Morphoagronomic characterization of a germplasm collection of *Furcraea* spp. and *Agave* spp.

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ABSTRACT

This work was carried out in Antioquia, Colombia, in a collection of the *Furcraea* and *Agave* genera, important in the country for manufacturing strings, sacks, geotextiles, and handicrafts Currently, to enhance its use, applications have been developed in textiles, biodegradable materials and thermo-acoustic insulation, among others. The aim of this study was to characterize phenotypically and agronomically 94 accessions. The variables were weighted according to the degree of discrimination; a dissimilarity dendrogram was constructed using UPGMA based on Gower's distance, and the cophenetic correlation coefficient was determined. Six groups were identified; on the one hand, the accessions of the *Agave* genus formed groups A and B, with and without spines, respectively, showing the highest elongation values. On the other hand, the *Furcraea* accessions formed groups C to F, with the highest average values of fiber per plant, allowing a first approach to identify promising clones for their use *per se* or utilized in plant breeding programs. This study represents an approach to knowing the morphological and agronomic variability of the collection and highlights the importance of maintaining the germplasm bank for *ex situ* conservation.

Keywords: Phenotypic variability; morphological descriptor; genetic distance; polymorphism; natural fibers; fique.

INTRODUCTION

Colombia is the leading worldwide producer of fique (*Furcraea* spp. L.) (Ovalle *et al.*, 2018). It is a peasant economy crop distributed in nine country departments, benefiting about 70,000 families. By 2017, 12,407 ha were reported, with a production of 20,855 t and an average dry fiber yield of 1.68 t ha^{-1} (Agronet, 2021). Fique is an agroindustrial crop used mainly as a source of fiber to produce packaging, strings, rugs, agrotextiles, and handicrafts, among others (Cadefique, 2018; Monja *et al.*, 2019). The percentage of fiber in the leaf is approximately 5%; the remaining 95% corresponds to biomass where juice, short fiber, and bagasse are found in a mixture, which, if not disposed of correctly, can contaminate surface waters and cause environmental damage (Ovalle *et al.*, 2018).

Fique belongs to the Agavaceae family, endemic to the Americas, and is found from the southeastern United States to Colombia and Venezuela. The family is comprised of eight genera, among which *Agave*, *Yucca*, and *Furcraea* stand out (Thiede & Eggli, 2020). About 200 species have been reported solely for Mexico, of which 65% are endemic to this country (García, 2001). The genus *Furcraea* Vent. includes 21 species of neotropical distribution. Four geographic distribution patterns are recognized by region: mountainous Mesoamerican, Caribbean, Andean, and Amazonian (Casierra *et al.*, 2006). In Colombia, according to Giraldo (2020b), five species of the genus have been reported: *F. foetida* (L.) Haw., *F. selloana* K. Koch, *F. cabuya* Trel., *F. acaulis* (Kunth) B. Ullrich, and *F. abisaii* Giraldo-Cañas. Moreover, Bernal *et al.* (2017) report that

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F. hexapetala Vent. is found in the country as a species cultivated in the departments of Cundinamarca and Boyacá (Tropicos, 2020).

Due to the genetic erosion that has been taking place in Colombia as only three (3) fique ecotypes (*uña de águila, bordo de oro,* and *ceniza*) have been cultivated, and also the current focus on conserving, knowing, and utilizing the genetic resources of the genus *Furcraea* and its related species, Corporación colombiana de investigación agropecuaria (AGROSAVIA) established a working collection of 144 accessions collected throughout the country in the departments of Antioquia, Boyacá, Caldas, Cauca, Cundinamarca, La Guajira, Huila, Nariño, Norte de Santander, Santander and Tolima (Medina, 2015).

Lobo *et al*. (2007) highlight the importance of recognizing the variability of the germplasm since the use potential of the working collections depends on the knowledge available. According to Hidalgo (2003), the characterization of a species allows estimating the variability of the population existing in its genome, and it can be phenotypic or genetic. As indicated by Rojas & Ardila (2000), Valencia *et al.* (2010), and Lobo (2006), biological diversity can have three values: of existence (diversity conservation), option (allows establishing valuable attributes), and use (use *per se* or as parental for breeding programs).

In the Agavaceae family, characterizations of the *Agave* spp. genus have already been carried out. For example, authors such as García *et al.* (2019) and Barrientos *et al.* (2019) indicate that characters such as color, leaf width and length, size, distribution, and spine presence and shape are considered the most important when discriminating taxa variability. However, for the *Furcraea* spp. genus, no morphological or agronomic characterizations are found, preventing a clear knowledge of the diversity of the species.

The aim of this study was to know the variability of 94 accessions from the working collection of Fique and Agave established in AGROSAVIA, through phenotypic characterization and agronomic attributes.

MATERIAL AND METHODS

Location

The characterization and evaluation were carried during 2017, out in the fique work collection established in the Research Center (CI) La Selva of AGROSAVIA, located in Rionegro, Antioquia, Colombia, at 2,120 meters above sea level and located at 06° 08' 06" N latitude and 75° 25' 03" W longitude. The site is in the low mountain humid forest life zone (bh-MB) according to Holdridge (2000), with an average temperature of 17 °C and average relative humidity of 78%.

Biological material

The fique work collection (144 accessions, and five plants per accession) was established in two phases from asexual propagules, collected in 13 departments of Colombia under the Collection Framework Permit 1466 of 2014 granted by Autoridad Nacional de Licencias Ambientales (ANLA) to Corporación Colombiana de Investigación Agropecuaria. Initially, the propagules were placed in the seedbed (nursery), and later they were transplanted to the field at a distance of 3 m between plants and rows. The first phase, i.e., the object of this work, included 94 accessions; the morphological characterization (during 2017) and agronomic evaluation (March – April 2017) were carried out four years after plant establishment.

For the morphological characterization, descriptors developed by the work team were applied, and the phenotypic characteristics of each of the five plants per accession were recorded.

For the agronomic evaluation, the leaves with angles lower than 45 ° of inclination were harvested, counted, and their length was measured and subsequently separated into three categories (CAT), I: long, II: medium, and III: small. Ten leaves (or less in the case of the plants that did not produce enough leaves) of CAT I were weighed, the spines were removed, cut at 45° on the underside of the leaf base, and weighed again, comprising one sample per plant.

Each sample was defibrated using a conventional blade machine (Figure 1A), obtaining the biomass (mixture of juice, bagasse, and short fiber) and long fiber. The biomass was carefully recovered from the lower part of the machine, weighed, and placed inside a lever-plunger system. Through manual pressure, the juice was separated from the mixture of short fiber and bagasse. Finally, each of these were weighed (Figure 1B). The wet long fiber was weighed and immersed in water for 18 hours, after which it was drained, shaken manually, and stretched on a wire rope where it was left to dry for 24 hours (Figure 1C), under average environmental conditions: solar rad 582.9 wat/m^2, relative humidity 61.3% and temperature 21.1 °C Once dry, it was weighed, packed, and sent to the laboratory for analysis.

The variables were recorded at the morphological and agronomic levels as presented below:

1) Morphological variables.

a) Morphological variables and states recorded in leaves:

i) Shape: 1. Narrowly lanceolate; 2. Widely lanceolate; 3. Obovate and lanceolate; 4. Lanceolate; 5. Ensiform.

ii) Surface shape: 1. Flat; 2. Convex; 3. Concave; 4. Slightly concave.

iii) Margin shape: 1. Entire; 2. Serrated; 3. Thorny; 4. Thorn rudiments; 5. Entire and dentate; 6. Entire and thorn rudiments; 7. Entire and thorny.

iv) Shape of the apex: 1. Acute (less than 45 °); 2. Medium (45 to 89 °).

v) Shape of the appendix at the apex: 1. Absent; 2. Stinger; 3. Mucron; 4. Double mucron.

vi) Surface on the upper side and underside (two (2) variables registered in the middle part of the leaf blade): 1. Smooth; 2. Rugged; 3. Semi-rugged. 4. Smooth towards the margins and rugged in the central part.

vii) Folds that give a wrinkled appearance: 0. Absent; 1. On the leaf blade; 2. In the curved foliar margin; 3. In the lamina and the curved foliar margin.

viii) Presence of anthocyanins in the margin and in the basal part (two (2) variables)

ix) Presence of wax.

x) Basal narrowness.

xi) Number of leaves per plant (fully developed).

xii) Length and width (recorded in cm, on the internal part of three leaves per plant).

xiii) Leaf thickness (recorded in the middle part of the leaf blade in mm).

b) Morphological variables and their states recorded in spines:

i) Shape of the apical, middle, and basal parts of the leaf (three variables): 1. Winged; 2. Absent; 3. Double in opposite directions, hunched upwards and straight; 4. Hunched downwards; 5. Hunched downwards and double in opposite directions; 6. Hunched downwards and straight; 7. Hunched upwards; 8. Hunched upwards and double in opposite directions; 9. Hunched upwards and hunched downwards; 10. Hunched upwards and straight; 11. Hunched upwards, split and double in opposite directions; 12. Hunched upwards, hunched downwards, and double in opposite directions; 13. Hunched upwards, hunched downwards and straight; 14. Hunched upwards, straight, and double in opposite directions; 15. Straight; 16. Straight with tips curved upwards; 17. Straight and hunched upwards; 18. Rudiments; 19. Triangular.

ii) Distribution in the apical and middle part of the leaf (two (2) variables): 0. Absent; 1. Regular; 2. Irregular.

iii) Color: 0. Absent; 1. Reddish; 2. Yellow; 3. Black; 4. Reddish yellow; 5. Purple.

iv) Length and width (recorded in mm, in 5 spines per plant)

v) Location along the leaf: 0. Absent; 1. Along the leaf margin; 2. In the middle part of the leaf; 3. Only on some leaves; 4. Basal; 5. Present in the middle part of the leaf and only basal; 6. Only in some leaves and in the middle part of the leaf.

vi) Presence in the first 10 cm of the apical part.

vii) Presence of rudiments in the margin.

viii) Presence of wings in the margin.

ix) Number of spines in 10 cm (registered in the middle part of the leaf).

2) Agronomic variables.

a) Plants that are flowering at the time the evaluation is carried out.

b) Number of leaves: sum of leaves of CAT I, II, and III.

c) Fiber length (m): established with a measuring tape.

d) Percentage of fiber in the leaf (%): (weight of the dry long fiber of defibrated leaves/weight of defibrated leaves) × 100.

e) Linear density (kg/m): weight of defibrated leaves in kg/(number of defibrated leaves × length of defibrated leaves in m).

f) Total length of harvested leaves (m):

Figure 1: Fique fiber extraction process (*Furcraea* spp.) in Rionegro, Antioquia, Colombia**. A.** Traditional machine used. **B.** Biomass separation system. **C.** Fiber drying. Photographs: **A.** Medina C., **B.** Orozco L, **C.** Grisales N.

(m): $\sum_{I=CATI}^{n=CATIII}$ *number of leaves x lenght of leaves (m)*

g) Total weight of harvested leaves (kg): total length of harvested leaves × linear density.

h) Fiber yield per plant (kg): percentage of leaf fiber × total weight of harvested leaves in kg.

i) Biomass yield per plant (kg): (weight of biomass in defibrated leaves in kg/weight of entire defibrated leaves in kg) × total weight of harvested leaves in kg.

j) Percentage of juice recovered in the defibrated leaves (weight of juice in defibrated leaves in kg/weight of defibrated leaves) × 100.

k) Elongation (%).

l) Resistance: (cN) according to the Colombian technical standard (NTC) 386 of 2011 and the American Society for Testing and Materials (ASTM) D-2256.

m) Title: (tex) according to NTC 842- ASTM D-1907.

n) Tenacity (cN/tex)

For the mechanical determination of the fiber, a universal testing machine LLOYD EZ20, 250 N-STRESS-CRE was used.

Data analysis

A dissimilarity dendrogram was constructed using the UPGMA method utilizing Gower's distance (1971) and validating the dendrogram employing the cophenetic correlation coefficient to group the accessions with similar characteristics (Sneath & Sokal, 1973). For this, each variable was assigned a subjective weight between 1 and 9, according to their degree of discrimination within the collection, with 1 being slightly discriminating and 9 highly discriminating. Finally, a descriptive analysis of each conformed group was carried out. The analyzes were performed using the R data analysis environment (R core team, 2021).

RESULTS

Six groups (A-F) were found at a Gower dissimilarity cutoff of 0.3, indicating that the accessions share 70% of their weighted characteristics (Figure 2) and showed a cophenetic correlation coefficient of 0.875.

Group A: This group is comprised of five accessions of the genus *Agave* spp. that did not flower during the evaluation (Figure 3A). The leaves presented an average epidermis thickness of 3.47 mm (Figure 3B), basal narrowness, wrinkles on their surface, a stinger-shaped apex (Figure 3C), and wax; no anthocyanins were found at the base. About 80% of the accessions showed slightly concave leaves, upper side and underside smooth to the touch, and 60% showed anthocyanins on the leaf margin and middle apex. On average, they developed nine black spines in the first 10 cm with a width of 1.33 mm, and a length of 4.87 mm, and regularly distributed along the leaf margin.

At four years of age, the accessions that comprised this group produced an average of eight harvestable leaves per plant and the shortest fibers of all groups (0.73 m in length). The average percentage of long fiber in the leaf was 1.27%; the fiber obtained per plant was 0.05 kg, and the biomass was 2.2 kg plant^{-1}, i.e., the lowest values of all the groups. The juice percentage recovered from the biomass was 27%, the highest value found of all the groups. Regarding the mechanical properties, the fibers

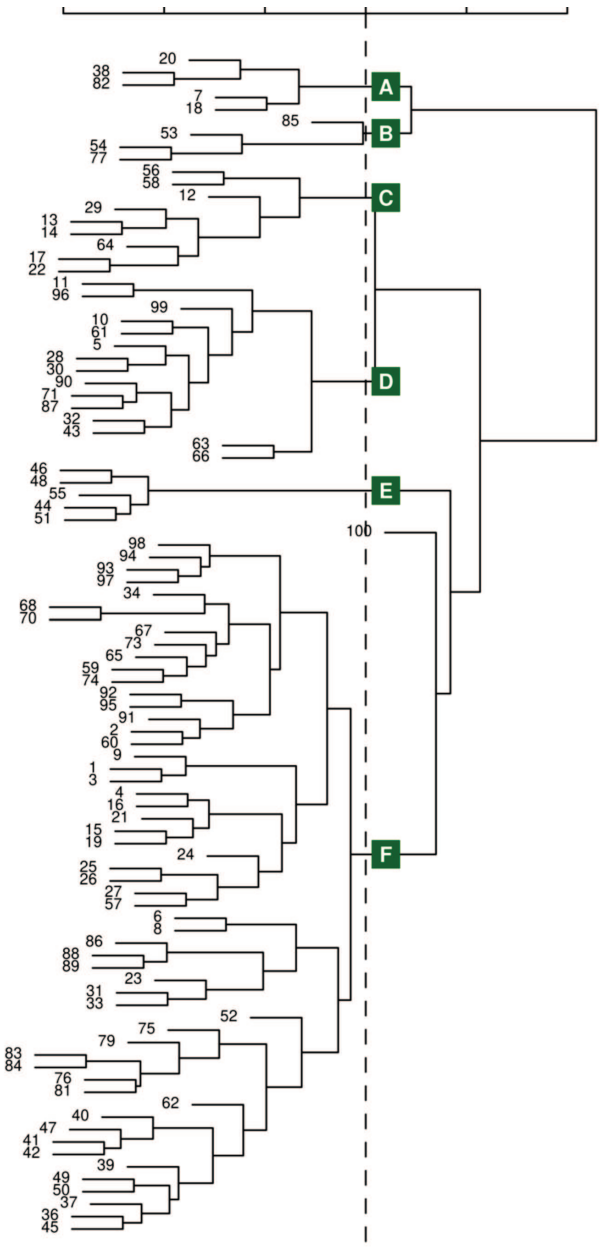

Figure 2: Grouping of 94 fique accessions (*Furcraea* spp. and related species) from the *ex-situ* collection established in AGROSAVIA, Centro de investigación La Selva (Coefficient of cophenetic correlation = 0.875). Source: elaborated by the authors.

presented the lowest average tenacity of 19.4 cN/tex (Figure 3D), and, in contrast, although with high dispersion, the highest elongation percentages (18.7%) (Figure 3E).

Group B: This group includes four accessions of the *Agave* spp. genus. The plants produced at four years of age an average of 61 leaves with a length of 72.2 cm, a width of 11.8 cm, and an epidermis thickness of 2.93 mm. No anthocyanins were found in the basal part nor in the leaf margin (Figure 4A); the leaves were smooth with a stinger (Figure 3C) and wax (Figure 4B). About 75% of the accessions have lanceolate, slightly concave leaves and an entire leaf margin (the remaining 25% have thorn rudiments) (Figure 4C). Further, 57% of the apex shape is medium, and 50% have basal narrowing of the leaf.

The number of harvestable leaves per plant at the evaluation point was 24, while the average length of the fiber was 0.95 m; the percentage of fiber in the leaf was 1.64%, and the percentage of juice recovered in the biomass was 17%. The fiber yield per plant was 0.12 kg, while the biomass yield was 4.46 kg plant^{-1}. Although there was a high dispersion, the tenacity of the fibers was the highest, with an average value of 34.6 cN/tex (Figure 3D) and an elongation of 11.0% (Figure 3E).

Group C: The group is comprised of nine accessions of the *Furcraea* spp. genus, with leaves with a length of 201.53 cm, a width of 21.44 cm, and a thickness of 2.38 mm; it has reddish yellow (Figure 5A) wings (Figure 4C); the upper side and underside are smooth, and no anthocyanins are observed on the foliar base. On average, a plant of this group produces 57 leaves, 88% of the accessions do not have wax (Figure 4B), 77% have pigmentation in the leaf margin, they have a middle apex, and do not have an appendix in the apex. In addition, the leaves are concave in 66% of the accessions, and 55% of these are wrinkled.

This group produced 24 harvestable leaves per plant, whose fibers were the longest of all, with an average of 1.9 m (Figure 5B). The percentage of fiber in the leaf was 2.17%, one of the three highest (Figure 5C), while the fiber yield per plant was 1.19 kg; the biomass yield was 39.6 kg plant $^{-1}$, and the percentage of recovered juice was 17%. The average tenacity of the fibers was 26.4 cN/tex, a midpoint between the groups, while the elongation was one of the lowest, with an average of 2.9% (Figure 3E).

Group D: This group of 15 accessions produces the highest number of leaves within the collection (Figure 6A) and does not have spines (Figure 4C). The leaves are

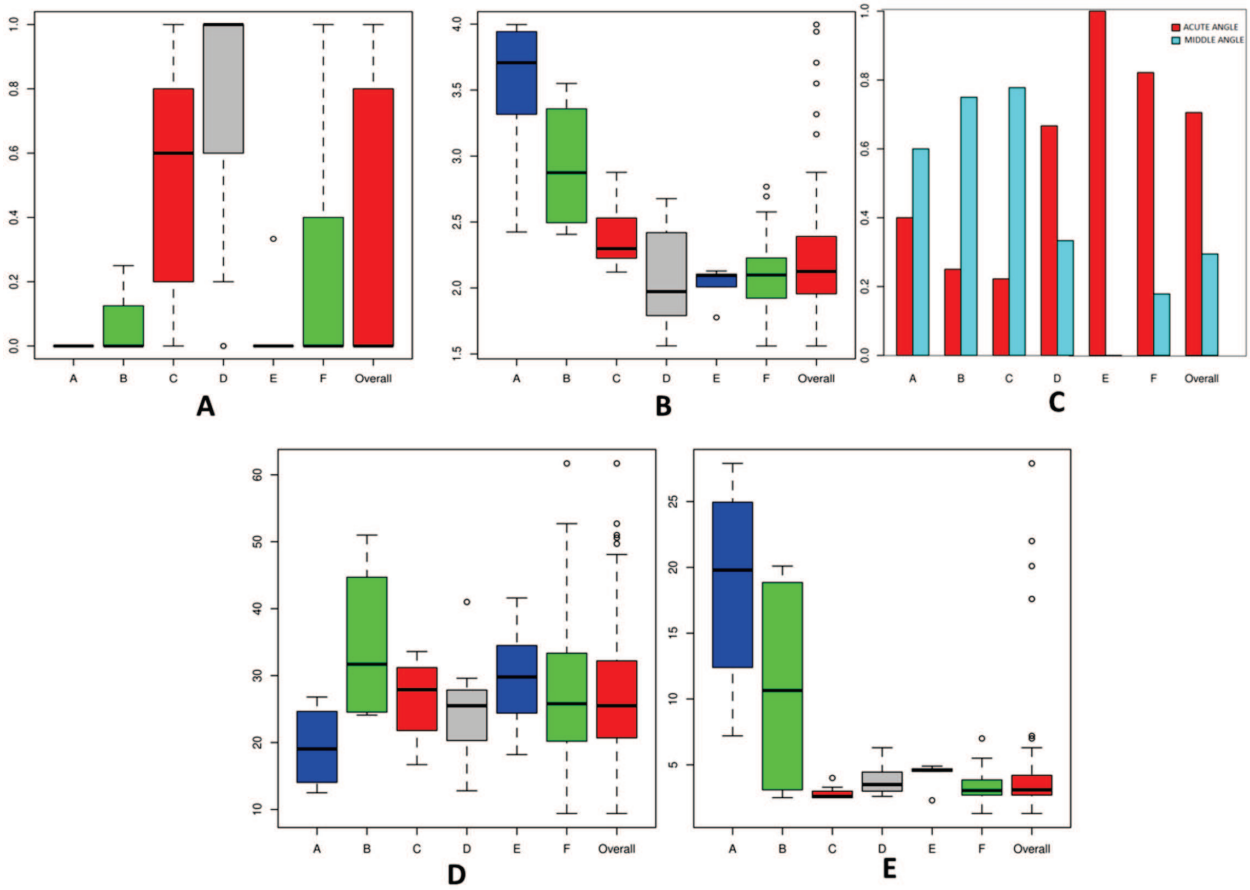

Figure 3A: Flowering plant. **B**. Epidermis thickness. **C**. Leaf apex shape. **D**. Fiber tenacity **E.** Fiber elongation, for the different groups formed by the analysis of variability of the work collection. Source: elaborated by the authors.

177.24 cm long and 20.71 cm wide, and the thickness of the epidermis is 2.08 mm. About 86% of the accessions have an entire leaf margin, 73% of these have smooth leaves, 66% lanceolate, and 86% concave; they do not have anthocyanins in the basal part, and 53% have anthocyanins in the margin; they do not have wax (Figure 4B) or an appendix at the apex.

The blade surface on the upper side is smooth, and in 53%, the blade on the underside is smooth towards the margins and rugged in the central part. About 80% of these do not have basal narrowness, and 66% have an acute form at the apex of the leaf. This group produced an average of 25 harvestable leaves per plant. The fiber length was 1.65 m, and the percentage of fiber in the leaf was 2.51%, the highest of all the groups (Figure 5B). The fiber yield per plant was 0.96 kg, the one of the biomasses was 28.7 kg, and the percentage of juice recovered was 18%. The tensile strength or tenacity presented by the fibers was, on average, 24.49 cN/tex, and the elongation percentage was 3.77%, i.e., one of the lowest.

Group E: This group includes five accessions of the *Furcraea* spp. genus, which, on average, produces the least amount of leaves per plant (39) (Figure 6A), showing rudiments of spines at the base of the leaf (Figure 4C) that have a yellow color, triangular shape, with a middle apex, a mucron-like appendage, and anthocyanins on the leaf margin (Figure 4A). The leaves are 186.68 cm long and 21.1 cm wide, and they do not have wax (Figure 4B) or basal narrowing; these are lanceolate and concave, with the surface of the blade smooth on the upper side, while the underside is rugged.

This group produced an average of 14 harvestable leaves per plant, the second lowest of the six (6) groups after group A (Figure 6B). On the contrary, the length of the fiber was one of the largest with a value of 1.70 m, as was its percentage in the leaf (2.23%), similar to groups C and D. The fiber yield per plant was 0.45 kg, the biomass 15.1 kg and the juice recovered from the biomass was 17%. The average tenacity presented by the fibers was 29.70 cN/tex, one of the highest, while the elongation was 4.20%.

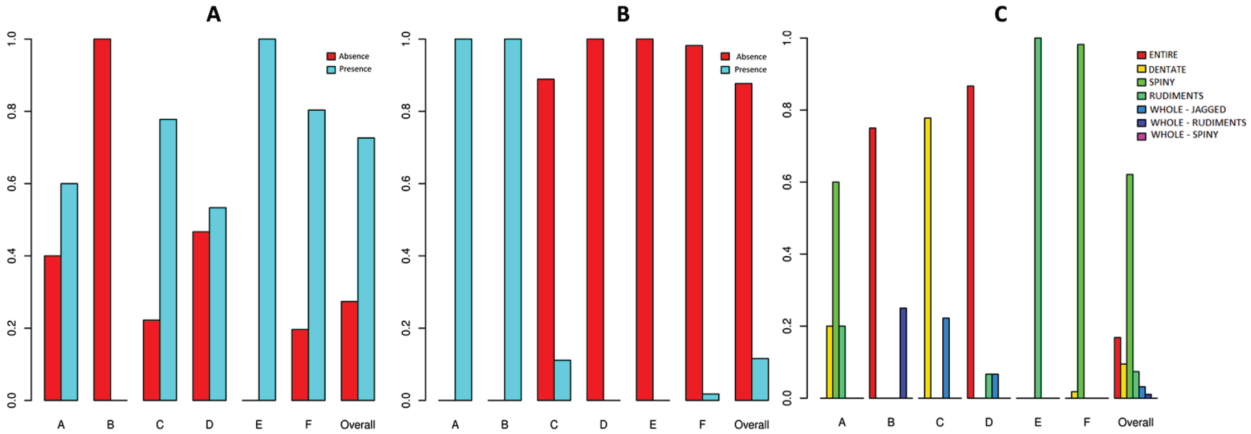

Figure 4A: Anthocyanins in the leaf margin, **B**. Presence of wax in the leaf blade, and **C.** Shape of the leaf margin in the groups formed by the variability analysis of the work collection. Source: elaborated by the authors.

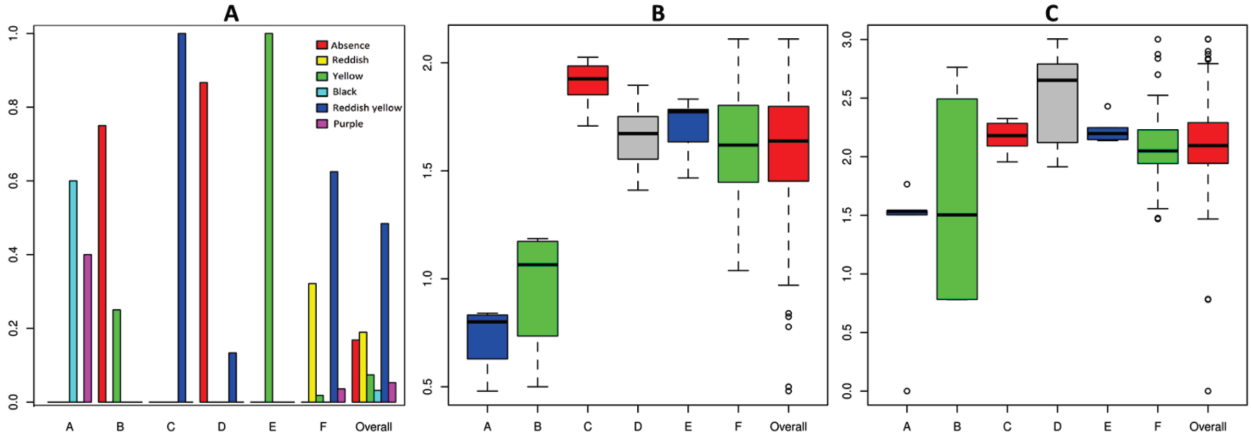

Figure 5A: Spine color, B. Fiber length, C. Percentage of long fiber in the leaf, in the groups formed by the variability analysis. Source: elaborated by the authors.

Group F: This group is comprised of 57 accessions of the *Furcraea* spp. genus (57.3% of the total collection); they have spines that are 5.5 mm long and 1.7 mm wide (Figure 4C) (Figure 7); they are unevenly distributed along the leaf and are curved upwards, reddish-yellow or reddish, and with an acute mucron (Figure 3C). The plants produced an average of 58 leaves during the evaluated period of 176.8 cm in length, 21.15 cm in width, and an average epidermis thickness of 2.0 mm; 98% of the accessions do not have wax (Figure 4B), 89% do not have anthocyanins in the basal part, and 80% show anthocyanins in the leaf margin and are concave; 67% do not have basal narrowness in the leaf, and the surface of the leaf blade in the upper side of 66% of the population is smooth.

About 26% of the accessions of this group began flowering in the fifth year of establishment in the field (Figure 3A). The agronomic attributes showed 21 harvestable leaves per plant, a medium level between the groups. A similar behavior showed the fiber length with 1.6 m, its percentage in the leaf was 2.10%, and the fiber

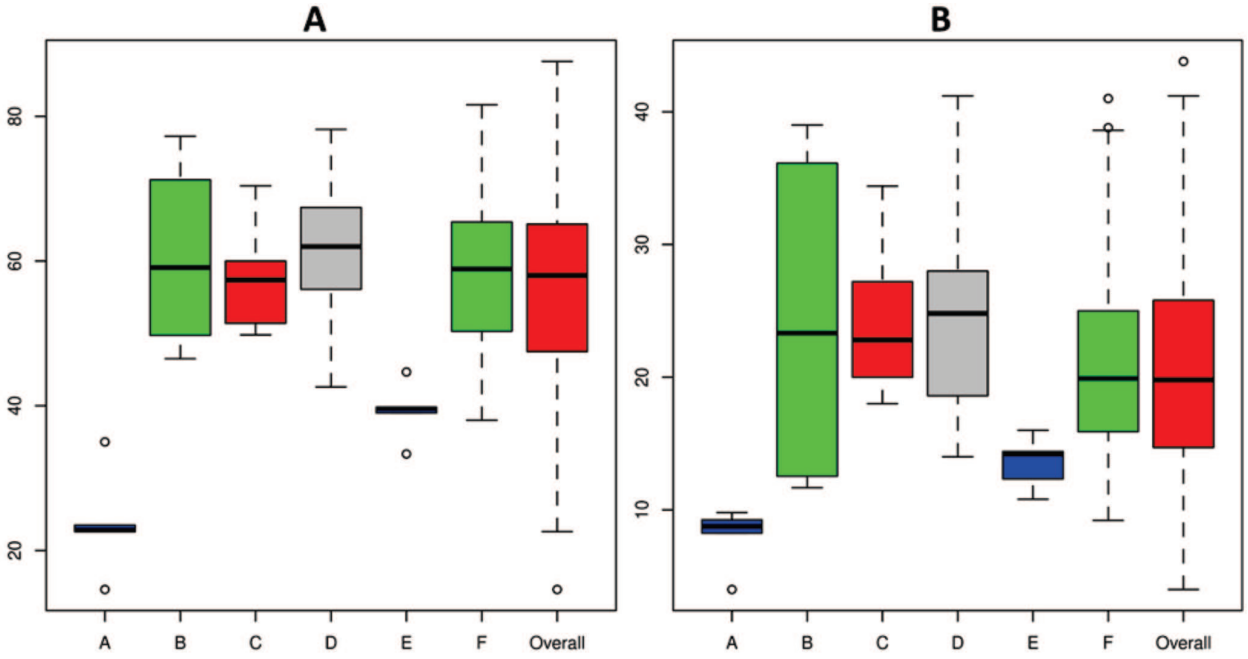

Figure 6A: Number of leaves produced per plant **B**. Number of leaves harvested per plant; for the different groups formed by the variability analysis of the work collection. Source: elaborated by the authors.

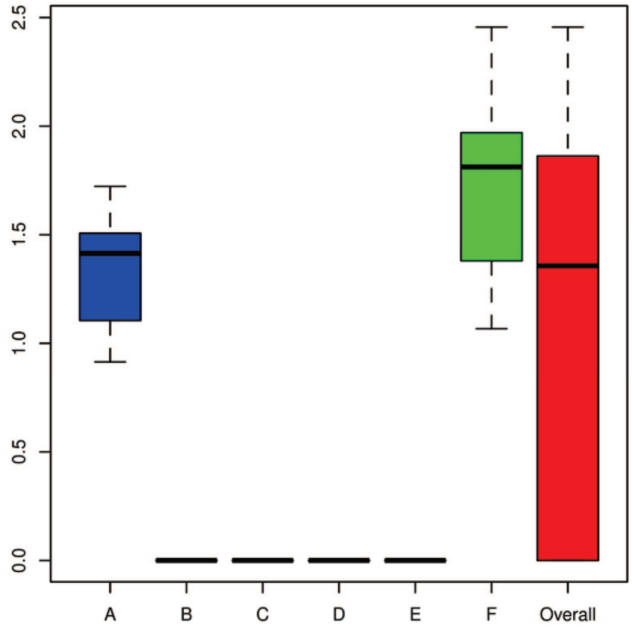

Figure 7A: Spine width in the groups formed by the variability analysis. Source: elaborated by the authors.

and biomass yield per plant were 0.66 kg and 21.8 kg, respectively. The percentage of juice recovered from the biomass was 20%, the second highest, while the tenacity of the fiber was very similar to that of group E, with an average value of 28.3 cN/tex, while the elongation percentage was 3.32%.

DISCUSSION

The six groups formed from Gower's dissimilarity analysis in the working collection of fique (*Furcraea* spp.) and Agaves indicate a wide variability. Whit the clustering method (UPGMA) a high cophenetic correlation coefficient was found, which shows that during the process the original data were not altered (Molina *et al.*, 2015).

Groups A and B were comprised of genotypes of the *Agave* spp. genus; meanwhile, the other groups (C to F) included accessions of the *Furcraea* spp. genus, finding a grouping pattern by local names and not by collection location. For Colombia, of the *Agave* genus, Giraldo (2020a and 2020c) report the species *A. cundinamarcensis* Berger; *A. berger* Trel. ex A. Berge; *A. pax* Gir.-Cañas; *A. wallisii* Jacobi; *A. americana* L.; *A. sylvesteriana* Giraldo-Cañas, and *A. sisalana* Perrine. Conversely, for the *Furcraea* genus, Giraldo (2020b) report the species *F. foetida* (L.) Haworth; *F. acaulis* (Kunth) B. Ullrich; *F. cabuya* Trelease; *F. abisaii* Giraldo-Cañas, and *F. selloana* K. Koch.

Of the variables described at the field level, there is a descriptor that includes a list of attributes recorded in characterization processes of other species of the Agavaceae family, such as stem shape (growth habit), number, shape, color, length, and width of the leaf, shape of the leaf margin, texture and presence of wax on the leaf, and presence, shape, color, length, and width of the spines (SAGARPA, 2014).

The average tenacity in group A (19.4 cN/tex), was lower than that of other natural fibers such as Sisal (49-61 cN/tex) or Hemp (31 cN/tex) but very similar to Aramid (15 -20 cN/tex), a synthetic fiber used as reinforcement in military garments. In group B (34.6 cN/tex) was compared with fibers such as Jute (26.4 -35.2 cN/tex) and Linen (29.0-33.4 cN/tex). Groups C, D, E and F presented values for this variable (24.5-29.7 cN/tex) similar to those of Cotton (26.4-43.1 cN / tex). The elongation of groups A and B (18.7 and 11.0%, respectively) was higher than that of fibers such as Hemp (1.3%), Sisal (2.0-2. 5%), or Ramie (3.5%), and like animal fibers such as Silk (17-25%) or synthetic fibers such as Aramid (10-20%), while for groups C, D, E and F this variable (2.87 and 4.20%) was higher than Sisal and Jute (1.5-2.5%) and close to Linen (1.5-4.5%) and Cotton (3.0-7.0%) (Lockúan, 2013)

Accessions of the *Agave* spp. genus of groups A and B produced the shortest leaves and the lowest fiber yields per leaf and plant; however, their high elongation makes them optimal materials to elaborate textiles or paper. On the other hand, the accessions included in groups C, D, E, and F belong to the *Furcraea* spp. genus and show the highest fiber yields with higher tenacity and lower elongation, promising for reinforcement of composite materials; even the attributes of group B can be part of this use.

Group A: possibly the genotypes that are included in this group correspond to one of the following species: *A. cundinamarcensis* Berger; *A. wallisii* Jacobi; *A. americana* L, and *A. sylvesteriana*, reported for Colombia by Thiede and Eggli (2020), and that share characteristics such as the presence of spines on the margin of the leaves. Barrientos *et al.* (2019) indicate that for the species *A. angustifolia* (Haw), the leaf (color, length, width, and their relationship, shape, and number) and spine characters (uniformity in size, length, distance, and number), are the most critical variables in the morphological taxa delimitation. It should also be recognized that these also represent importance when discriminating the species included in this study.

This group produced the shortest fibers of the six formed. Further, the percentage of fiber in the leaf and the fiber and biomass yields per plant were the lowest. For its part, the average tenacity found agreed with the values reported by Bessadok *et al.* (2008) for *A. americana* (7.2-22.3 cN/tex; 65-201 Mpa), as well as the elongation percentage of 19.1-22.3%, which were the highest values found of all the groups.

Group B: in this group, there is an accession of *A. sisalana* Perrine widely used for the extraction of natural hard fibers, with about 70% of the world production collected in the Colombian Atlantic coast and reported for the first time in the country in the canyon of the Dagua and Bitaco rivers, Valle del Cauca department (Giraldo, 2020c). In addition, the species *A. pax* Gir.-Cañas reported by Giraldo (2020a) may also be found.

The accessions of this group showed, on average, one of the lowest values of fiber length, percentage of fiber in the leaf, and fiber and biomass yields per plant after group A. The average tenacity value obtained was the highest of all groups (34.6 cN/tex), although it was below the values stated by Li *et al.* (2007) for *A. sisalana* of 45.7-84.8 cN/tex (412-764 MPa), as well as the elongation percentage since the value obtained, was 11.0%, and the reported was 2.5- 5%. However, when observing the individual values, the F54 and F77 accessions found in the same branch of the dendrogram agreed with the values reported for this species.

Group C: This group has the longest, widest, and thickest leaves in the collection; it includes most of the plants commonly called Bordo de Oro, classified by Ovalle *et al.* (2018) as *Furcraea* "Castilla" that is synonymy of *F. foetida* L. (Thiede & Eggli, 2020). According to Compañía de Empaques (2005) and Forero and Ante (1999), these are native to Colombia and widely cultivated in Antioquia, with leaves of 2 to 3 m, handling and soil demanding, and their fiber yield is 3 to 4% of the leaf. Colunga (1997) expresses that characteristic such as its leaf size, higher fibrosity, smaller size, and the number of spines, such as those observed in this group, represent a domestication process.

The fibers obtained from this group had the highest length (1.9 m). Although the average percentage of long fiber in the leaf was in the middle point, the fiber and biomass yield per plant were also the highest, showing that these accessions are among the most promising in fiber production. The average tenacity of the fibers agreed with the range reported by Delvasto *et al.* (2010) for fique (4.8-63.4 cN/tex; 43-571 Mpa). However, the average elongation of this group was the lowest (2.9%) of all, far from the value reported by the same authors (9.8%).

Group D: this group includes the accessions commonly known in Colombia as Ceniza, characterized by having a life cycle of 5 to 8 years, although there are longer-lived plants. They have a dry fiber yield of 2.5 to 4%, and these plants are susceptible to the macana virus and pink disease (Pérez, 1974). The genotypes that comprise this group may belong to the species *F. foetida* L. reported in Colombia by various authors (Bernal *et al.*, 2017; Thiede & Eggli, 2020; Giraldo, 2020b).

The accessions included in this group showed one of the highest numbers of harvestable leaves per plant and the highest percentage of fiber in the leaf. However, the leaves and, therefore, the fibers presented a shorter length than those of group C. This is why the fiber and biomass yield per plant was lower, placing it as the second most promising group in fiber production. Average fiber tenacity was one of the lowest of the four *Furcraea* spp. groups, while elongation had the highest variability.

Group E: includes materials commonly known as Pirulero from the department of Santander, municipalities of San Joaquín, Mogotes, and Aratoca. The accessions found in this group have spine rudiments or small teeth from 1-3 mm long at the leaf base; the rest of the leaf does not have spines. These were classified by Thiede and Eggli (2020) as *F. foetida* L.

Among the groups comprised of *Furcraea* spp. accessions, this was the one that produced the least number of harvestable leaves, with an average of 14 units. Furthermore, although its fibers had one of the highest lengths (1.7 m) and the highest percentages of fiber in the leaf (2.23%), the fiber and biomass yields per plant were the lowest of the genus; meanwhile, they presented the highest average tenacity (29.70 cN/tex), similar to that reported by Delvasto *et al.* (2010).

Group F: The plants in this group are characterized by having spines on the leaf margin and mucron, commonly known in Colombia as Uña de Águila, Ayalero, and Jardineña. According to Thiede and Eggli (2020), among the species of the *Furcraea* genus reported in the country that show characteristics similar to those of the group, the following are highlighted: *F. acaulis* (Kunth) B. Ullrich, cultivated in the departments of Cesar, La Guajira, and Norte de Santander; *F. cabuya* Trelease; *F. hexapetala* (Jacquin) Urban; *F. Sealana* K. Koch, cultivated in Antioquia, Cauca, Cundinamarca, Huila, Magdalena, Santander, Tolima and Valle, and *F. abisaii* Giraldo-Cañas, registered in Boyacá and Cundinamarca (Giraldo, 2020b).

The accessions of this group produced an average value in variables such as harvestable leaves per plant (24), fiber percentage in the leaf (2.10%), fiber and biomass yield per plant (0.66 kg and 2.18 kg, respectively), and fiber tenacity (26.4 cN/Tex); meanwhile, the elongation percentage before rupture was the second lowest of all groups (3.32%).

This study reports inter and intraspecific variability for the *Furcraea* and *Agave* genera. According to Figueredo *et al.* (2017), morphological variations in the *Agave* genus may be due to the heterogeneous environments where they are distributed and to the expression of their genomic variability. This allows demonstrating the importance of prioritizing and delving into spatial and temporal genetic variability and diversity studies for the conservation, maintenance, knowledge, and use of natural resources (Sherwin & Moritz, 2000).

CONCLUSIONS

The accessions evaluated in this study allowed identifying a separation between the *Agave* and *Furcraea* taxa represented in two and four groups, respectively. Considering that this collection was established clonally, wide intra and interspecific variability are observed.

The accessions of groups A and B produced the shortest leaves with the lowest fiber yields per leaf and plant. However, as these showed higher elongation, they were classified as optimal materials for elaborating textiles or papers.

Group C showed one of the highest values of harvested leaves, dry fiber per plant, high tenacity, and lower elongation, making it promising for genetic breeding programs either as a parental or elite clone or raw material for the elaboration of composite materials.

The only geographic grouping observed corresponded to the accessions collected in the department of Santander (group E).

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