Original Paper

Evaluation of the physical properties of banana pseudostem for textile application

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Abstract. *Handling waste resulting from food production in an environmentally sustainable manner is a highly important issue. Residues from banana cultivation generate waste that often lacks proper management. The objective of this research was to evaluate the physical properties of banana* *pseudostem for textile application, with specific reference to the species* Musa paradisiaca, Musa sapientum *and* Musa acuminata*. A completely randomized design was applied with three treatments, corresponding to the species under study, carrying out five repetitions for each treatment. The fiber extraction was artisan and followed the following steps: cutting, cleaning and transport (pseudostem), extraction, combing, drying and storage (fiber). The results of the statistical analysis showed that* Musa sapientum *fibre has the most length (123.34 cm}, greater elongation (7.93%), and the highest resistance (30.52 MPa) and linear density (0.070 dtex), when compared with the results of the species* M. paradisiaca *and* M. acuminata*. All the species under analysis had a circular cross section.* Musa acuminata *presented the greatest uniformity in the arrangement of filaments. In addition, the three evaluated species are similar to abaca, ramie and sisal in length and thickness. Finally, it was found that the cost of production of the artisanal extraction of banana fibre requires an approximate investment of $3.60. In conclusion, the fiber obtained from the three of the species studied has appropriate physical properties for textile application.*

1. Introduction

An estimated 33% of the 2.01 billion tons of municipal solid waste produced annually around the world is not handled in an environmentally sustainable manner. Since more than half of garbage is being deposited in an open area, the trajectory of waste increase will have significant effects on the environment, human health, and economic growth (World Bank, 2022). Consequently, waste management becomes a priority for every nation. In the United States of America, for example, the environmental impacts of food waste are equal to the quantity of water and energy required to power more than 50 million households, the amount of fertilizer necessary to cultivate all of the country's plant-based foods for human consumption, an area of agricultural land equivalent to California and New York or greenhouse gas emissions of more than 42 coal-fired power plants (Environmental Protection Agency, 2021).

The food supply chain makes use of a wide range of resources, such as land, water, energy, and chemical inputs. Among the phases of the food supply chain, primary production is the one that uses the most different types of environmental inputs. While greenhouse gas emissions, water and energy usage, and the use of pesticides and fertilizers are mostly associated with primary production, they are also present across the whole food supply chain (Jaglo *et al.,* 2021)

As consumer requirements evolve and consumption patterns alter, the sustainability of food production and consumption as a whole is seriously threatened. As a result, the supply chains for food and energy are linked to complex and interrelated environmental and socioeconomic effects (Sala *et al.,* 2017). In order to address a range of sustainability questions, a number of methodologies are required due to the diversity of issues and viewpoints associated with food systems. This calls for a shift to systemic thinking, whereby the effects of planetary carrying capacities, or the sustainability thresholds known as planetary limits, are maintained through patterns of global production and consumption (Malley *et al.,* 2021). Food systems include the whole supply chain, from agriculture through production, trading, distribution, consumption, and waste generation. Food systems that are "resource-smart" are essential given the growing global population (Filho *et al.,* 2022).

Banana production generates 0.86 kg of greenhouse gas emissions per kilogram (Ritchie, & Roser, 2020). In addition. banana is a highly commercialized product, and, with the gradual growth of its production, there is a directly proportional increase in the generation of waste (Diniz *et al.,* 2014; Chávez & Rodríguez, 2016). According to crop management practices, the pseudostem is eliminated immediately after harvest, generating approximately three tons of residue for each ton of bunches harvested, resulting in a waste ratio of approximately 3: 1 (Balda *et al.,* 2021; Universidad Politecnica de Madrid, 2016; Diniz *et al.,* 2014).

The abundance of banana by-products makes them a renewable resource, which can be converted into raw material and with potential to be easily biodegradable, which has a positive environmental acceptance and greater commercial viability (Padam *et al.,* 2014). In addition, it has been determined that banana fibre has high strength, good brightness, light weight and great moisture absorption, properties that make it an ideal candidate in textile applications (Abad *et al.,* 2012). Moreover, obtaining and extracting natural fibres is easier and presents reduced costs compared to artificially obtained fibres (Armas et al., 2016).

According to production statistics from the Ministry of Agriculture and Livestock of Ecuador (MAGAP, 2017), bananas represent 16% of the total planted area, being the third most produced plantation. According to MAGAP (2017), with a production of 307 143 t of bananas in Manabí, more than 900 t of residues would have been generated (including only the pseudostem). Therefore, without proper management practice of these by-products, a large amount of valuable untapped products will be lost (Haro et al., 2017; Kumar et al., 2018). However, there are no studies that describe the physical properties of the banana fibre produced in Ecuador. Therefore, the purpose of this research was to evaluate the physical properties of banana pseudostem for textile application.

2. Literature review

Worldwide, the development of the agricultural industry generates a large amount of waste, due to the implementation of new techniques and technologies to produce and satisfy the demand that is generated on a large scale. But many times, due to ignorance of the different technological alternatives that exist for the treatment of agricultural residues, it is not used effectively since it is estimated that these include a great cost (Nadeem *et al.,* 2022).

Due to the use of cutting-edge methods and technology to create and satiate the massive demand, the industry's expansion globally produces a significant quantity of waste. However, it is frequently not used efficiently because there is a lack of understanding of the many possibilities for treating agricultural waste. In this respect, Sustainable Development Goal (SDG) 12 of the Agenda 2030 for Sustainable Development is defined as "Ensure sustainable modes of consumption and production," and target 12.5 affirms the need "by 2030, [to] significantly reduce the generation of waste through prevention, reduction, recycling, and reuse." In order to promote sustainable consumption and production, it is stated that infrastructure must be built that is sustainable, essential services must be more readily available, and good, green employment must be created. All of this should result in a higher quality of life for everyone and contributes to the realization of SDG, the reduction of future economic, environmental, and social costs and the improvement of economic competitiveness (Economic and social overview of Latin America and the Caribbean, 2019).

According to the approach proposed by the United States Environmental Protection Agency (EPA, 2015), the use of by-products generates opportunities to: i) address climate change; ii) increase food security, productivity, and economic efficiency; and iii) conserve energy and other resources. In addition, the implementation of these measures has the potential to increase employment, decrease methane emissions from landfills, and conserve resources. Moreover, the EPA's proposed hierarchical pyramid for the recovery of organic waste has six levels, with the reduction in the source representing the preferred scope (Figure 1).

As was said in the preceding section, losses or waste along the food chain or manufacturing are a source of banana waste or byproducts. The pseudostem, a name given to the banana plant's trunk, is composed of leaf sheaths that are encircled by a soft inner core (Figure 2). In addition, the majority of the biomass wastes of banana plants are the pseudostems, which only bear fruit once in their lifetime before being replaced. It is estimated that each hectare of banana plantations produces roughly 220 tons of biomass trash (Balda *et al.,* 2021).

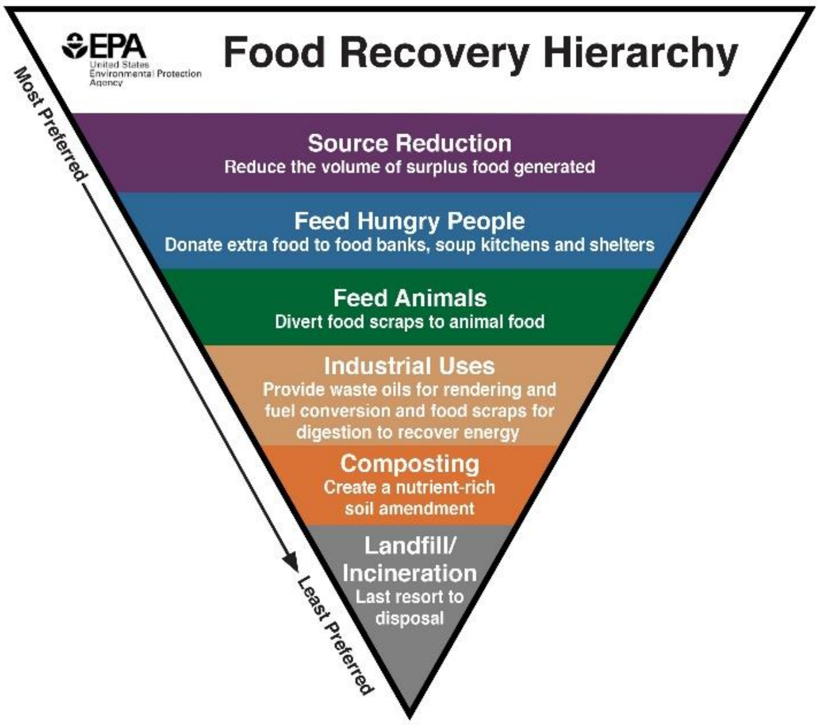

Figure 1. Food Recovery Hierarchy. Source: https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy

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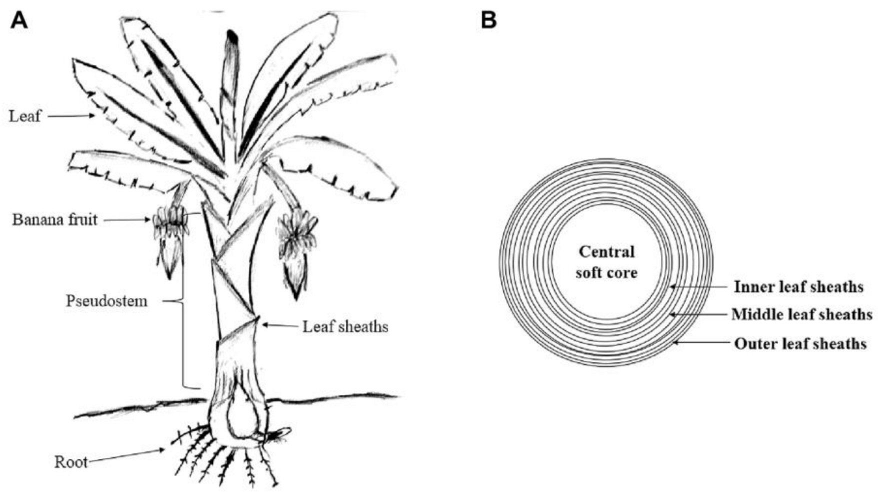

Figure 2. Representation of A: Banana Plant and B: Cross-sectional view of banana pseudostem Source: (Balda *et al.,* 2021).

Various banana plant components, including the leaves, pseudostem, pith, and fruit peels, can be utilized in both food- and non-food-based applications, including the creation of tea bags, biofertilizers, wastewater treatment, paper (Tripathi *et al.,* 2019), textiles, and composite materials (Padam *et al.*, 2014). (Akinyemi & Dai 2020). Research is being done on using banana pseudostem to obtain high-quality fibre. Banana pseudostem fibres have similar mechanical characteristics to conventional reinforcements, much as other natural fibres. This offers business extra advantages as an environmentally friendly option because it is a fibre of vegetable origin (Yan *et al.,* 2016).

This research contributes to the subject of study by providing information on the physical characteristics of banana fibre from three different species that were gathered in Ecuador's coastal area, for which the literature contains no prior references for the type of data mentioned above. Moreover, a manual extraction method that can be used by any producer is described, and a cost analysis that enables proving the financial advantage of banana fibre extraction is outlined.

3. Materials and methods

As well as bibliographic, our research is experimental and deductive, and statistical methods were applied for its execution. A completely randomized design to the three treatments (corresponding to the species under study) with five repetitions per treatment was applied.

3.1. Place of extraction of banana pseudostems

The banana pseudostems were extracted in the Mocoral community of the Canuto parish, Chone – Manabí, at coordinates 597187; 9909044 (Zone 17S) and 62 meters above sea level. In this area, the climate is tropical with an average rainfall of 121.9 mm, an average temperature of 26ºC and 83.5% relative humidity (National Institute of Meteorology and of Ecuador - INAMHI, 2019).

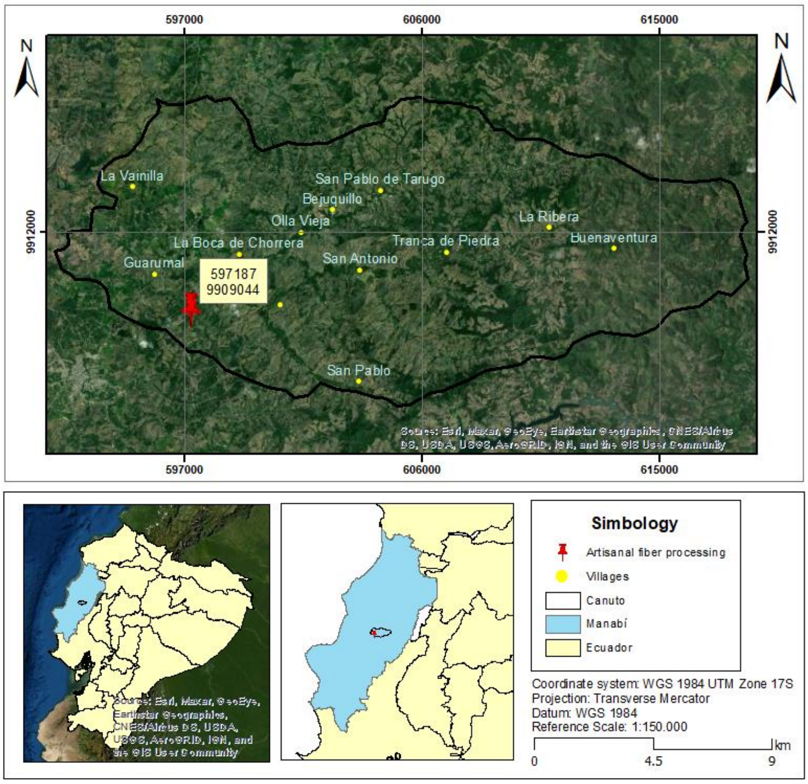

Figure 3. Geographical location of the place of extraction of the banana pseudostems.

3.2. Determination of the physical properties of the fibre of the pseudostem of the species Musa sapientum*,* Musa paradisiaca *and* Musa acuminata

The collection of pseudostems was carried out at age nine months of the banana plants, the time when the fruit is harvested. A cut was made ten cm from the soil, cleaning the pseudostems of leaves in the field adapting the procedure proposed by (Motaleb *et al.,*2021; Libertejidos SanAgustin, 2019). The processing of the fibre was manual and, in Figure 4 the steps carried out until the fibre was obtained are graphically detailed. To calculate the efficiency of the process, the number of sheaths and length of each pseudostem was considered.

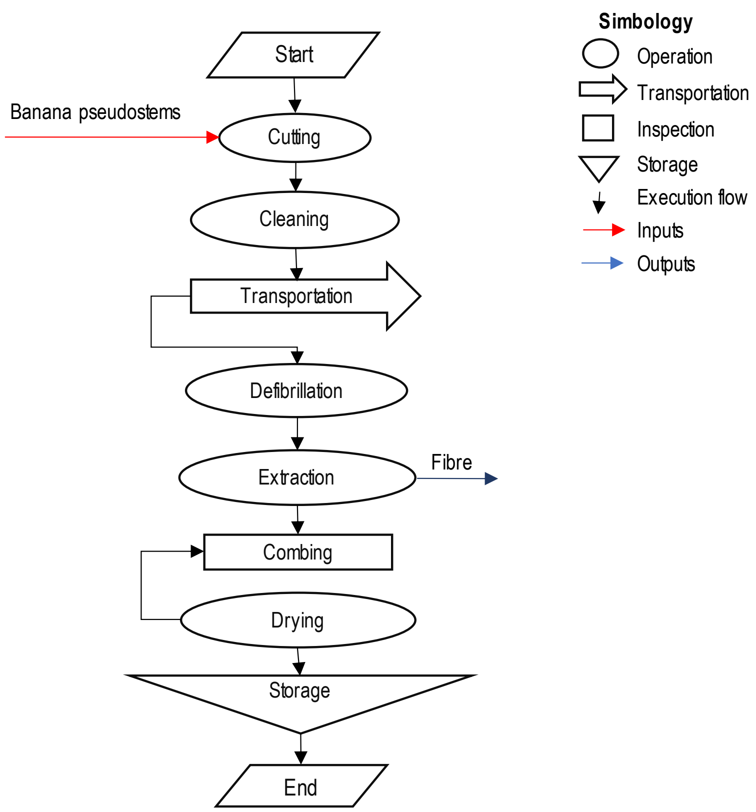

Figure 4. Process diagram for the artisanal extraction of banana pseudostem fibre.

Once the fibre was obtained, the physical properties described in Table 1 were analysed.

Property	Equipment / instrument	Unit	Reference
Length	Flexometer	Centimeter (cm)	Carrera (2017)
Thickness	Microscope OPTIKA B-150, images were processed in ImageJ software	Microns (µm)	Carrera (2017)
Cross section shape	Microscope OPTIKA B-150	-	Carrera (2017)
Linear density	$\varrho_l = \frac{m_b}{n_f x l_f}$ ϱ_l: Linear density m_b: Fibre bundle mass (mg) n_f: Number of fibres in the bundle l_f: Length of bundle fibres (mm)	Decitex (dtex)	Ecuadorian Technical Standard NTE INEN-ISO 1973 First edition 2014-01
Resistance	Texturometer SHIMADZU EZ-LX.	Megapascal (MPa)	Carrera (2017)
Elongation	Texturometer SHIMADZU EZ-LX.	Percentage (%)	Carrera (2017)

Table 1. Description of the analysed physical properties of the banana pseudostem fibre.

The analysis of variance (ANOVA) and the Tukey test (95%) were applied in the JASP software to determine statistically significant differences between the treatments (for the species under study). Likewise, a comparison was made with the thickness and length properties of other plant species used for textile purposes (Table 2).

Type of fibre	Thickness (µm)	Length (mm)	Reference
Abaca (*Musa textiles*)	250-300	2000-4000	(Freire, 2019)
Cotton (*Gossypium*)	5-20	20-40	(Alonso, 2015; Carrera, 2017)
Hemp (*Cannabis sativa*)	16-50	35-40	(Alonso, 2015; Carrera, 2017)
Jute (*Hibiscus cannabinus, H. sabdariffa, Abutilon avicennae, Urena lobata, U. sinuata*)	12-30	2	(Alonso, 2015; Carrera, 2017)
Linen (*Linun usitatissimum*)	20-25	13-55	(Alonso, 2015; Carrera, 2017)
Ramie (*Boehmeria nivea* and *Boehmeria tenacissima*)	25-75	50-150	(Alonso, 2015; Carrera, 2017)
Sisal (*Agave sisalana*)	200-400	500-2000	(Alonso, 2015; Carrera, 2017)

Table 2. Thickness and length of other vegetable fibres used in textile industry.

3.3. Estimation of the cost of the artisanal extraction process of banana pseudostem fibre

Based on 125 g of fibre (equivalent to 500 meters), an economic estimate ($) was made considering the costs described in Figure 5 and the items listed on Table 3. For the cost of labour, the hourly wages set by the Comptroller General of the State of Ecuador (2021) were used. The salary of a labourer per hour is $ 3.62, while that of a supervisor reaches $ 4.07 (Office of the Comptroller General of Ecuador, 2021). Since the supervisor does not fulfil a role that requires his presence throughout the extraction process, 0.2 was considered in quantity. The cost of a spatula and a comb that are used in practically the entire process was taken into account. Finally, applying formula 1 (Valenzuela, 2014), the unit cost of the artisanal extraction process was obtained.

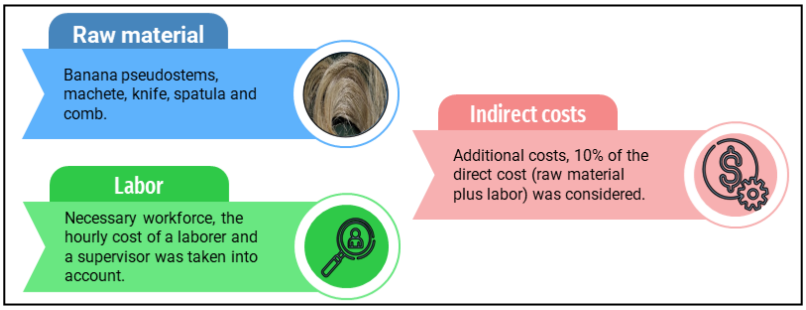

Figure 5. Description of the elements considered for the economic estimation.

Unit cost = (Cost of production) / (Total of units) (1)

Artisanal extraction of banana pseudostem fibre (500 m; 125 g)					
LABOUR					
Description	Quantity A	Pay/ hour B	Cost/hour C = A*B	Efficiency R	Cost D = C*R
Labourer	1	3.62	3.62	0.50	1.81
Supervisor	0.2	4.07	0.81	0.50	0.41
Subtotal N					2.22
MATERIALS					
Description		Unit	Quantity A	Unit cost B	Cost C = A*B
Banana pseudostems		-	5	0	0.00
Spatula		-	1.00	0.70	0.70
Comb		-	1.00	0.30	0.30
Subtotal O					1.00

Table 3. Quantity, cost and efficiency considered for the economic estimation.

Results and Discussion

It was found that *Musa sapientum* pseudostem had an average length of 170 cm and 8 sheaths, producing about 308.30 g of fiber. The efficiency of the process for *Musa paradisiaca* rated second with 150 cm of length, 7 sheaths and 277.50 g of fiber. Finally, with *Musa acuminata* 113.70 g of fibre was produced with pseudostems of 6 sheaths and 140 cm length.

As regards the fibre itself, it was determined that the species with the longest average length was *Musa sapientum* with 123.34 cm, followed by *Musa paradisiaca* with 113.04 cm, while *Musa acuminata* presented 98.75 cm in length. Furthermore, *Musa paradisiaca* presented a narrow data distribution, in contrast to *Musa acuminata* (Figure 6).

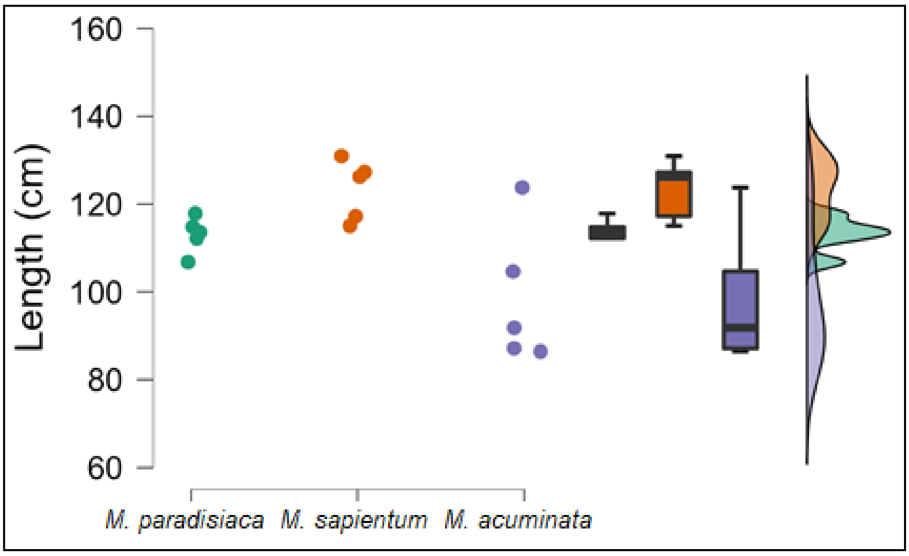

Figure 6. Length of the species under study.

After applying the ANOVA, it was determined that there is a significant statistical difference between factors (species), as observed in Table 4 with a significance equal to 0.008. Regarding the multiple comparison, *Musa paradisiaca* and *Musa sapientum* are similar, forming one group. *Musa paradisiaca* and *Musa acuminata* are two groups with a statistically significant difference (Table 5).

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	1526.100	2	763.050	7.330	0.008
Residuals	1249.229	12	104.102		

Note. Type III Sum of Squares

Table 4. ANOVA - Length (cm).

		Mean Difference	SE	t	p_{tukey}
1	2	-10.310	6.453	-1.598	0.284
	3	14.290	6.453	2.214	0.109
2	3	24.600	6.453	3.812	0.006

Note. P-value adjusted for comparing a family of 3

Table 5. Length Post Hoc Comparisons - Treatment

For a fibre to be useful in textile industry, it must have a very small diameter/thickness in relation to its length, be relatively flexible and present homogeneity to obtain yarns with the same characteristics (Arsène *et al.,* 2017; Alonso, 2015; Nguyen & Nguyen, 2022). The fibres obtained by hand show a greater elongation to the pseudostem layers due to the tension exerted in the extraction. Nevertheless, the length of the three species exceeds the thickness considerably. Therefore, their length is appropriate for textile purposes.

The average thickness of *Musa acuminata* is the smallest, with an average of 30.45 µm, *Musa paradisiaca* is 56.96 µm in thickness, while *Musa sapientum* is the thickest species with 64.62 µm (Figure 7), reflecting a minimal distribution in the thickness data for *Musa sapientum*, given that the values range from 63.04 to 64.76 µm.

The results of the ANOVA applied to the data of this parameter showed that there is a statistically significant difference (Table 6). Similarly, the multiple thickness comparison revealed that the three species under study are different in terms of this characteristic (Table 7), presenting three subsets for alpha = 0.05.

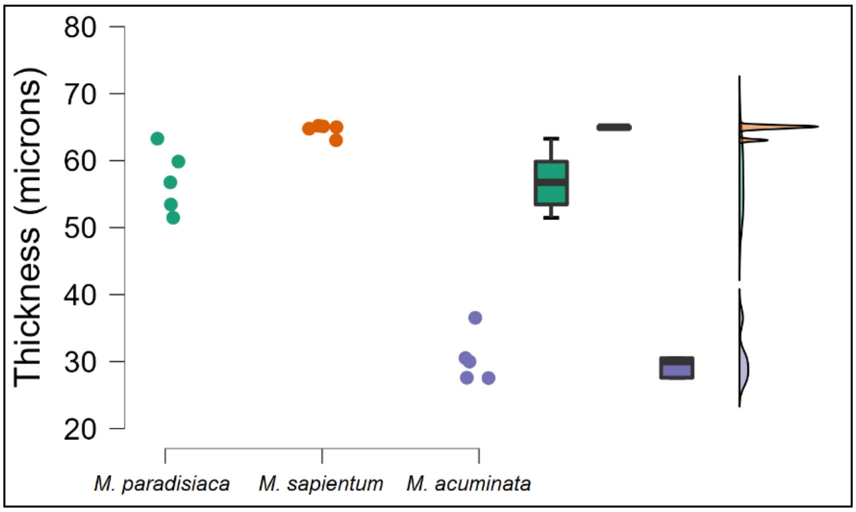

Figure 7. Data of the thickness of the species under study.

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	3216.009	2	1608.005	130.599	< .001
Residuals	147.751	12	12.313		

Note. Type III Sum of Squares

Table 6. ANOVA - Thickness (microns)

		Mean Difference	SE	t	p_{tukey}
1	2	-7.658	2.219	-3.451	0.012
	3	26.516	2.219	11.948	< .001
2	3	34.174	2.219	15.399	< .001

Note. P-value adjusted for comparing a family of 3

Table 7. Thickness Post Hoc Comparisons - Treatment

In India *Musa sapientum* fibre has been found to have a diameter ranging from 80 to 100 µm (Kulkarni *et al.,* 2010), whereas in Ecuador the fibre of the same species has a smaller diameter, which can reach up to 75 µm. Thinner fibres are better valued in the textile industry (Carrera, 2017; Chand, & Fahim, 2021; Priyadarshana *et al.,* 2020). However, in the case of *Musa acuminata* the extraction process is difficult since the fibre is much more susceptible to ruptures, indicating that in the studied species the thickness is directly proportional to the resistance of the fibre. On the other hand, between the length and thickness of the fibre of the studied species exists a ratio of 1: 10 000.

As regards the shape of the cross section, *Musa paradisiaca* has a circular shape (Carrera, 2017; Debnath, 2017; Ramesh, 2018) as shown in Figure 8, the fibre of this species is composed of continuous filaments with circular ends.

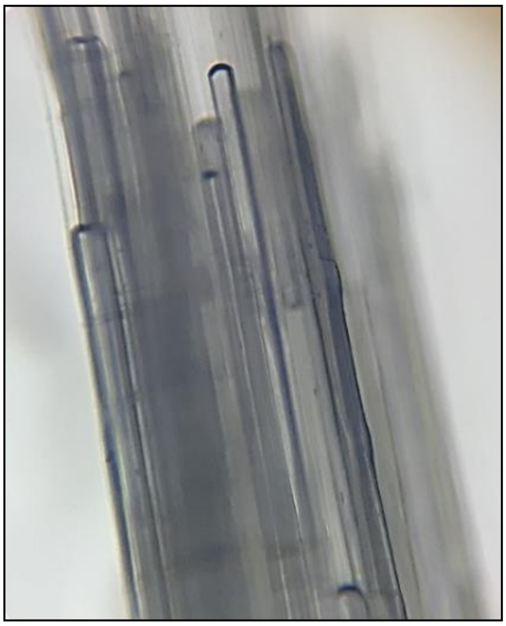

Figure 8. *Musa paradisiaca* cross section.

Musa sapientum showed a circular cross section with a peculiar configuration that can vary from circular to oval (Carrera, 2017; Motaleb *et al.,* 2021). Thus, this species presents shorter and less uniform filaments as shown in Figure 9.

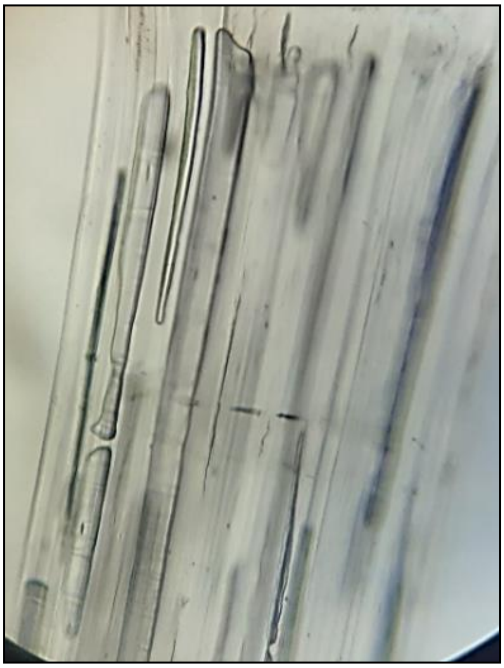

Figure 9. *Musa sapientum* cross section.

Musa acuminata has a circular cross section with filaments similar to those of *Musa paradisiaca*, although less uniformity is observed in their distribution (Figure 10). The circular shape imparts a strong shine to the fibre or filament because incident light is reflected unevenly, and this tends to result in a rather harsh brightness. When the fibre or filament is transformed into thread or cloth, its circular shape allows it to reflect the same amount of incident light despite the irregularity of its reflection. Furthermore, this shape results in a high bending stiffness, rigid fibre and less flexible due to its regular diameter (Kusić *et al.,* 2020; National Program for Technological Enhanced Learning [NPTEL], 2012; Subagyo & Chafidz, 2018).

Musa paradisiaca has an average of 0.062 dtex of linear density, presenting an atypical value of 0.064 that is far from the narrow distribution of the data for this species. Meanwhile, *Musa sapientum* is the species with the highest value in this parameter (0.070 dtex) and *Musa acuminata* the species with the lowest linear density (0.055 dtex), results that are graphically expressed in Figure 11.

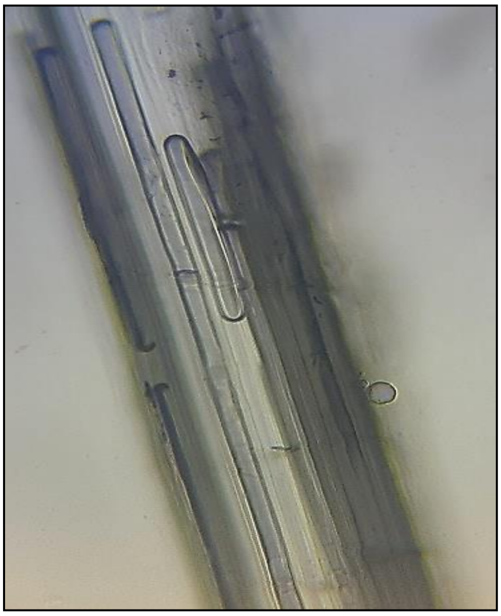

Figure 10. *Musa acuminata* cross section.

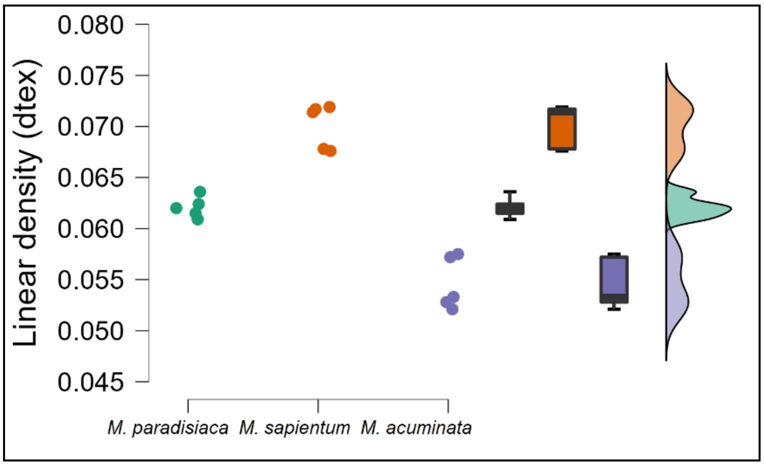

Figure 11. Linear density of the species under study.

According to the ANOVA performed, the linear density of the species under study shows a statistically significant difference (Table 8). Likewise, the Tukey HSD test revealed that there are differences between treatments, forming three subsets for alpha = 0.05 (Table 9).

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	6.008e-4	2	3.004e-4	72.793	< .001
Residuals	4.952e-5	12	4.127e-6		

Note. Type III Sum of Squares

Table 8. ANOVA - Linear density (dtex).

		Mean Difference	SE	t	p_{tukey}
1	2	-0.008	0.001	-6.226	< .001
	3	0.007	0.001	5.837	< .001
2	3	0.015	0.001	12.064	< .001

Note. P-value adjusted for comparing a family of 3

Table 9. Linear density Post Hoc Comparisons – Treatment.

Figure 12 synthesizes the distribution of the resistance data of the three species under study, indicating that the species with the most resistant fibre is *Musa sapientum* with 30.52 MPa. *Musa paradisiaca* obtained an average of 27.58 MPa and *Musa acuminata* is the least resistant species with 22.65 MPa.

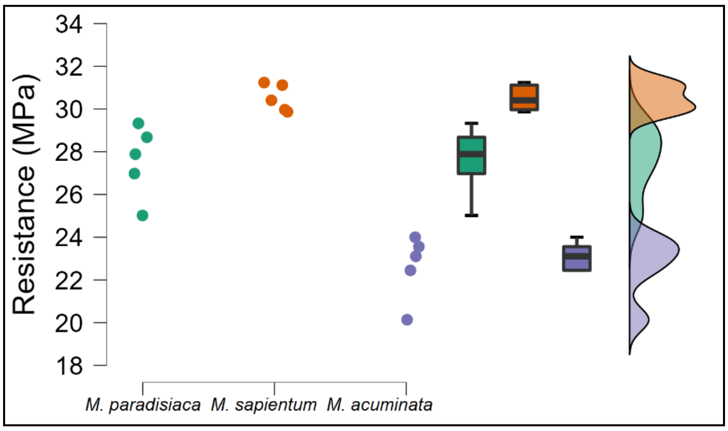

Figure 12. Resistance of the species under study.

The result of the ANOVA applied indicates a statistically significant difference ($p < .001$) between the three species (Table 10). In agreement with the results of the ANOVA, the Tukey HSD test shows that the three species are different in terms of resistance, with three subsets for alpha = 0.05 (Table 11).

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	158.129	2	79.065	42.931	< .001
Residuals	22.100	12	1.842		

Note. Type III Sum of Squares

Table 10. ANOVA - Resistance (MPa).

		Mean Difference	SE	t	p_{tukey}
1	2	-2.942	0.858	-3.428	0.013
	3	4.928	0.858	5.742	< .001
2	3	7.870	0.858	9.169	< .001

Note. P-value adjusted for comparing a family of 3

Table 11. Resistance Post Hoc Comparisons – Treatment.

The resistance of banana fibre in India ranges between 24-32 MPa, and this resistance can be increased up to 90 MPa through reinforcement treatments. Logically, there are many factors that influence the resistance of the fibre, such as nature resin and fibre chemistry, fibre orientation, aspect ratio, fibre length, uniform fibre distribution, and surface area, as well as others (Kavitha & Aparna, 2021; Senthilkumar et al., 2018). These values coincide with the findings of this investigation, especially with *Musa sapientum* and *Musa paradisiaca*, since *Musa acuminata* presented values below 24 MPa.

Since elongation is equivalent to resistance, it was obtained that *Musa sapientum* has greater elongation (7.93%), while *Musa paradisiaca* has 5.86% and *Musa acuminata* showed 4.83% elongation (Figure 13). In the textile field, it is known that mercerization (treatment with sodium hydroxide) gives cotton an exceptional elongation of between 10 and 30% (Alonso, 2015; Zheng et al., 2021). Therefore, considering that no treatment has been carried out on the fibres of the species under study, it is inferred that the elongation could be considerably increased when applying a textile treatment to the fibre.

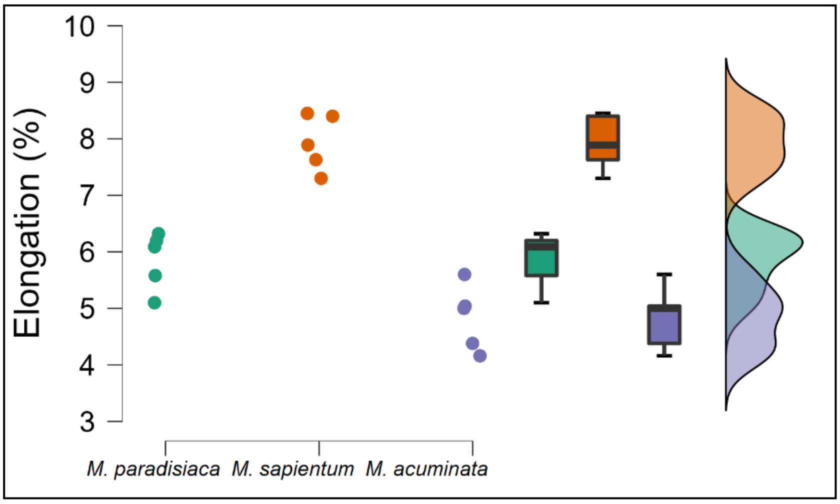

Figure 13. Elongation of the species under study.

In this case, the ANOVA also reflects a statistically significant difference (Sig. = 0.000) as shown in Table 12. While, the results of the Tukey HSD test (Table 13), reflect that the difference is significant between all three species in terms of elongation, forming three subsets.

Cases	Sum of Squares	df	Mean Square	F	p
Treatment	24.920	2	12.460	44.861	< .001
Residuals	3.333	12	0.278		

Note. Type III Sum of Squares

Table 12. ANOVA - Elongation (%).

		Mean Difference	SE	t	ptukey
1	2	-2.076	0.333	-6.228	< .001
	3	1.022	0.333	3.066	0.025
2	3	3.098	0.333	9.295	< .001

Note. P-value adjusted for comparing a family of 3

Table 13. Elongation Post Hoc Comparisons - Treatment

Figure 14 shows the fibre extracted from the three species under study, where it is evident that all species are similar in colour, while in volume *Musa sapientum* and *Musa paradisiaca* have greater corpulence. In the case of length, M*usa sapientum* is the one with the greatest uniformity to the naked eye.

Figure 14. View of the extracted fibre. From left to right: *M. sapientum, M. acuminata, M. paradisiaca*

In the economic estimation made, for the equipment item, 5% of the cost of labour was considered to include the cost of tools such as machetes and knives. Regarding transportation, no item was considered because in this case the pseudostems were manually moved to the place of fibre extraction. Likewise, the value of banana pseudostems was not considered since in the area where the project was carried out they are considered by-products.

Table 14 shows the economic estimate made, demonstrating that the artisanal extraction of 500 m (125 g) banana fibre requires an investment of approximately $ 3.60. Given the lack of estimates of this type, it was not possible to make a comparison of items with other findings. However, 1 g of Musa textiles fibre is $ 0.002. Although this value is lower than that estimated for banana fibre, it should be emphasized that improvements in the efficiency of the extraction process can reduce production costs (Pera, 2019).

THESE PRICES DO NOT INCLUDE TAXES	Direct cost (N+O)	**3.27**
	Indirect cost (10% Direct cost)	**0.33**
	Total	**$3.60**
	Unit cost by meter	**$0.01**
	Unit cost by gram	**$0.03**

Table 14. Results of the cost of production analysis.

5. Conclusions

Transforming agricultural waste into textile fibre has great potential for rendering human trajectories more sustainable and recycling banana pseudostems can play an important role in this process. The fibre of the three species studied (*Musa paradisiaca, Musa sapientum* and *Musa acuminata*) presents favourable conditions for its use in the textile industry, and, taking into account its characteristics, could be used in the elaboration of various products, depending on the specific requirements. The species with the best physical properties is M. *sapientum*, whose fibre showed better values in the evaluated physical characteristics (length, thickness, cross-section shape, linear density, resistance, and elongation). However*, M. paradisiaca* and *M. acuminata* also present appropriate characteristics for their use for textile purposes, those products that require less fineness would have a better finish with *M. acuminata* fibre. Likewise, local producers of *M. paradisiaca* could give added value to the by-product of this species, which is quite similar to *M. sapientum.* The artisanal extraction of 500 m (125 g) of banana pseudostem fibre requires an approximate investment of $ 3.60, resulting in a unit cost per meter equal to $ 0.01 and a unit cost per gram of $ 0.03. These values could be used as a basis to set a sale price of the fibre of the species studied. The practical contribution of the above, lies in the fact that a baseline is presented on the mechanical properties of the pseudostem fibre of three banana species from Ecuador.

Therefore, in future research it is suggested that studies of other properties of the fibre are necessary in order to fully ascertain its application in the textile field.

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