influence of Night Temperature on Growth and Development of Cotton (Gossypium hirsutum L.). I. Fruiting and Boll Development. Agronomy Journal, v.60, p.292-295, 1968.

[11] Hake K, Bragg K, Mauney J, Metzer B. Causes of high and low micronaire. Cotton Physiology Today, v. 1, no. 12, p.4, 1990.

[12] Hair JF, Black WC, Babin BJ, Anderson RE. Multivariate Data Analysis, 8th ed., Cengage Learning, 2018.

[13] Fonseca RG, Farias JCS. HVI Test Results and Their Interpretation (ASTM D-4605) (HVI Test Results and Their Interpretation (ASTM D-4605)). In: Technical Circular 66 (In: Technical Circular 66), Empresa Brasileira de Pesquisa Agropecuária-EMBRAPA (Brazilian Agricultural Research Corporation-EMBRAPA), Campina Grande, PB, Brazil, 2002.

[14] Echer FR, Rosolem CA, Raphael JPA. Plant development and fiber quality. In: Safra 2018-Fiber Quality Manual-Associação Matogrossense dos Produtores de Algodão-AMPA (In: Fiber Quality Manual Harvest 2018, Association of Cotton Producers of Mato Grosso-AMPA), Cuiabá, MT, Brazil: Instituto Mato-Grossense do Algodão-IMAmt (Mato-Grossense Cotton Institute-IMAmt), p.206–237, 2018.

[15] Bachelier B, Gourlot JP. The cotton fiber. In: Safra 2018, Fiber Quality Manual, Associação Matogrossense dos Produtores de Algodão-AMPA (In: Harvest 2018, Fiber Quality Manual, Association of Cotton Producers of Mato Grosso-AMPA), Cuiabá, MT, Brazil: Instituto Mato-Grossense do Algodão-IMAmt (Mato-Grossense Cotton Institute-IMAmt), p.28–153, 2018.

[16] Lokhande S, Reddy KR. Quantifying temperature effects on cotton reproductive efficiency and fiber quality. Agronomy Journal, v.106, n.4, p.1275-1282, 2014.

[17] Lv F, Liu J, Ma Y, Chen J, Abudurezikekey AK, Wang Y, Chen B, Meng Y, Zhou Z. Effect of shading on cotton yield and quality on different fruiting branches. Crop Science, v.53, p.2670-2678, 2013.

[18] Marques ES. Ordinance No. 131, of August 13, 2019 (Ordinance No. 131, of August 13, 2019). Available from <https://apps.agr.br/zonamento-agricola-2019-2020/>

[19] Liakatas A, Roussopoulos D, Whittington WJ. Controlled-temperature effects on cotton yield and fiber properties. Journal of Agricultural Science, v.130, n.4, p.463-471, 1998.

[20] Resende MAV, Freitas JA, Lanza MA, Resende MDV, Azevedo CF. Divergência genética e índice de seleção via BLUP em acessos de algodoeiro para características tecnológicas da fibra (Genetic divergence and selection index via BLUP in cotton accessions for technological characteristics of the fiber). Pesquisa Agropecuária Tropical (Tropical Agricultural Research), v.44, n.3, p.334-340, 2014.

[21] Soares LCS. Efeito da temperatura e chuva sobre a qualidade da fibra e produtividade de algodão no estado de Mato Grosso (Effect of temperature and rainfall on fiber quality and cotton yield in the state of Mato Grosso), Escola Superior de Agricultura Luiz de Queiroz (Luiz de Queiroz College of Agriculture), Universidade de São Paulo (University of São Paulo), Piracicaba, SP, Brazil, 2015. (Doctoral Thesis).

[22] SIBCS. Sistema Brasileiro de Classificação de Solos (Brazilian system of soil classification). Empresa Brasileira de Pesquisa Agropecuária-EMBRAPA (Brazilian Agricultural Research Corporation-EMBRAPA). 5a ed. (5th ed.), Brasília, DF, Brazil: EMBRAPA-Solos (EMBRAPA Soils), 2018.

[23] Thornthwaite CW, Mather JR. The water balance. Nex Jersey: Drexel Institute of Technology-Laboratory of Climatology, Publications in Climatology, Centerton, 1955, p.104.

[24] Zhao W, Meng Y, Li W, Chen B, Xu N, Wang Y, Zhou Z, Oosterhuis DM. A model for cotton (Gssypium hirsutum L.) fiber length and resistance formation considering temperature-radiation and N nutrient effects. Ecological Modelling, v.243, p.112-122, 2012.

[25] Wang X, Deng Z, Zhang W, Meng Z, Chang X, Lv M. Effect of waterlogging duration at different growth stages on the growth, yield and quality of cotton. PLoS ONE, p.1-14, 2017.