Journal of Hunan University

(Natural Sciences)

Vol. 52 No. 3

March 2025

Available online at

https://jonuns.com

Open Access Article https://doi.org/10.55463/issn.1674-2974.52.3.4

Standardized Production of Artisanal Paper from *Gynerium sagittatum* Residues as a Sustainable Strategy for Zenú Handicrafts

Yehys. C. Osorio López[1], José Fernando Pineda Vergara[1], Alicia Humánez Alvarez[2], Javier Darío Canabal Guzmán[3], Helmer Muñoz Hernández*[3], Joaquín Fernando Canabal Guzmán[1]

[1] University of Sinú 'Elías Bechara Zainum', Faculty of Science and Engineering, Montería, Colombia. Undergraduate in Industrial Engineering, ing.yehys0328@gmail.com, jjffppvv@gmail.com, joaquincanabal@unisinu.edu.co

[2] University of Sinú 'Elías Bechara Zainum', Biomedical Research and Molecular Biology Group, Faculty of Health Sciences, Montería, Colombia. Undergraduate Degree in Biology and Chemistry, aliciahumanez@unisinu.edu.co

[3] University of Sinú 'Elías Bechara Zainum', Faculty of Economic, Administrative and Accounting Sciences, Monteria, Colombia. Undergraduate degree in Business Administration, javiercanabal@unisinu.edu.co, helmermunoz@unisinu.edu.co

* Corresponding author: helmermunoz@unisinu.edu.co

Article History:

Received: February 1, 2025
Revised: March 7, 2025
Revised: April 2, 2025
Accepted: April 9, 2025
Published: April 30, 2025

Abstract: This study presents the development of a standardized process for producing artisanal paper from *Gynerium sagittatum* (locally known as *Caña Flecha*) residues, a byproduct of Zenú handicraft production, carried out at the Industrial Engineering Laboratory of Universidad del Sinú Elías Bechara Zainúm. The objective was to obtain a paper with appropriate strength, appearance, and quality using accessible and low-cost techniques. The methodology involved mechanical and chemical fiber treatment, followed by sieving, pressing, and drying. Various process parameters were tested, including cooking time (2–3 hours), chemical agents (NaOH, $CaCO_3$, CaO), water volume, and drying time (2–4 days). The final product exhibited satisfactory mechanical and esthetic properties. The novelty of this research lies in transforming local agro-industrial waste into a sustainable material for artisanal use, aligning traditional craftsmanship with the principles of innovation, recycling, and environmental responsibility.

Keywords: *Gynerium sagittatum,* Caña Flecha, Zenú handicrafts, artisanal paper production, sustainable materials, agro-industrial waste, fiber processing, eco-friendly manufacturing, circular economy, traditional crafts and innovation, low-cost paper production, indigenous technologies, natural fiber pulp, chemical treatment of the plant fibers, Colombia's sustainable development.

利用箭叶木残渣进行手工纸的标准化生产，是Zenú手工艺的可持续战略

摘要：本研究介绍了一种利用 Gynerium sagittatum（当地称为 Caña Flecha）残留物（Zenú 手工艺品生产的副产品）生产手工纸的标准化工艺的开发，该工艺在 Sinú Elias Bechara Zainúm 大学的工业工程实验室进行。目标是使用可行且低成本的技术获得具有适当强度、外观和质量的纸张。该方法包括机械和化学纤维处理，然后进行筛分、压制和干燥。测试了各种工艺参数，包括蒸煮时间（2-3 小时）、化学药剂（NaOH、$CaCO_3$、CaO）、水量和干燥时间（2-4 天）。最终产品表现出令人满意的机械和美学性能。这项研究的新颖之处在于将当地的农业工业废弃物转化为可持续的手工艺材料，将传统工艺与创新、回收和环境责任的原则相结合。

关键词： 箭叶木、箭杖、泽努手工艺品、手工造纸、可持续材料、农工业废料、纤维加工、环保制造、循环经济、传统工艺与创新、低成本造纸、本土技术、天然纤维纸浆、植物纤维的化学处理、哥伦比亚的可持续发展

1. Introduction

The purpose of this research is to approach the standardization of a sustainable process for the production of pulp and paper manufacturing, using non-wood fiber from Caña Flecha, to produce handcrafted cards to be used as a potential marketing strategy to increase the added value and promotion of the crafts made by the Zenú indigenous communities. The raw material for paper production consists of plant cellulose fibers, which can come from wood and non-wood sources [1]. Currently, most of the world's paper production comes from wood. Pulp production is based on 89% wood fibers, with the remaining 11% made from other fibers. In this research, a study was conducted on the industrial and/or artisanal processes used for pulp and handcrafted paper production, selecting various materials for use through an experimental design combining fixed and variable process parameters to produce paper and choosing the best combination of parameters that provides a process that is easy to operate and manage, using simple and easily obtainable economic resources, while also resulting in the production of higher-quality cards.

Caña Flecha is a native tropical grass found in the rural regions of Córdoba and Sucre [2]. By 2016, approximately 200 hectares were cultivated in the municipalities of Tuchín and San Andrés de Sotavento, where part of the Zenú indigenous community is located.

Between 50% and 60% of the collected Caña Flecha plant is wasted after extracting the fiber for crafting, resulting in byproducts such as leaves, stems, roots, and inflorescences discarded into the fields. Although natural, these residues impact the environment [3, 4].

The innovation related to Caña Flecha residues could serve as a promising solution by combining sustainable practices with the appreciation of the crafts produced by the Zenú Indigenous communities. In this context, the proposal to produce handcrafted paper cards made from Caña Flecha residues represents a viable and easily adaptable method to increase the added value of the crafts developed by the Zenú indigenous people. Crafts are the main economic activity of this community, and most members are exclusively dedicated to crafting products.

As part of an initial research macroproject, the objective was to identify and develop economically promising products derived from the by-products of Caña Flecha. This process involved a thorough analysis of the scientific literature and the traditional practices and customs of the Zenú community. This analysis proposed eight potential alternatives, each offering environmental sustainability, economic diversification, and efficient resource utilization. Several key factors were considered in the selection process, including the appropriability of the technology, the development time, and the production-to-sale cost ratio. One of the eight selected alternatives was the production of handmade paper, which is discussed in detail in this article.

2. Literature Review

2.1. Alternative Fibrous Materials for Paper Production

In recent years, there has been a growing interest in the use of non-wood fibrous materials, such as agricultural residues, for paper manufacturing. Studies have demonstrated that materials like banana stems, bamboo, and various grass species possess high cellulose content, making them viable and sustainable alternatives to wood-based pulp [5]. Using such resources contributes to reducing deforestation pressures and supports the circular economy principles.

2.2. Environmentally Friendly Paper-Making Techniques

Traditional paper production processes are often associated with the use of harsh chemicals, raising significant environmental concerns. However, recent research has introduced more eco-friendly methods, including treatments with hydrogen peroxide and acetic acid, which effectively remove lignin under mild conditions while preserving cellulose fibers and minimizing the environmental impact [5].

2.3. Innovation in Traditional Handicraft Production

Traditional craft industries face increasing pressure to adopt innovations that ensure long-term sustainability. The current literature highlights the importance of incremental innovations aimed at adding value, improving production efficiency, and reducing raw material consumption. These approaches help preserve cultural heritage while enhancing market competitiveness [6].

2.4. The Role of Traditional Crafts in Biodiversity Conservation

Plant-based handicrafts rooted in traditional knowledge play an important role in biodiversity conservation. Practices passed down through generations contribute to the sustainable management of natural resources and help preserve the genetic diversity of native species. Supporting such crafts promotes not only cultural heritage but also environmental sustainability [7].

2.5. Research Gap

Despite the progress made in exploring alternative fiber sources and promoting sustainability in artisanal production, there is a notable lack of empirical research dedicated to the standardization of paper-making processes using *Gynerium sagittatum* (Caña Flecha) residues. Specifically, the literature lacks detailed studies on the optimization of production parameters such as cooking time, chemical concentrations, and drying conditions, as well as comprehensive mechanical property evaluations of the resulting paper. Furthermore, limited attention has been given to the socio-economic implications of implementing such technologies within traditional artisan communities.

In summary, further research on the standardization of artisanal paper production from *Gynerium sagittatum* waste—particularly focusing on process optimization and the socio-environmental impact of such practices—is both relevant and necessary to advance sustainable innovation in traditional handicraft industries.

3. Materials and Methods

The study is based on an applied experimental approach, using the empirical-inductive scientific method to optimize the handmade paper manufacturing process from Caña Flecha waste. Factorial experimentation was employed, in which independent variables (type and concentration of reagents, type of raw material, and cooking time) were manipulated, and their effects on the dependent variables (de-lignification degree, pulp quality, and paper strength) were observed. The experiments were conducted in a semi-controlled environment using trial-and-error techniques and progressive optimization. Based on the results obtained at each phase of the study, the experimental conditions were adjusted. This approach allowed for establishing a replicable methodology to produce handmade paper, contributing to the process sustainability and economic viability.

Stems and leaves of Caña Flecha obtained from the residues of the manufacture of handicrafts by the Zenú indigenous people were used. Several experiments were carried out to identify the most appropriate part of the Caña Flecha among those mentioned above to produce the pulp. The chemical process for delignification was chosen using the following chemicals: NaOH, $CaCO_3$, and CaO, with different concentrations. Of the five experiments applied, the first two analyzed the softening of the raw material to produce pulp, the third and fourth experiments analyzed the corresponding analyses for making paper, and the last was carried out to improve the process times.

Experiment 1. Analysis of the softening of Flecha Caña stalks for pulp production.

The first experiment was carried out using Flecha Caña stalks and three types of chemicals in different amounts to verify which provided fiber softening and removal of lignin and other components. Three types of chemicals were used as variable parameters: CaO, $CaCO_3$, and NaOH, each in three quantities: 5%, 10%, and 15% of the number of stems. The number of stems is 10 g, the amount of water is 750 ml, and the cooking time is 2 hours.

Figure 1 shows the cooking of two of the different solutions. Figure 2 shows the samples cooked in various solutions and whether the Caña yielded when softened. If it did not, the following sample was taken at a higher concentration, and the experiment was repeated.

Figure 1. Different samples in the firing process in experiment 1. *Source*: Research team

Figure 2. Results of the different samples using the chemicals at different concentrations. *Source*: Research team

Experiment 2. Analysis of the softening of Flecha Caña leaves for pulp production.

Based on the previous results, a second experiment was conducted, this time using Flecha Caña leaves as a source of cellulose fibers and the same chemicals mentioned above. For this experiment, only one variable parameter was used, namely the three basic chemicals: CaO, $CaCO_3$, and $NaOH$. The amount of chemicals, 20% of the leaf weight, the amount of leaf 10 g, the amount of water 500 ml, the cooking time of 3 h, and the liquefying time of 3 min were kept as fixed parameters. This second experiment analyzed leaf softening in terms of the type of chemical used. Figure 3 shows some samples during the cooking process.

Figure 3. Samples of Caña leaves with different chemicals during the cooking process. *Source*: Research team

Experiment 3. Analysis of the quality of the pulp, made by the chemical method with NaOH, for transformation into paper.

The previous experiment noted the need to select the Flecha Caña leaves to be used. To guarantee the quality of the pulp, the complex parts should be removed, and the softer parts cut with scissors into approximately 5 cm pieces.

As the leaves softened more when cooked using NaOH, this experiment produced the softening with NaOH, varying its concentration by 5, 10, and 15% of the leaf amount. For this experiment, the leaf was 10 g, the water was 500 ml, the cooking time was 3 h, and the liquefying time was 3 min.

Each of the samples cooked with different amounts of chemicals was washed very well with running water at the end of the cooking process. Gloves were worn to avoid contact with NaOH. The paste was finally obtained by liquefying the sample for 3 min with sufficient water.

The pastes were sieved to remove the excellent parts, and the mixture was spread evenly on the racks. The paper was formed when the water evaporated, and the mixture was dried on the rack. The drying process can take one to two days; when the paper is dry, it is removed from the frame.

The Flecha Caña leaves were weighed on the electric balance and divided into three samples of 10 g in their respective containers. Experiments were carried out with three samples of the same weight, and the concentrations of sodium hydroxide varied. 0.5 g, 1 g, and 1.5 g of NaOH were weighed to determine the best results in the lignin separation process. First, the electric cooker is switched on during the cooking process, and the water is expected to boil. When the water is boiling, the properly weighed sodium hydroxide and the Flecha Caña leaves are added. The samples of sodium hydroxide and Flecha Caña leaves were cooked for 3 h.

The electric cooker is switched off at the end of the cooking process, and the Caña Flecha leaves are washed. Wearing gloves to avoid contact with NaOH is recommended. The samples were cleaned thoroughly.

Figure 4: Washed and filtered simples. Source: Research team

Figure 5 shows the process of sieving the paper pulp after liquefying, which consists of liquefying each sample for 3 minutes. Finally, they are sieved to obtain the pulp.

Figure 5. Pulp screening. Source: Research team

Figure 6 shows the Flecha Caña fiber pulp after the sieving process, after which the pulp obtained is soaked to spread evenly on the frame.

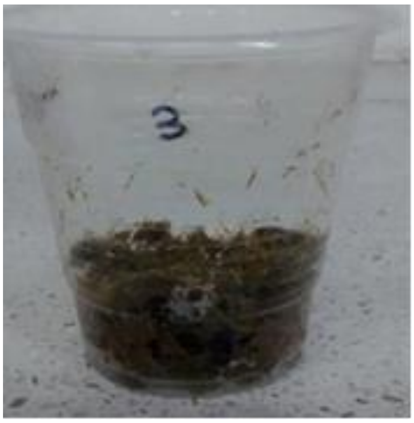

Figure 6: Flecha Caña fiber pulp. Source: Research team

The water must be allowed to drain from the racks; most of the water is removed when the paper is pressed. The drying process varies from two to three days. The paper should be carefully removed from the frame.

Figure 7. Paper drying process. Source: Research team

Figure 7 shows a sample of paper after the drying process. Figure 8 shows the result of the experiment with Flecha Caña leaves at 15% sodium hydroxide.

Figure 8. Paper sample with Flecha Caña leaves in 15% sodium hydroxide. Source: Research team

Experiment 4. Analysis of the pulp quality, made by the chemical method with CaO and NaOH, for transformation into paper.

In this experiment, besides the correct softening of the Flecha Caña leaves and the proper transformation into a quality paper, the production of odor due to NaOH cooking will also be analyzed. The softening process of the Flecha Caña was carried out with the softest parts of the leaves cut into 5-cm pieces and then cooked in two solutions of 5% NaOH, varying the amount of CaO by

15% and 20%. The amount of leaf is 10 g, the cooking time is 3 hours, and the amount of water is 500 ml.

The samples obtained shall be washed in running water and liquefied for 3 minutes using sufficient water. The pulps shall be sieved to remove the excellent parts and spread on the racks to be dried and made into paper.

Experiment 5. Analysis and improvement of pulp production and paper converting time.

Based on the previous experiments, it was observed the need to perform an analysis of the production time of the paper pulp within the production time it is intended to improve the cooking time of the samples; for this purpose, it is required to vary the cooking time of the samples by 1 hour and 2 hours; the leaves will be cooked in the solution of 5% NaOH and 15% and 20% CaO. For this experiment, the number of leaves was 10 g, and the amount of water was 500 ml. The same steps will be performed for pulp production and paper making.

4. Results and Achievements

4.1. Achievements and Results of Experiment 1

Samples of Caña Flecha stem boiled in CaCO3 concentrations of 5, 10, and 15% by weight did not show softening, nor did those of CaO. The Sodium Hydroxide samples did show softening, making them promising for pulp production. However, the test with the 10 and 15% NaOH concentrations could not be completed, as slightly suffocating vapors were produced, so the experiment was immediately suspended and carried out outside the laboratory later. The stem is a rugged plant region, so fiber softening can take a very long cooking time. The cellulose fiber sources were changed to dried Flecha Caña leaves, softer vegetable regions, to obtain a more straightforward process.

4.2. Achievements and Results of Experiment 2

The two samples boiled in CaCO3 and CaO by weight showed little softening. The NaOH samples showed stronger softening and promise for pulp production using Flecha Caña leaves. In this experiment, the importance of selecting the parts of the leaves to be used, cutting and discarding the complex parts, and improving the cooking time of the samples was observed.

4.3. Achievements and Results of Experiment 3

The pulp made using 15% NaOH obtained the best paper appearance and strength. However, the hydroxide generates a strong and uncomfortable smell when baking, and the baking time of the samples is very long. For experiment 4, the aim is to decrease the amount of NaOH in the solution and use the CaO base to complement it so that it does not generate odor and its handling is less toxic.

4.4. Achievements and Partial Results of Experiment 4

The two pulps made using 5% NaOH and adding 15% and 20% CaO produced paper with good appearance and strength, respectively. The odor generated during firing was comfortable. For experiment 5, the aim was to reduce the firing times.

4.5. Achievements and Results of Experiment 5.

The cooking time for paper production and manufacture was improved. The paper obtained has a good appearance and strength with a firing time of 1 hour and 2 hours, as shown in Figure 9.

Figure 9. Paper samples of Flecha Caña waste with 5% NaOH, 15% CaO, and 20% CaO solutions.
Source: Research team

4.6. Final Results of the Experiments

Table 1 shows the activities and times of pulp production and papermaking. This approach to the standardization of the process was made as the experiments progressed and improved with the following.

The sheets must be cut approximately for 1m² of Flecha Caña paper. 5 cm, one hour of cooking time with the solution of water, 5% NaOH, and 15% CaO wash the softened leaves with plenty of water for 10 minutes and blend the leaves for 3 minutes; if the capacity of the blender is too small for the number of leaves, it is necessary to divide the quantities and repeat the process. In this case, it is essential to repeat the process 4 more times. Therefore, the total blending time was 15 min, the sieving and pressing activity was 60 min, and the preparation for drying the paper was 5 min. Paper drying takes 2 to 4 days, and paper extraction takes 30 minutes; if the paper needs to be cut into 5x4cm cards, the cutting time is 30 minutes. The cooking time remains the same regardless of the amount of raw material; in this case, it is necessary to use a container with a larger capacity. Likewise, the liquefying time does not vary, and the drying time depends on the exposure to the sun.

Table 1. Description of the pulp production and papermaking processes (Source: Own elaboration)

Activity	Procedure	Time (min)
Cutting	Leaves of the Caña Flecha are cut to approximately 5 cm	30
Weighing	The amount of raw material and chemicals to be used in the process is weighed	10
Cooking	The leaves of the Caña Flecha were cooked in a solution of 5% NaOH and 15% CaO	60
Washing	The softened Caña Flecha leaves were washed with plenty of water.	10
Blending	The leaves are blended to obtain the pulp	3
Sieving and pressing	The pulp is sieved and spread into the desired shape, then pressed in the mold	60
Drying the paper	The samples are exposed to the sun. The drying time is between 2 and 4 days	5
Removing the paper	The paper is removed from the molds	30

All the above experiments are the first approach to the study and standardization of the manufacturing process and the production of paper with Caña Flecha waste, which allowed us to respond to combinations of parameters to obtain a product with the predefined characteristics of strength, appearance, and quality. Quantitative measurements were carried out to determine the mechanical properties such as grammage, thickness, paper tension test, cutting test, and paper color test.

5. Analysis and Discussion of the Results

5.1. Chemical characterization of Caña Flecha

Table 2 shows the chemical characterization of Flecha Caña, which will make it possible to verify whether it can be an alternative source of cellulose for pulp production and paper manufacturing.

Table 2. Chemical characterization of Flecha Caña (Source: Own elaboration)

Scientific Name	*Gynerium sagittatum*
Moisture (%)	8.88 ± 0.09
Total Ash (%)	2.18 ± 0.16
Organic Extractives (%)	7.06 ± 0.22
Aqueous Extractives (%)	5.66 ± 0.68
Klason Lignin (%)	24.18 ± 1.08
Holocellulose (%)	63.10 ± 1.98
Pentosans (%)	24.16 ± 0.19
Cellulose (%)	38.95 ± 0.19

The percentages of the chemical composition, as the percentage of lignin revalidated by [8], will be compared with the results obtained from other fiber sources.

Table 3. Chemical composition of *Guadua angustifolia* and *bambusa tulda on* a dry basis (Source: Own elaboration)

Species	Water (%)	Alcohol benzene	Lignin (%)	Pentosans (%)	Ash (%)	Cellulose (%)
Guadua angustifolia	10.09	4.03	19.72	11.65	5.16	59.77
Bambusa tulda	5	1.9	24.2	18.4	2	64.4

Table 4 shows the physicochemical properties of pineapple on a dry basis. This table will allow us to obtain another comparable reference of the values.

Table 4. Physicochemical properties of pineapple stubble on a dry basis (Source: Own elaboration)

Scientific Name	Ananas comusus, variety champaka
Moisture (%)	13.50 ± 0.20
Total Ash (%)	4.60 ± 0.01
Solubility in hot water (%)	38.45 ± 0.02
Solubility in cold water (%)	36.90 ± 0.02
Cyclohexanol/ethanol Extracts (%)	8.74 ± 0.01
Holocellulose (%)	42.70 ± 0.01
Lignin (%)	27.72 ± 0.01
Alpha-Cellulose (%)	45.12 ± 0.02

"An important result to consider is lignin because it is necessary to reduce it in the papermaking process so that the fibers can adhere and form the sheet. More specialized chemical processes are needed to eliminate it" [9]. The percentage of lignin in Caña Flecha is 24.18% ± 1.08, being 19.72% in *Guadua angustifolia*, 24.20% in *Bambusa tulda* and 27.72% ± 0.01 in *Ananas comusus*. These values show slight variation between them and a low percentage of lignin. This is fundamental when choosing the process to obtain the pulp, and in the case of using a chemical process, the concentration of these will be lower, which would imply less severe digestion conditions, and finally the process will tend to be clean, sustainable and with less environmental impact.

The cellulose values of bamboo and bamboo are higher than those of Flecha Caña, and "although cellulose content is a determining factor for the use of organic waste in paper production, it is not the only property to be considered" [9]. The holocellulose value for *Ananas Comusus* is 42.70% ± 0.01, making 63.10 ± 1.98 for Caña Flecha, which represents the product obtained after delignification and is formed by hemicellulose and cellulose, holocellulose in Flecha Caña is higher.

5.2. Pulp Yield

Table 5 represents the conditions and yields of the pulps obtained from the chemical pulping process. This range of yields is within the theoretical yields of the pulp obtained from this process.

Table 5. Conditions and yields of slurries obtained from the chemical process (Source: Own elaboration)

Pulps	Sample	NaOH Concentration (%)	CaO Concentration (%)	Temperature (°C)	Time (min)	Yield (%)
A1	1	5	15	100	60	48.30
A2	2	5	15	100	60	49.45
A3	3	5	15	100	60	48.15
B1	4	5	20	100	60	49.20
B2	5	5	20	100	60	49.50
B3	6	5	20	100	60	48.60

Table 6. Conditions and yields of slurries obtained from the soda process (Source: Own elaboration)

Pulps	Temperature (°C)	NaOH Concentration (%)	Time (min)	Yield (%)
O1	170	5	60	46.33
O2	160	6	60	47.43
O3	160	7	60	45.95
O4	160	4	60	49.20
O5	170	7	60	43.35
O6	170	4	60	43.51
O7	160	5	60	43.51
O8	150	7	60	49.30
O9	150	6	60	46.65
O10	150	5	60	52.80
O11	150	4	60	51.10

Table 6 shows that the yields obtained with another source of raw material are very similar and show little variation.

The table shows that the boiling temperature is higher than the one used in the experiments, the boiling time is the same, and the percentage of NaOH concentrations varies. The soda process is limited to one concentration, contrary to the experiments carried out by the research team in which two chemicals are present in the solution. Yield variations were homogeneous between the results obtained for *Guadua angustifolia* and *Gynerium sagittatum*.

The yield obtained for the grass is the expected yield for pulp production by the chemical process. The results are congruent with the theoretical yield, which indicates that Flecha Caña is a potential source of pulp and paper pulp.

5.3. Mechanical Properties of the Paper

5.3.1. Grammage

The grammage that makes it possible to determine which type of paper was obtained during the process is the weight of the paper over the area of the paper. To determine the location of the paper samples, the measurements of their sides were set at 0.07 m and 0.055 m to establish the same area for each sample.

Table 7 shows the weight, area, grammage, and average grammage of each paper sample of the different chemical combinations.

The grammage of the samples varies between 597.40 g/m2 and 701.30 g/m2, which, according to the standardized measures of paper grammage, indicates that they correspond to cardboard.

Table 7. Sample weights (Source: Own elaboration)

Combination of Chemicals	Paper Sample	Paper Weight (g)	Paper Area (m²)	Grammage (g/m²)	Average Grammage (g/m²)
5% NaOH, 15% CaO	1	2.6	0.00385	675.32	675.32
	2	2.7	0.00385	701.30	
	3	2.5	0.00385	649.35	
5% NaOH, 20% CaO	4	2.3	0.00385	597.40	632.03
	5	2.6	0.00385	675.32	
	6	2.4	0.00385	623.38	

5.3.2. Thickness

The thickness of each sample was measured using the micrometer screw, as shown in Figure 10.

Figure 10. Measuring the thickness of the samples (Source: Research team**)**

Table 8 shows the 10 thickness measurements taken for each sample. The 10 previous thickness measurements per sample were averaged. The thickness of the cardboard obtained was between 2.1 mm and 2.3mm; different measurements were obtained for the same sample, thus showing that the cardboard was not homogeneous.

Table 8: Thickness of the samples obtained (Source: Own elaboration)

	Combination of Chemicals					
	5% NaOH - 15% CaO			5% NaOH - 20% CaO		
Test tube	**Sample 1 (mm)**	**Sample 2 (mm)**	**Sample 3 (mm)**	**Sample 4 (mm)**	**Sample 5 (mm)**	**Sample 6 (mm)**
1	2.10	2.30	2.13	2.20	2.15	2.25
2	2.20	2.15	2.25	2.16	2.20	2.10
3	2.15	2.20	2.30	2.19	2.14	2.20
4	2.13	2.15	2.14	2.25	2.18	2.19
5	2.16	2.20	2.22	2.18	2.17	2.17
6	2.10	2.10	2.20	2.14	2.10	2.16
7	2.14	2.16	2.23	2.17	2.20	2.14
8	2.13	2.16	2.21	2.19	2.19	2.15
9	2.10	2.20	2.22	2.21	2.21	2.10
10	2.23	2.14	2.18	2.15	2.15	2.18
$\bar{X}$	**2.15**	**2.16**	**2.22**	**2.19**	**2.18**	**2.18**

Table 9 shows the annotations obtained from the micrometer screw; the measurements were taken carefully so as not to damage the samples.

Table 9. Average thickness of the obtained samples (Source: Own elaboration)

Combination of Chemicals	Paper Sample	Average Thickness (mm)
5% NaOH, 15% CaO	1	2.150
	2	2.164
	3	2.219
5% NaOH, 20% CaO	4	2.168
	5	2.148
	6	2.184

The average thickness for sample 1 is 2.15mm, sample 2 is 2.164mm, sample 3 is 2.219 mm, sample 4 is 2.168mm, sample 5 is 2.148mm, and sample 6 is 2.184mm. The samples show variations, indicating that each sample pressing was not homogeneous. The variations between the samples are not very large.

5.3.3. Tensile Strength Test

A dynamometer determines the force applied to the cardboard required to break it. As with the previous measurements, 10 notes were taken for each sample and averaged. The dynamometer used was a 2 N dynamometer.

Ten 0.5 cm x 5 cm test specimens are cut for each cardboard sample, as shown in Figure 11, and each test specimen is measured with the dynamometer. The time it takes to break when the force is applied is also recorded.

Figure 11. 0.5 cm x 5 cm test tubes (Source: Research team**)**

Each specimen was taped at the end of the dynamometer to make the respective measurements. The two sides of the dynamometer are held together, and the end of the specimen is carefully stretched until it breaks. Finally, the data observed are noted. Table 10 shows the data obtained by measuring the specimens with the dynamometer. This indicates the force required to break the cardboard; the minimum force required is 1.5 N, and the maximum is 2.0 N.

Table 10. Force required to tear the cardboard per test tube (Source: Own elaboration)

Combination of Chemicals						
	5% NaOH - 15% CaO			**5% NaOH - 20% CaO**		
Test tube	**Sample 1 (N)**	**Sample 2 (N)**	**Sample 3 (N)**	**Sample 4 (N)**	**Sample 5 (N)**	**Sample 6 (N)**
1	1.6	2.0	1.5	1.8	1.9	1.6
2	1.8	1.9	1.7	1.7	2.0	1.7
3	1.7	1.7	1.6	1.5	1.9	1.8
4	1.9	1.8	1.8	1.6	1.5	1.7
5	2.0	1.9	1.6	1.8	2.0	1.5
6	1.5	2.0	2.0	1.7	1.7	1.8
7	1.8	1.5	1.5	1.5	1.9	1.7
8	1.5	1.8	1.8	1.8	1.8	1.9
9	1.7	1.7	2.1	1.7	1.7	1.6
10	1.8	2.0	1.6	1.7	1.7	1.8
$\bar{X}$	**1.71**	**1.87**	**1.64**	**1.65**	**1.9**	**1.65**

Table 11. Tensile strength of cardboard per specimen (Source: Own elaboration)

Combination of Chemicals						
	5% NaOH - 15% CaO			5% NaOH - 20% CaO		
Test tube	**Sample 1 (N/m)**	**Sample 2 (N/m)**	**Sample 3 (N/m)**	**Sample 4 (N/m)**	**Sample 5 (N/m)**	**Sample 6 (N/m)**
1	6400	8000	6000	7200	7600	6400
2	7200	7600	6800	6800	8000	6800
3	6800	6800	6400	6400	7200	6400
4	7600	7200	6800	6400	8000	7600
5	8000	7600	6400	6400	8000	7200
6	6000	8000	6800	7200	7600	6800
7	6400	7200	7200	7600	7200	6800
8	6000	7600	6400	7200	7200	6400
9	6800	7200	7600	6800	7600	7200
10	7200	8000	6400	7200	7600	7200
$\bar{X}$	**6840**	**7480**	**6560**	**6600**	**7600**	**6600**

Table 11 lists the results obtained by applying the tensile strength formula.

Table 12 shows the maximum strength to which the paper can be subjected.

Table 12: Maximum tensile strength of the paperboard (Source: Own elaboration)

Combination of Chemicals	**5% NaOH, 15% CaO**	**5% NaOH, 20% CaO**
Force (N)	1.73	1.74
Area (m²)	0.00025	0.00025
Maximum Resistance (N/m² = Pa)	6920	6960
Maximum Resistance (kgf/cm)	70564.36	70972.25

The average strength was calculated by dividing the average strength by the area of the samples. The maximum strength of the paperboard for the combinations of chemicals does not represent a significant difference between them. However, samples with a higher proportion of chemicals have a higher strength.

5.4. Cut Test

To determine whether cardboard is deformation-resistant, it is cut on all four sides. Figure 12 shows the cardboard sample before the respective cuts are made.

The sample was found to be manipulable during the cardboard cutting test. At the end of the cutting test, as shown in Figure 13, it was observed that the cardboard samples are resistant to simple deformations, their cuts are regular, they are easy to manipulate, and they allow esthetic tools to be easily added to add value to the products of the indigenous people.

Figure 12. Cardboard sample before cutting (Source: Research team)

Figure 13: Cut samples (Source: Research team)

5.5. Color Test

Due to the esthetic use of the material, a color test is necessary to indicate whether it is possible to paint on the samples. Conventional paint is used, and the samples are painted. Figure 14 shows the result of the color test applied to a sample and that it is possible to paint on the cardboard.

Figure 14. Color test of Flecha Caña leaf board (Source: Research team)

6. Conclusion

6.1. Summary of the Results

This study provides empirical evidence for the viability of *Gynerium sagittatum* (Caña Flecha) residues as a raw material for the production of artisanal paper, thereby reinforcing the potential of sustainable resource utilization within the Zenú indigenous community. The experimental procedures employed yielded a paper product with satisfactory characteristics in terms of mechanical strength, visual appeal, and overall quality. These findings support the proposition that Caña Flecha waste can serve as a feasible input for low-cost, environmentally responsible production methods, aligning with the broader objectives of eco-efficiency and cultural preservation in artisanal practices.

The resulting material, with an average grammage of 650 g/m², closely resembles cardboard in terms of texture and density. Its most immediate application lies in the fabrication of distinctive labels and cards that accompany Zenú handcrafted items. These tags, which include information such as product type, artisan identity, and branding, not only authenticate the origin of the item but also enhance its market value by linking it to the principles of sustainability and cultural integrity.

6.2. Limitations

Despite the promising outcomes, this study presents several methodological limitations. Notably, the experimental design lacked a statistically rigorous framework, relying instead on exploratory and descriptive methods. As a result, the findings cannot be generalized or considered conclusive in terms of the optimal process parameters. Additionally, environmental variables such as humidity and temperature during the drying phases were not systematically controlled, which may have influenced product consistency.

6.3. Practical Implications

The approach described herein offers tangible opportunities for value-added product development within the Zenú artisan economy. The use of Caña Flecha waste for paper production promotes circularity, reduces organic waste, and creates differentiated branding elements for handmade products. Institutions supporting indigenous entrepreneurship could integrate this process into training and production frameworks, thereby fostering sustainable innovation and reinforcing cultural identity in commercial contexts.

6.4. Future Research Directions

Future studies should adopt a more rigorous experimental methodology, including factorial designs and statistical modeling, to determine the optimal variables such as fiber treatment conditions, chemical concentrations, and drying times. Expanding the scope of application beyond labeling—into packaging materials, biodegradable containers, or eco-friendly stationery—may open new market avenues.

Additionally, research should focus on process optimization, particularly with regard to reducing the energy and time inputs in fiber preparation and drying. Life cycle assessments (LCAs) could also be conducted to quantify the environmental benefits of this approach relative to conventional materials.

Finally, interdisciplinary studies combining material science, environmental engineering, and ethnographic analysis may further illuminate how traditional knowledge systems can synergize with contemporary sustainability frameworks, contributing to the resilience and economic autonomy of indigenous communities.

Declarations

Author Contributions

Conceptualization, H.M.H. and Y.C.O.L.; methodology, H.M.H.; software, J.F.P.V.; validation, H.M.H., J.D.C.G. and J.F.C.G.; formal analysis, H.M.H. and A.H.A.; investigation, H.M.H. and Y.C.O.L.; resources, H.M.H.; data curation, H.M.H., J.D.C.G. and J.F.C.G.; writing—original draft preparation, H.M.H., J.D.C.G. and A.H.A.; writing—review and editing, H.M.H.; visualization, A.H.A., J.D.C.G. and J.F.C.G.; supervision, H.M.H.; project administration, Y.C.O.L. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Funding

Funding information is not available.

Acknowledgment

The authors gratefully acknowledge the academic support provided by the University of Sinú in Colombia.

Conflict of Interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

References

[1] NAVARRO, S., & PARDO, L. *Proyecto de asesoría en diseño, asistencia técnica, tecnológica y comercial a las familias que posean o deseen desarrollar una actividad artesanal y que estén vinculadas al Programa Desarrollo Alternativo PDA Valencia/Zaragoza*. Artesanías de Colombia, 2008. http://repositorio.artesaniasdecolombia.com.co/bitstream/001/2029/1/INST-D%202008.%2051.pdf

[2] ARTESANÍAS DE COLOMBIA. *Caña Flecha*. 2020. https://artesaniasdecolombia.com.co/PortalAC/Publicacion/cana-Flecha_183

[3] MOSQUERA RAMÍREZ, A. E., & SALAMANCA TORRES, A. d. P. *Caracterización socioeconómica y desempeño productivo del oficio artesanal de Caña Flecha en los territorios indígenas de los almendros en el municipio de el Bagre, San Antonio II en el municipio de Zaragoza y el Volao en el municipio de Necoclí departamento de Antioquia* (p. 112). Centro de Investigación y Documentación para la Artesanía – CENDAR, Artesanías de Colombia, 2015.

[4] GOBERNACIÓN DE CÓRDOBA. *Mejoramiento de la cadena productiva de la Caña Flecha (Gynerium Sagitatum Aubl.) como alternativa al desarrollo socioeconómico de la comunidad indígena Zenú asentada en los municipios de Tuchín y San Andrés de Sotavento, departamento de Córdoba*. Gobernación de Córdoba, 2012.

[5] KOLYA H, & KANG C-W. Save Forests Through Sustainable Papermaking: Repurposing Herbal Waste and Maple Leaves as Alternative Fibers. *Materials*, 2025, 18(4): 910. https://doi.org/10.3390/ma18040910

[6] SHAFI M., SZOPIK-DEPCZYŃSKA K., CHEBA K., CILIBERTO C., DEPCZYŃSKI R., & IOPPOLO G. Innovation in traditional handicraft companies towards sustainable development. A systematic literature review. *Technological and Economic Development of Economy*, 2022, 28: 1-18. https://doi.org/10.3846/tede.2022.17085

[7] BASTIAN E. The role of traditional plant-based handicrafts in biodiversity conservation. *Plural Magazine*, 2024, https://www.pluralmagazine.net/news-1/2024/8/19/the-role-of-traditional-plant-based-handicrafts-in-biodiversity-conservation

[8] NIÑO LOZANO J. F. *Potential and social-environmental benefits of using lignocellulosic materials generated in linear projects*. Master's thesis, Universidad Nacional de Colombia, 2013.

[9] GONZÁLEZ VELANDIA, K. D., DAZA REY, D., CABALLERO AMADO, P. A., & CHADAE MARTÍNEZ, G. Evaluación de las propiedades físicas y químicas de residuos sólidos orgánicos a emplearse en la elaboración de papel. *Luna Azul*, 2016, 43: 499–517. https://doi.org/10.17151/luaz.2016.43.21

参考文:

[1] NAVARRO, S. 和 PARDO, L. 为拥有或希望开展手工艺活动的家庭以及与瓦伦西亚/萨拉戈萨 PDA 替代发展计划有联系的家庭提供设计、技术、工艺和商业援助的咨询项目。哥伦比亚工艺品，2008。http://repositorio.artesaniasdecolombia.com.co/bitstream/001/2029/1/INST-D%202008.%2051.pdf

[2] 哥伦比亚手工艺品。箭杖。 2020。https://artesaniasdecolombia.com.co/PortalAC/Publicacion/cana-Flecha_183

[3] MOSQUERA RAMÍREZ, A. E., 和 SALAMANCA TORRES, A. d. P. 安蒂奥基亚省埃尔巴格雷市杏树土著领地、萨拉戈萨市圣安东尼奥二世和内科克利市埃尔沃拉奥土著领地 Caña Flecha 工艺的社会经济特征和生产表现（第 112 页）。工艺研究与文献中心 – CENDAR，哥伦比亚工艺品，2015 年。

[4] 科尔多瓦省。改善 箭芦（Gynerium Sagittatum Aubl.） 的生产链，作为科尔多瓦省图钦市和圣安德烈斯德索塔文托市泽努土著社区社会经济发展的替代方案。科尔多瓦政府，2012。

[5] KOLYA H，和 KANG C-W。通过可持续造纸拯救森林：将草药废料和枫叶重新用作替代纤维。 材料, 2025, 18(4): 910. https://doi.org/10.3390/ma18040910

[6] SHAFI M.、SZOPIK-DEPCZYŃSKA K.、CHEBA K.、CILIBERTO C.、DEPCZYŃSKI R. 和 IOPPOLO G. 传统手工艺公司向可持续发展的创新。系统的文献综述。经济技术与经济发展，2022, 28： 1-18。https://doi.org/10.3846/tede.2022.17085

[7] BASTIAN E. 传统植物工艺在生物多样性保护中的作用。 复数杂志， 2024，https://www.pluralmagazine.net/news-1/2024/8/19/the-role-of-traditional-plant-based-handicrafts-in-biodiversity-conservation

[8] NINO LOZANO J. F. 使用线性项目中产生的木质纤维素材料的潜在效益和社会环境效益。哥伦比亚国立大学硕士论文，2013。

[9] GONZÁLEZ VELANDIA, K. D.、DAZA REY, D.、CABALLERO AMADO, P. A. 和 CHADAE MARTÍNEZ, G. 用于造纸的有机固体废物的物理和化学性质的评估。蓝月，2016，43：499-517。https://doi.org/10.17151/luaz.2016.43.21

Word count: 6,179 words, excluding references.

Peer review information:

Whether the manuscript was fast tracked? - No
Number of reviewer report submitted in first round: 3 reports
Number of revision rounds: 2 rounds
Final revised version submitted: April 2, 2025