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Multivariate analysis of fiber characteristics of dense cotton in different harvest systems

Elizabeth Haruna Kazama[1*], Francielle Morelli Ferreira[2], Rouverson Pereira da Silva[1], Antonio Renan Berchol da Silva[3], Diego Augusto Fiorese[4]

[1]Department of Rural Engineering, State University of Julio de MesquitaFilho, Faculty of Agricultural Sciences and Veterinary, Jaboticabal, Brazil
[2]College of Biological and Agricultural Sciences, University of Mato Grosso, Alta Floresta, MT, Brazil
[3]Department of Land and Rural Engineering, Federal University of Mato Grosso, Faculty of Agronomy, Veterinary Medicine and Animal Science, Cuiabá, MT, Brazil
[4]Institute of Agricultural and Environmental Sciences, Federal University of Mato Grosso, Sinop, MT, Brazil

***Corresponding author: bethkazama@hotmail.com**

Abstract

Cotton fiber characteristics are influenced by the genetic and environmental factors, such as management, climate maturation, and significantly by harvesting conditions. The objective of this study was to analyze the variables of cotton fiber characteristics depending on the manual, picker, and stripper harvest systems, and two cultivars (FMT 701 and IMACD 408) using multivariate statistical methods. The experiment was conducted in Juscimeira, Mato Grosso, Brazil, by a split-plot design randomized in complete block (RCB) with five replications.The cotton samples, taken from the storer basket of harvesters, were derived by manual as well as mechanical harvesting. The fiber characteristics were analyzed in fiber classification laboratory of BM&F according to the HVI (High volume instrument) system. The hierarchical and non-hierarchical clusters and the principal components were grouped into three clusters based on the harvesting system types, according to the variables of fiber characteristics. The principal component analysis indicated that the harvesting system influenced the quality of the fiber, in particular, the impurity content, which affects other fiber characteristics, except for the length. Hence, the desired characteristics of cotton fiber quality were observed in the manual harvesting system, followed by the picker system, and finally the stripper system.

Keywords: biplot; fiber length, fiber strength, *Gossypium hirsutum*, cluster analysis, principal components.
Abbreviations: AMAREL_yellowness; AREA_percentage of area occupied by impurities; COUNT_number of surface impurities; ELONG_elongation; LEAF_leaf grade; MAT_maturity; CP 1_principal component 1; CP 2_principalcomponent 2; CP 3_ principalcomponent 3; PORCFB_fiber percentage; REFLECT_reflectance; RES_tensile strength; SFI_short fiber index; UHM_length; UI_length uniformity.

Introduction

The value of cotton is determined by fiber characteristics, such as length, length uniformity, strength, elongation, maturity, fineness, shine, color, non-fibrous material content, water content, and durability (Costa et al., 2006). This set of physical properties also determines the selling price of the cotton lint. Most phenotypic traits in plants are quantitative and are controlled by both the genotypic and environmental factors, as well as the interaction between them (Mei et al., 2012). Hence, breeders find it difficult to obtain higher-quality fiber and maintain its productivity (Meredith, 1984).
Some fiber quality variables, such as length, length uniformity, strength, and elongation, are genetically controlled; however, features such as micronaire, reflectance, and yellowing are both controlled genetically and by environmental conditions (Krieg and Hequet, 2005; Saha et al., 2008). The main environmental factors that affect the fiber characteristics include temperature, management, water availability, soil properties, and the harvesting operations (Kelley and Boman, 2005). Cotton fiber characteristics are fundamental to the wiring techniques employed in the weaving industries as they play an influential role in determining the physical properties of the wire such as its breaking force. A strong correlation exists between the fiber characteristics such as length, strength, elongation, and fiber maturity, and the regulation of spinning machines, increasing efficiency, and production of the machines. These features promote higher resistance in yarns and fabrics for various types of mechanical friction, resulting in improved quality of products, such as softer tissue, bulkiness, flexibility, and a good fit in clothing. Other important fiber characteristics regarding the color and fluorescence of the material are the variables of reflectance and yellowness. The reflectance (REFLECT) is defined as the value corresponding to the amount of light reflected from the cotton fiber, indicating its brightness. Yellowness (AMAREL) is the value corresponding to the degree of yellowing of the fibers. These variables are taken into consideration as they can cause spots or changes in the color tones of yarns and fabrics. In general, industries search for high percentages of reflectance and low yellowness indices (Santana et al., 2008). The content of non-fibrous materials such as vegetable or mineral impurities directly affect the index of breakage and waste during the spinning process and increase the imperfections in the fiber assembly (Lima, 2014). Thus, raw materials with lower

values of variables such as LEAF (leaf grade), COUNT (number of surface impurities), and AREA (percentage of area occupied by impurities) are desirable. Harvesting is an expensive but extremely important step in the production process of a crop. If poorly executed, it may result in qualitative and quantitative losses in the final product. This implies that the crop should be well harvested by applying maturing and defoliants impurities that reduce the contamination of the fiber (Faircloth et al., 2004). For harvesting cotton, two types of machines are employed: the harvester spindles (picker), which removes only the cotton, and the stripper harvester, which is equipped with a pulley system that removes whole cotton bolls and the involucre (EMBRAPA, 2003). The picker harvester mainly consists of spindles that rotate and selectively extract the open seed cotton bolls from the cotton plant without pulling the involucre (Belot and Vilela, 2006). The stripper harvester is composed of a set of fingers that form a comb (width may vary between 3.0 m and 7.2 m) (Silva et al., 2010). Here, the reel hits the frangible plants and the machine collects the bolls with bracts along with the woody fragments (Martin, 2006). The multivariate statistical analysis is an important tool used to analyze the information that would be otherwise difficult to interpret with univariate methods (Beebe et al., 1998). In this context, the multivariate analysis of all the variables is done because they are interrelated with each other, and the information obtained is generated in groups and not individually (Grobe, 2005). In this context, cotton management is directly related to the quality of the fiber since the harvesting system can negatively influence the final product. Thus, the objective of this study was to analyze the variables of cotton fiber characteristics depending on the types of harvest system, manual picker and stripper and two cultivars (FMT 701 and IMACD 408) using multivariate statistical methods.

Results and Discussion

Cluster analysis

The dendrogram obtained by cluster analysis (Fig. 1) allowed the division of the variables into groups by the Euclidean distance between the accesses using the Ward's method. When the cutting distance was defined at 15, two groups were formed: manual and mechanical harvesting system. If the greatest difference between the groups was set at 13, three groups were formed: (I) manual, (II) picker, and (III) stripper harvesting systems. This division resulted in the ordering of accesses according to the quality of the cotton fiber function performed by the harvesting system. In the case of manual harvesting system, the cultivars were presented as the determining factor to take on different groups, i.e., cultivar FMT 701 had the best fiber quality values, keeping right in the dendrogram, compared to cultivar IMACD 408. Mechanized harvesting systems influenced the genotypic characteristics of the fibers, which was led by the fact that the FMT 701 and IMACD 408 were randomly found in groups II and III. When the number of clusters equal to three, a cluster analysis was done by the non-hierarchical method, k-means, for the confirmation of the order. The variables, except the elongation variable, showed significant differences ($p \leq 0.05$), indicating that the elongation variable was not representative for the differences between groups as shown in Table 1.

The mean standard of fiber characteristics in each group, set to manual, picker, and stripper harvesting system, according to k-means analysis (Fig. 2) shows that the manual harvest group obtained the highest mean for the fiber characteristics that was considered to be the most desirable: UHM, UI, RES, PORCFB, and REFLECT. However, the AMAREL variable also had a higher mean value, although considered not desired.

Relationship among morphological traits

The mechanical harvesting systems had higher mean values for the variables that were related to impurities, i.e., LEAF, AREA, and COUNT. This indicates that the harvesting system influences the degree of presence of impurities. These values can be explained due to the extraction mechanism of the bolls since manual harvesting removes the cotton seed selectively with minimal impurities, justifying the lowest result obtained. However, as the rotating spindles of picker harvesting extract the seed cotton open bolls of the plant less aggressively without pulling the involucres, resulting in a lower content of impurities when compared to the stripper harvesting system.The stripper harvesting system consists of pulling off by the comb of the platform, collecting the bolls with bracts and leaf fragments, resulting in a higher impurity content.

It can be emphasized that the picker harvesting system is close to the manual harvesting system in relation to the percentage of fiber. This is because the percentage of fiber possessed intrinsically within the genotype of the cultivars remained unaffected by picker harvesting, which is considered to be a softer harvesting system than that of the stripper mechanism. As the stripper system is more aggressive, it can change the percentage of fiber material due to the greater amount of impurities collected at the time of harvest. McAlister and Rogers (2005) found a significant reduction in the strength of fibers from 27.04 to 23.24 g tex^{-1} for picker and stripper harvesting systems, respectively. Faulkner et al. (2011) evaluated the mechanized harvesting systems and observed a difference in UI 80.4 (picker) to 79.4 (stripper). The high content of impurities caused a decrease in reflectance and increased the yellowness when the means of mechanical harvesting was compared to the manual harvesting. In an experiment carried out in Turkey using a tractor with a mounted platform, with a picker system, Oz (2014) noted that the harvesting system caused a decrease in the quality of variables related to color of the cotton, which corroborated this work. However, the same author found no effect of mechanical harvesting in variables such as length and uniformity of the fiber. Three main components were extracted with eigenvalues greater than one. The main components allowed an understanding of the complex relationships contained in the fiber characteristics. Three eigenvalues were used that explained 80.02% of the variability in the original data (53.38% in CP1, 16.64% in CP2, and 9.99% in CP3) (Table 2). The interpretation of the results of the principal components was based on the assumption that CP 1 was represented on the abscissa axis while CP 2 and CP 3 were represented on the coordinate axis. Furthermore, the signs of the coefficients (positive or negative) expressed the relationship between the variables, direct and inverse, respectively (Bussad and Morretin, 1987). The correlations between the variables and the main components are shown in Table 3. At CP1, representing impurities and fiber quality, all variables correlated with the exception of UHM, considering a correlation greater than 0.50. The variables such as ELONG (0.5132), SFC (0.6837), LEAF (0.9511), COUNT (0.8995), and AREA (0.8900) showed positive correlation. When one of the variables increased, the other tended to increase proportionately, emphasizing the high contribution and correlation of

Table 1. Analysis of variance for each variable of the groups formed by the non-hierarchical cluster analysis, k-means.

Variable	Square sum between groups	Degrees of freedom	Square sum in the groups	Degrees of freedom	F values	Probability (p)
UHM	14.644	2	14.356	27	13.771	0.000075
UI	11.280	2	17.720	27	8.594	0.001294
RES	10.403	2	18.597	27	7.551	0.002484
ELONG	2.644	2	26.356	27	1.354	0.275135
SFC	9.082	2	19.918	27	6.155	0.006274
LEAF	27.219	2	1.780	27	206.379	0.000000
COUNT	23.669	2	5.331	27	59.944	0.000000
AREA	23.991	2	5.009	27	64.654	0.000000
MAT	15.689	2	13.311	27	15.912	0.000027
PORCFB	27.184	2	1.816	27	202.033	0.000000
AMAREL	10.833	2	18.166	27	8.051	0.001810
REFLECT	25.423	2	3.577	27	95.943	0.000000

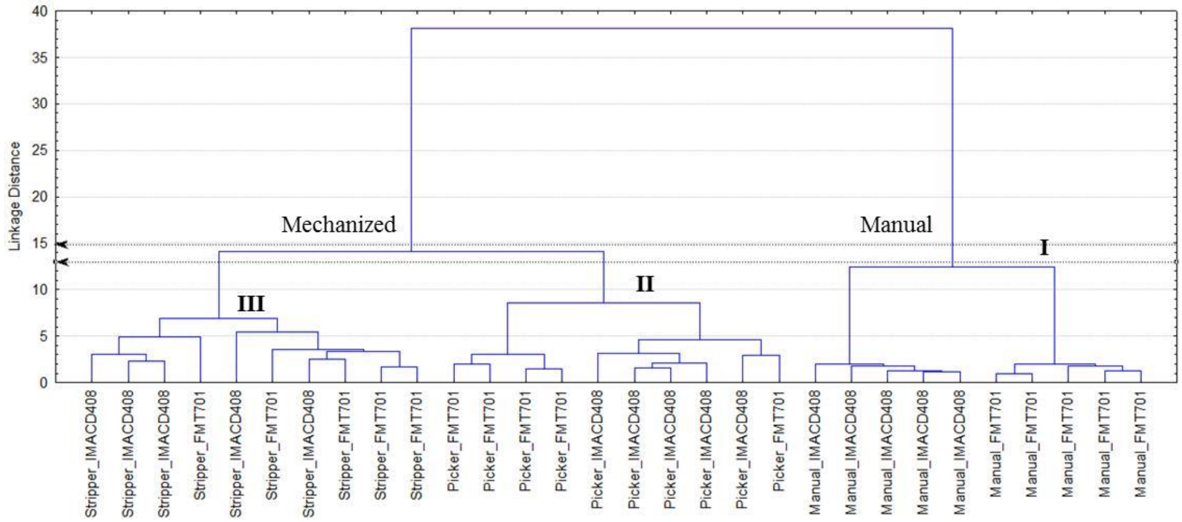

Fig 1. Dendrogram of hierarchical cluster analysis according to cultivars (FMT 701 and IMACD 408) and three harvesting systems (manual, picker, and stripper).

variables related to the impurities for this main component. Variables with negative correlation were UI (−0.6306), RES (−0.7032), MAT (−0.7155), PORCFB (−0647), AMAREL (−0.6963), and REFLECT (−0.9260). These variables exhibited the desired characteristics for industries' textiles, except for the AMAREL variable (−0.6963). At CP2, representing elongation and length, the variable UHM (0.8915) showed an inversely proportional correlation to the rate of ELONG (−0.6299) and PORCFB (−0.6587). This indicates that the longer the fiber, the smaller is its percentage. At CP3, variables that compose this component are ELONG (0.5125) and AMAREL (−0.5936). Even though these variables also contributed to the other components, it shows that there is a relationship between the longer elongation and less yellowness of the fibers. Cotton fibers are a model of cellular development and elongation, which occurs in four stages: initiation, elongation, synthesis of the second cell wall, and maturation (Basra and Malik, 1984; Kim and Triplett, 2001). The cotton fiber initiation stage acts as a key that determines the number of fibers in each ovule while the ratio and the duration of the cell elongation determine the length and fineness (Smart et al., 1998; Ruan et al., 2001). Furthermore, studies show that several genes are responsible for fiber elongation (Chen et al., 2011).

Baxevanos et al. (2013) tested six commercial cultivars in Greece for five years and found that the variables of fiber and elongation percentage were strongly controlled by the genotype while the variables of strength, length, and uniformity were moderately controlled by the genotype. Short fiber index and color were poorly controlled by the genotype; however, all these variables have been strongly influenced by the environmental factor (phenotype), especially productivity, resistance, index of short fibers, yellowness, and reflectance. Short fibers are undesired in textile processing because they are considered as waste and reduce production efficiency. The factors that affect the rate of short fibers can be genetic, environmental, ginning, and application of defoliants (Oz, 2014). A search for more mature fibers is necessary since the maturity strongly influences resistance, and short fibers do not support the efforts suffered from harvesting due to spinning, breaking down, and increasing the content of short fibers (Lima, 2014). For this reason, the variable correlates inversely with maturity variables, percentage of fiber and resistance, uniformity and reflectance (Table 3). McAlister III and Rogers (2005) observed a significant increase in the picker (9.5) and stripper harvesting (16.7) systems for the SFI.

The variables with greater significance in the formation of the main component showed higher values of the correlation coefficients (Table 3). Thus, the variables like LEAF (0.9511), COUNT (0.8995), AREA (0.8900), and REFLECT (−0.9260) were the most significant for the discrimination of the groups. The impurities were observed to be the determinants of the discrimination, and their influence negatively impacted in terms of lower quality in fiber for the mechanized harvesting systems, especially the stripper. The

Table 2. Eigen values of the covariance matrix to fiber characteristics.

Principal component	Eigenvalue	Total variance (%)	Cumulative eigen value	Accumulated %
1	6.41	53.38	6.41	53.38
2	2.00	16.64	8.40	70.02
3	1.20	9.99	9.60	80.02
4	0.96	8.01	10.56	88.03
5	0.50	4.16	11.06	92.19
6	0.39	3.26	11.45	95.46
7	0.20	1.63	11.65	97.09
8	0.13	1.11	11.78	98.20
9	0.11	0.94	11.90	99.14
10	0.06	0.46	11.95	99.61
11	0.03	0.28	11.99	99.89
12	0.01	0.11	12	100

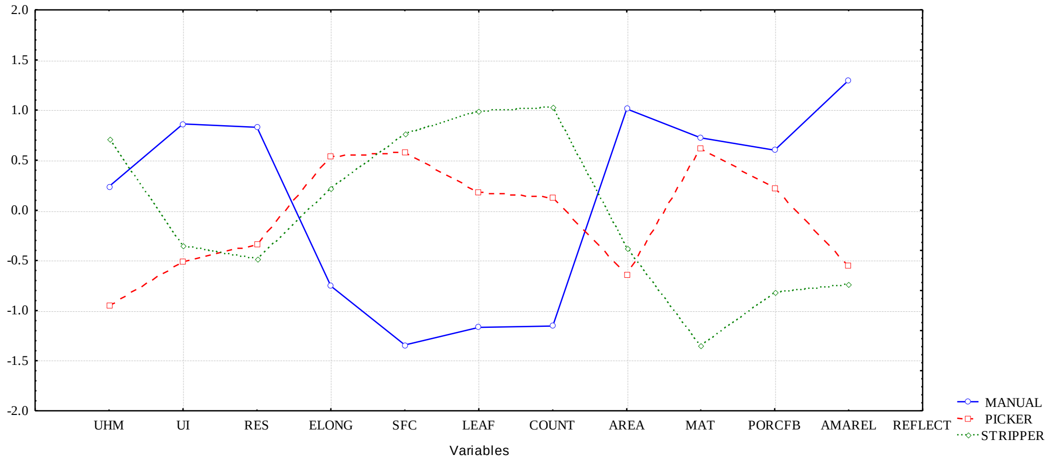

Fig 2. Average standard of the fiber characteristics for non-hierarchical clustering analysis (k-means) according to harvesting system. Where, UHM-length, UI-length uniformity, RES-tensile strength, ELONG-elongation, SFC-short fiber index, LEAF-leaf grade, COUNT-number of surface impurities, AREA-percentage of area occupied by impurities, MAT-maturity, PORCFB – fiber percentage, AMAREL-yellowness, and REFLECT-reflectance.

variable UHM (0.8915) also obtained a high correlation coefficient; however, CP2 was independent of one, which states that the length was not influenced by the impurities of the material. The plot and the correlation of variables presented in the main components (Fig. 3, Fig. 4 and Table 3) characterized the variables that most discriminated in the groups I, II, and III (manual, picker, and stripper harvesting system, respectively). The variables MAT, REFLECT, PORCFB, AMAREL, and UI are responsible for the discrimination of the manual harvesting system located to the left of CP1 (negative correlation) while the variables AREA, COUNT, LEAF, and SFC are responsible for the discrimination of the stripper system, located to the right of CP2, and the picker harvesting system is presented as an intermediary. At CP2, UHM (0.8915) was presented with greater significance discriminating accesses to the top of the biplot graph (Fig. 3), indicating that the stripper harvesting system has a larger length than the picker system. At CP3, in the biplot graph (Fig. 4), the ELONG and AMAREL variables were in opposite directions and presented the distribution of crop systems.

Materials and Methods

Plant materials

In this study, two cultivars have been used. Cultivar FMT 701 (Mato Grosso Foundation), which is recommended for cultivation in Brazil, has a long cycle with a high plant size and a cylindrical plant shape. The plant has little pilose, ovate with apples of medium size with a fiber yield of 39–42% and has median adherence fiber. Cultivar IMACD 408 (Mato Grosso Cotton Institute) has average leaves, little pilose and is well cut. The intermediate cycle has a pyramidal architecture of material that requires a careful growth regulator. It is suitable for both mechanical and manual harvesting and has average plume retention with a fiber yield of around 44% (Pupim-Junior et al., 2005).

Data sets and statistical analysis

The experiment was conducted during the 2012 season in Juscimeira, Mato Grosso, Brazil. The research area shows approximate geographical coordinates: 16 °22'16.92" South Latitude and 55° 6'55.99" West Longitude with an average altitude of 505 m. According to the Köppen classification, the tropical climate with dry winters and rainy summers was considered for the study. The soil of the area is classified as Red Latossol, with an average textural class (EMBRAPA, 2013). Cotton was produced in a dense culture system, with a spacing of 0.45 m between rows and seeded on January 4, 2012, under no-tillage system. It used a split-plot design randomized in complete block (RCB), considering two levels for factor A (two cultivars, FMT 701 and IMACD 408) and three levels for factor B (three crop harvest systems: manual, picker, and stripper, with five replications). The application of the multivariate analysis data set was standardized so that each variable was maintained with zero mean and unit variance. Original data were subjected to hierarchical cluster analysis using Euclidean dissimilarity as the coefficient of

Table 3. Correlation between each main component and cotton fiber characteristics.

Variable	CP 1	CP 2	CP 3
UHM	−0.0587	0.8915	0.3259
UI	−0.6306	−0.0122	0.1749
RES	−0.7032	0.2630	−0.1851
ELONG	0.5132	−0.6299	0.5125
SFC	0.6837	−0.3579	0.1808
LEAF	0.9511	−0.0172	−0.1578
COUNT	0.8995	0.2418	−0.1522
AREA	0.8900	0.3156	−0.1417
MAT	−0.7155	0.0930	0.4708
PORCFB	−0.6470	−0.6587	−0.2179
AMAREL	−0.6963	−0.0393	−0.5936
REFLECT	−0.9260	0.0771	0.2070

CP1: principal component 1; CP2: principal component 2; CP3: principal component 3.
Bold variables have significant importance for the CP. Equal signs indicate direct relationship and contrary, indirect.

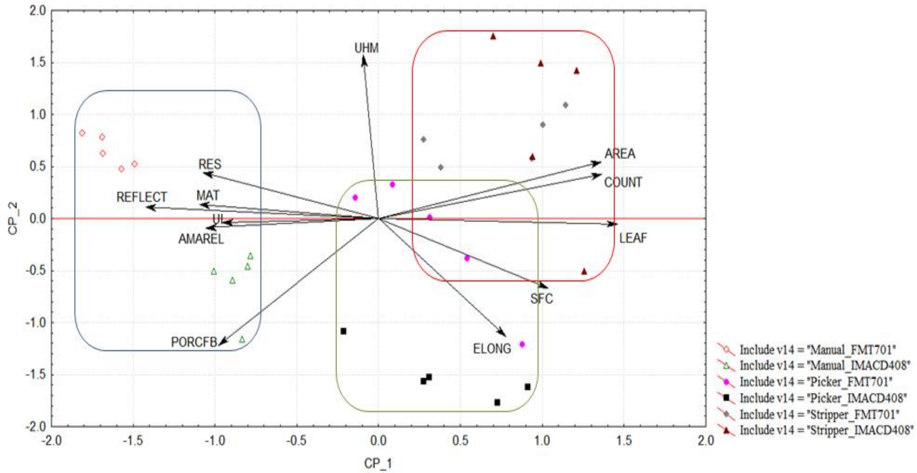

Fig 3. Biplot graph for fiber characteristics in harvesting systems (Manual, picker and stripper) CP 1 x CP 2.Where: UHM-length, UI-length uniformity, RES-tensile strength,ELONG-elongation, SFC-short fiber index, LEAF-leaf grade, COUNT-number of surface impurities, AREA-percentage of area occupied by impurities, MAT-maturity, PORCFB – fiber percentage,AMAREL-yellowness, REFLECT-reflectance.

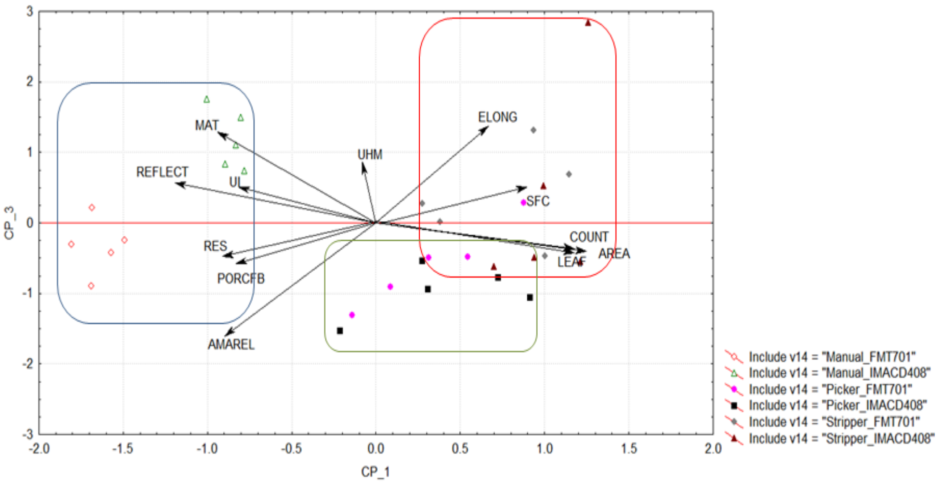

Fig 4. Biplot graph for fiber characteristics in harvesting systems (Manual, picker and stripper) CP 1 x CP 3.Where: UHM-length, UI-length uniformity, RES-tensile strength,ELONG-elongation, SFC-short fiber index, LEAF-leaf grade, COUNT-number of surface impurities, AREA-percentage of area occupied by impurities, MAT-maturity, PORCFB – fiber percentage,AMAREL-yellowness, REFLECT-reflectance.

similarity, and the similarity between the groups was determined by Ward's method (Ward, 1963). The non-hierarchical cluster analysis (k means) was processed, where k is the number of groups displayed in the hierarchical cluster analysis (Sokal and Sneath, 1973). The principal component analysis allows to condense the largest amount of original information contained in n variables (n = 12 in this study) in p-orthogonal latent called principal components (p = 3, in this study). The principal components are linear combinations of the original variables created with the two largest eigenvalues of the data covariance matrix (Hair, 2005). Thus, the initial set of 12 variables became further characterized by three latent variables, which allowed their location in two-dimensional figures (ordering accesses to the main components). The suitability of this analysis was verified by the amount of total information obtained from the original variables retained by the principal components showing higher eigenvalues bigger than one (Kaiser, 1958). The eigenvalues below the unit were not considered as relevant, following the Kaiser criteria.

Measured traits

The results of seed cotton productivity were obtained from the manual samples taken from each plot, before the passage of the harvesters. A total of 3911 kg ha^{-1} of cultivar FMT 701 and 4108 kg ha^{-1} of cultivar IMACD 408 was obtained. The water content of the seed cotton at harvest time was 9.5%.
The seed cotton samples derived from the manual and mechanical harvesting (taken from the storer basket of harvesters) were benefited by machines rolls at MT Foundation in Rondonopolis, MT, Brazil. The fiber characteristics (percentage of fiber, length, length uniformity, maturity, strength, short fiber index, yellowness, color, reflectance, impurities, and area) were analysed in the Fibers Classification Laboratory of BM & F with an HVI system.

Conclusion

The cluster analysis indicated that cultivar FMT 701 had better fiber characteristics compared to that of IMACD 408.
The hierarchical and non-hierarchical cluster analysis, as well as principal components, ordered the accesses on three groups of harvesting systems, manual, picker and stripper, according to the based on the variables of fiber characteristics.Harvesting systems and phenotypic factors influenced the cotton quality, discriminating the quality of cotton fiber in relation to genotype factor, i.e., the cultivar.
The principal component analysis indicated that the harvesting system influenced the quality of the fiber, particularly due to the impurity content, which affects the other fiber characteristics, except for the length.

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