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ORIGINAL
Review article

Fique products and experiments: a systematic review of the literature*

Productos y experimentos elaborados con fique: una revisión sistemática de literatura

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Abstract
Colombia is the largest producer of fique (Furcraea spp.) in the world and it is a major crop in the country because it is planted in 13 of the 32 departments of the country. The article presents a systematic review of fique documents. Products and experiments derived from it are examined. As a methodology, a review of scientific publications in the databases Scopus, Scielo, Redalyc, Science Direct and Google Scholar was carried out. This included documents with the word fique, for a period from 2019 to 2023. The results provide information regarding the country of location of the documents, methodology, topics, products and experiments carried out with fique. As a conclusion, it is observed that there are several products made with fique with high technical requirements, aesthetic and symbolic value, innovation and commercially competitive in the market. These products give a satisfactory response to all the stimuli granted by public and private entities that make it possible to reach the final product.
Keywords: Fique, Fique Bagasse, Fique Fiber, Fique Juice, Fique Juice

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* Original article. Research and innovation article. Review article. Work linked to the Corporación Universitaria Minuto de Dios (UNIMINUTO) and Universidad CESMAG, Colombia. Business model based on circular economy, aimed at the fique association located in Yascual - Nariño.

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Resumen
Colombia es el mayor productor de fique (Furcraea spp.) a nivel mundial y es un cultivo de importancia nacional debido a que es sembrado en 13 de los 32 departamentos del país. El artículo presenta una revisión sistemática de documentos relacionados con el fique. El objetivo consiste en examinar productos y experimentos elaborados con fique. Como metodología, se realiza una revisión de publicaciones científicas en las bases de datos *Scopus, Scielo, Redalyc, Science Direct y Google Scholar,* acogiendo documentos que incluyeran la palabra fique, en un periodo desde 2019 hasta 2023. Los resultados ofrecen información respecto al país de ubicación de los documentos, la metodología, los temas, productos y experimentos realizados con fique. Como conclusión se observa que existen varios productos elaborados con fique con alta exigencia técnica, valor estético, simbólico, innovación y competitivos comercialmente en el mercado, dando respuesta satisfactoria a todos los estímulos otorgados por las entidades públicas y privadas que hicieron posible llegar al producto final.
Palabras clave: Fique, Bagazo de Fique, Fibra de Fique, Jugo de Fique

SUMMARY

Introduction

Colombia is the world's largest producer of fique (Furcraea spp.) and is a crop of national importance because it is grown in 13 of the country's 32 departments, on which around 420,000 people depend economically (MADR, 2018). The areas of fique cultivation have grown in recent years due to the recent ecological and environmental boom driven by the need to replace synthetic products that generate environmental impact (Gholampour & Ozbakkaloglu, 2020). It is especially gaining interest due to its potential for the production of a variety of value-added exportable products, such as biodegradable packaging, vegan leather, agro mantles, textiles, composite materials for building construction, vehicle parts, ballistic protection elements, and biopesticides (Luna et al., 2009; Neves et al., 2018; Oliveira et al., 2019).

Fique is mainly propagated asexually through bulbils and tillers. One plant of Furcraea macrophylla can produce up to 3,000 bulbils, which grow on the flowering stem, while the tillers grow on the stem of the plant and are larger than the bulbils, have developed leaves, are more limited in number, have little uniformity in age and size and are mainly used for reseeding (Perez, 1974). The crop's success depends largely on the quality of the planting material; however, one of the current technical problems is that farmers propagate the plants in acidic and not very fertile soils to which fertilizers are not usually applied (CADEFIQUE, 2006). This situation makes nutrition a limiting factor, as insufficient nutrition causes metabolic changes reflected in low plant growth (Ortiz-González, 2021).

The genus Furcraea, to which fique belongs, and the genus Agave are found within the Agavaceae family, with a phylogenetic closeness; therefore, they are similar compared to the control. The best growth response was obtained in the exponential fertilization treatments, independent of light conditions and with constant fertilization at full sun exposure, where biomass increases of 74.00% and 176.00% were found concerning the control. The management of lighting and fertilization is key to the growth of fique in the nursery stage.

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On the other hand, the Department of Santander is located in the north of the country, being part of the Andean region, bordering to the north with the department of Cesar and Norte de Santander, with Boyaca to the east and south, with Antioquia to the west and finally with Bolivar to the northeast, in this territory its culture and economy revolve mainly around agricultural and livestock activities, Mogotes stands out about the other municipalities of the department, in this territory are the cultivation of fique, sugar cane, beans, among others, as the main activities of the Guanentina region for its unique production and climate, this municipality being the second in production and processing of fique fiber in the department. In this sense, the cultivation of fique, consolidates the department of Santander as the third with the highest participation in its production after Cauca and Nariño with a production area of 1,760 ha and a yield of 1.2 for the year 2018, according to the Ministry of Agriculture. Artisanal production uses hand tools and highly skilled workers, who must perform all the tasks necessary to transform raw materials into products; these tasks or functions generally correspond to a specific trade (Riveros, 2022).

Colombia is the world's largest producer of fique fibers (Furcraea bedinghausii), with a net production of 30,000 tonnes per year (Guancha et al., 2022). The systematic review is carried out to account for advances and trends in elements and experiments carried out with fique fibers, fique bagasse, fique juice, and fique cellulose nanofibres. Going deeper into these aspects is important because it strengthens the theoretical body on issues related to fique in terms of its productivity and broadens the vision that can favor the work of different professionals who have fique as an object of study. The results can offer valuable information to those developing studies on this topic.

Resolution scheme

1. Research problema

What products and experiments have been made with fique?

2. Methodology

This work's important purpose is to review the recent literature on fique elements and experiments systematically. The overall primary objective of a systematic literature review method is elaborating recent knowledge in a research area to map uncertainties and gaps that need further study (Petticrew & Roberts, 2008), which is carried out through the identification, collection, and analysis of relevant literature (Wright et al., 2007). A systematic review can contribute to exploring themes, trends, and weaknesses (Macpherson & Jones, 2010). Figure 1 shows the systematic review process undertaken. The systematic review process to obtain the final sample of documents for analysis consists of 3 parts, according to Crossan & Apaydin (2010): data collection, data analysis, and synthesis.

2.1 Research questions

The research aims to answer the following questions:

- RQ1: What is the most common methodology used in fique documents?
- - RQ2: What products are made from fique?

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- - RQ3: What experiments have been carried out with fique fiber?
- - RQ4: What experiments have been carried out with fique bagasse?
- - RQ5: What experiments have been carried out with fique juice?
- - RQ6: What experiments have been carried out with fique cellulose nanofibres?

2.2 Research

En primera instancia se aplica la cadena de búsqueda constituida por los términos clave, como aparece en la tabla 1, en las bases científicas. Además, también se combinaron con palabras similares para captar un mayor número de artículos a examinar, de acuerdo a la tabla 2.

Table 1. ***Key terms and their synonyms***

KEY TERMS	SYNONYMOUS/ RELATED TERMS
Fique	Agave Pita Maguey Cabuya Penca

Source: own elaboration.

Table 2. ***Search string***

PRINCIPAL TERM	SEARCH STRING
Fique	(Products and experiments made with fique and fique bagasse and fique fiber and fique game or Agave or Pita or Maguey or Cabuya or Penca)

Source: own elaboration.

En la primera etapa, la recopilación de datos se inició con una búsqueda de la información contenida en las bases de datos como Scopus, Scielo, Redalyc, Google Scholar, Science Direct, Dialnet y Doaj, como se muestra en la Tabla 3, a fin de centrarse en revistas revisadas por pares de forma análoga a otras revisiones efectuadas en el campo (Cacciotti *et al*., 2015; Delgado *et al.*, 2015).

2.3 Selection

The articles found were filtered according to the type of access, years, subject area, document type, and language, as shown in table 3.

Table 3. ***Application of filters in scientific databases***

REFINE	SCOPUS	SCIELO	REDALYC	SCIENCE DIRECT	GOOGLE SCHOLAR	DIALNET	DOAJ
Type of open access	25	680	570205	26712	12600	47	20
Year (2019-2023)	47	268	131823	227	14400	47	15
Subject area (Chemical Engineering)	140	173	1.871	58	1342	47	19
Type of document (Article)	82 82	263 220	672 567	37 37	850 696	29	20 1
Thesis) **(Report)**	 12	 10	57		 2 12	12	

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English language		
Spanish language	6	2

Source: own elaboration.

The title, keywords, abstract, introduction, methodology, results, and conclusions were analyzed in all the articles. Inclusion and exclusion aspects were considered for the review: firstly, the article was written about fique; secondly, it related to materials made with fique; and thirdly, it referred to experiments carried out with fique. The selection of articles was carried out in 5 stages (because 7 scientific databases were taken into account) with the following phases:

- Phase 1: Exclusion of repeated articles.
- Phase 2: Exclusion of articles that had to be paid for.
- Phase 3: Relevant articles according to the research topic after analysis (title, keywords, abstract, introduction, methodology, results, and conclusions).

From the search in scientific databases, 54 documents relevant to the study were found, as detailed in table 4.

Table 4. ***Documents relevant to the study***

REFINAR	SCOPUS	SCIELO*	REDALYC	SCIENCE DIRECT	GOOGLE SCHOLAR	DIALNET	DOAJ
Filtered documents	82	263	672	37	850	29	20
Duplicate documents	40	115	320	24	421	14	8
Documents requiring payment	15	52	112	13	0	0	0
Appropriate documents	12	10			11	8	13
Documents to be examined							54

Source: own elaboration.

2.4 Quality assessment

Recently published journal papers were selected. The abstracts were then screened to eliminate filtering errors in the scientific databases, i.e., papers that did not comply with the research topic and year of search). Only scientific papers were considered for this literature review. For the relevance and inclusion of the documents, the first consideration was based on reading the title, which had to contain the subject of fique, and then focusing on materials made with fique. The summary was also examined to find out about the study's objective and methodology; likewise, the text was read to get an overall idea and its contribution to the review article under construction.

The validity criterion considered throughout the information-gathering process is related to the scientific authority of the institutions and researchers who have published in the media consulted and is based on knowledge of the process of publishing an article in scientific journals. First, the papers are chosen by an editorial committee in which renowned academics participate; then, they are evaluated by a scientific committee whose members come from different countries and various academic disciplines; then, there are the academic peers to examine the quality, relevance, and new contribution within the discipline.

The above process is supported by the databases that were reviewed for the article, which publicize it as an element of quality to give reliability to researchers. Likewise, another of its values is to collect articles from indexed journals, which gives them another plus of credibility and quality. The selected documents were evaluated according to five criteria: relevance of the content, clarity of the research objective, adequate description of the context in which the research was developed, clarity and rigor of the methodological design of the research, and scientific rigor in the analysis of the data (Revelo et al., 2018).

3. Research results

The 54 research papers were selected taking into account the last 5 years distributed in table 5. The largest research material belongs to Colombia, with Brazil in second place.

Table 5. ***Year of publication***

YEAR	NUMBER
2019	8
2020	10
2021	8
2022	23
2023	5
Total	54

Source: own elaboration.

In addition, it was distributed according to country of origin, as shown in table 6.

Table 6. ***Country to which the research documents belong***

COUNTRY	N° ARTICLES
Colombia	40
BraZil	6
United States	2
India	2
Spain	2
Argentina	1
Peru	1
Total	54

Source: own elaboration.

The methodology used in the documents reviewed was also analyzed, as shown in table 7. In the materials investigated, the experimental type of research predominates; secondly, the mixed approach and finally, the qualitative approach with the ethnographic method. Thus: "In an experimental study, the context is constructed and the independent variable is intentionally manipulated and the effect of this manipulation on the dependent variable is observed. That is, the researcher directly influences the experiment" (Hernández et al., 2014, p. 153). Secondly, mixed methods represent a set of systematic, empirical, and critical research processes and involve the collection and analysis of quantitative and qualitative data, as well as their integration and joint discussion, in order to make inferences from all the information collected (meta-inferences) and achieve a greater understanding of the phenomenon under study (Hernández et al., 2014, p. 534).

Third, articles using the qualitative approach, rather than clarity about research questions and hypotheses preceding data collection and analysis (as in most quantitative studies), qualitative studies may develop questions and hypotheses before, during, or after data collection and analysis. These activities often serve first to discover the most important research questions and then refine and answer them. The action and inquiry move dynamically in both directions, between the facts and their interpretation, and results in a rather "circular" process in which the sequence is not always the same, as it varies with each study (Hernández et al., 2014, p.358).

Likewise, (Caines, 2010 and Álvarez, 2003, cited by Hernández et al., 2014, p.482) consider that the purpose of ethnographic research is to describe and analyze what people in a given site, stratum, or context usually do (participants in "action" are analyzed), as well as the meanings they give to that behavior performed in common or special circumstances, and finally, to present the results in a way that highlights the regularities involved in a cultural process. Ethnographic designs study categories, themes, and patterns related to cultures. On the other hand, the different themes of fique in the documents were selected as presented in table 8.

Table 7. ***Methodology used***

METODOLOGY	N°
Type of experimental research	50
Mixed approach	3
Qualitative approach: Ethnographic method	1
Total	54

Source: own elaboration.

Table 8. ***Fique issues***

TOPIC	N° ARTICLES
Fique fibres	26
Fique bagasse	5
Fique juice	4
Fique cellulose nanofibres	3
Insulation from fique	3
Sheepskin cloth	3
Fique fabric	2
Fique bran	1
Manufacture of materials from fique	5
Concentration of zinc in fique	1
Fique sacking	1
Total	54

Source: own elaboration.

3.1 Products made from fique

The fique plant mainly produces ropes and packaging in tropical American countries such as Colombia, Brazil, Ecuador, Costa Rica, and the Antilles. It provides important economic income to agricultural populations that live from its cultivation (Gómez et al., 2020). Using fique to reinforce biocomposite materials has advantages over polymers, such as availability, renewability, low density, corrosion resistance, low cost, and biodegradability (Luna et al., 2017). Likewise, fique fiber is mainly grown in South American countries such as Colombia, Ecuador, Costa Rica, Brazil, Venezuela, and the Antilles and is mainly used for the production of coffee sacks and ropes; however, mechanical studies have been carried out that show its great potential for use as reinforcement of composite materials (Gómez et al., 2018). The use of natural fibers as reinforcement for civil construction materials has grown in recent decades (Coudert, 2020).

A quadcopter drone made of a natural composite material reinforced with fique fiber and polyester matrix, corresponding to 35.40% of the structure's weight, was also manufactured and programmed by the Hand lay-up manual manufacturing technique. The design of the quadcopter frame was made using CAD software, SolidWorks, and was laser cut (Gomez et al., 2022). According to the Kankuama women and various studies on the subject, in the past, they mainly wore colored fique backpacks known as mochila rayá and cargueras or mochilón,

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which are used to carry heavy things. At the beginning of the 20th century, the mochila rayá was the most widely recognized in Colombia. It is made with horizontal stripes of different colors and was sold by the dozen. The chinchorros, on the other hand, were used for sleeping, as a girth for animals, and to adorn donkeys and mules in the process of milling panela. The chinchorros were used to put on the muzzles of donkeys and calves so that they would not eat the grass on the road and so that they would walk quickly (Echavarría et al., 1999, Solano et al., 2023). The design of eco-roofs in recycled plastic material reinforced with fique fiber (furcraea andina) was also developed for sustainable housing in the rural sector of Tocaima, Colombia (Aranzales, 2020).

Fique is an endemic agave species; its fibers are commonly used for low-tech applications such as manufacturing sacks and ropes for food packaging and handicrafts (Gomez et al., 2020). The main sectors and applications where fique fiber is used are automotive, aerospace, marine, sporting goods, electronic applications, construction, furniture, and packaging. Vehicle manufacturers make door panels, seat backs, roof covers, parcel trays, instrument panels, and interior parts from composites due to weight reduction and low cost (Gil et al., 2021).

3.2 Experiments carried out with fique fibres

Bioinsulation has gained great interest recently due to its potential to reduce energy consumption without negative environmental impacts. Fique, one of the most important crops in Colombia, has shown low thermal conductivity, which makes it a potential replacement for common insulating materials. However, there are few studies on its thermal properties. In order to improve the understanding of fique as a thermal insulator, a morphological analysis of raw fique fibers and thermogravimetry (TGA) and differential scanning calorimetry (DSC) tests of three fique samples, namely natural untreated fique, fique washed with a commercial softener and fique after soaking for 24 hours in the same softener (García et al., 2019).

Also, buildings consume much energy during all life cycle stages. One of the most efficient ways to reduce their consumption is to use thermal insulation materials; however, these generally negatively affect the environment and human health. Bio-insulation is presented as a good alternative solution to this problem, thus motivating the study of the properties of natural or recycled materials that could reduce energy consumption in buildings. Fique is a very important crop in Colombia. To contribute to the knowledge of the properties of its fibers as a thermal insulator, the measurement of its thermal conductivity using equipment designed according to the ASTM C 177 standard and a kinetic study of its thermal decomposition from thermogravimetric data through the method of adjustment of the Coats-Redfern model are reported (García et al., 2021).

On the other hand, the biocomposites were prepared from a ternary matrix of polylactic acid (PLA), polycaprolactone (PCL), and thermoplastic starch (TPS) and reinforced with fique fibers native to southwestern Colombia. The influence of surface modification by alkalinization of the fique fibers on the interfacial properties of the biocomposite was studied by extraction tests. Additionally, the effect of short fique fibers in three proportions (10.00%, 20.00%, and 30.00% (w/w)) on the tensile mechanical properties of the composite was evaluated. Experimental results indicated that the ternary matrix's interfacial shear strength (IFSS) was predominantly influenced by PCL and was characterized by developing a weak interface that failed due to matrix creep. In addition, incorporating short fique fibers increased the elastic modulus of the composite to values similar to those estimated with the Tsai-Pagano model. The alkalinization treatment of the fique fibers improved the interface with the composite matrix,

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and this phenomenon was evidenced by the results of the micromechanical and tensile characterizations of the composite (Mina et al., 2020).

The behavior of natural fiber-reinforced laminated polymer composites (NFRPC) under mechanical stresses is analyzed in another direction. The samples were fabricated with an epoxy resin matrix reinforced with a multilayer natural fique fiber in a commercial bi-directional weave configuration. Different reinforcement contents were prepared without additives, considering the simplicity in processing, cost of fabrication, and applications where this material could be used with high-performance standards. Charpy notch impact and 3-point bending tests were performed to study the mechanical behavior and fracture work, which improved significantly with the fibers, showing an increase from 5 to 30 kJ/m2, a significant improvement for ballistic applications. These results compare with Split-Hopkinson pressure bar tests performed in previous analyses (SHPB) for the same material. The microstructure was investigated by scanning electron microscopy. The results reveal that the formulation supports this material as a high-performance solution for impact applications and is suitable to replace expensive traditional materials (Rua et al., 2021).

In this vein, polymer composites reinforced with natural fabric have recently been investigated as potential ballistic armor for personal protection against different ammunition levels. In particular, a fabric made of fique fibers extracted from the leaves of the Andean Furcraea andina was applied as reinforcement for polymer composites used in a multi-layer armor system (MAS). The superior performance of fique fabric composites as a second MAS layer prompted this brief report on determining absorbed energy and velocity limiting capability in independent ballistic tests. Individual plates of epoxy composites, reinforced with up to 50% by volume of fique cloth, were ballistically tested as targets against high velocity 7.62 mm impact ammunition, ~840 m/s for the first time. The results were statistically analyzed by the Weibull method and ANOVA. The absorbed energies of 200-219 J and limiting velocities of 202-211 m/s were found to be statistically similar for the epoxy composites reinforced with fique cloth from 15.00% to 50.00% vol. Predominantly, these findings are better than those reported for plain epoxy and aramid cloth (KevlarTM) used as separate plates with the same thickness. The macro-cracks in the 15.00% and 30.00% vol. fique cloth composites compromise their application as armor plates. The delamination breakdown mechanism was revealed by scanning electron microscopy. In contrast, the integrity was maintained in the 40.00% and 50% vol composites, ensuring superior ballistic protection compared to Kevlar (Souza, Santos, Colorado, et al., 2021).

However, there are no reported studies on accelerated aging by water immersion in fique-epoxy fiber composites. This work aimed to fill this gap by investigating epoxy matrix composites reinforced with fique fabric at 40.00% vol. The epoxy matrix and composite, both aged and unaged, were characterized by weight variation, water absorption, morphology, colorimetry (CIELAB method), Fourier transform infrared spectroscopy (FTIR), and dynamic-mechanical analysis (DMA). The main results were that water degradation shows complex microfibril structures, plasticization of the epoxy resin, and detachment of the fique/epoxy fiber matrix. The most intense color change was obtained for the epoxy aged by water immersion at 1440 h. Cole-Cole diagrams revealed the materials' heterogeneity (Oliveira et al., 2022). In another sense, a review of some relevant aspects to take into account in the use of natural fibers in the composites industry, such as their origin, chemical composition, extraction methodology, physical and mechanical properties, and some necessary treatments to improve adhesion when they are used as reinforcement of polymeric matrices, was carried out. In addition, some of the results obtained in research focused on providing technical aspects for using bamboo fibers guadua angustifolia as a reinforcement material are highlighted. It should be noted that the review presented in this paper focuses on fibers of plant origin (Luna et al., 2022).

On the other hand, the production and subsequent evaluation of the durability of alternative composite materials that can be used to construct beehives. The materials are based on high-density polyethylene and agro-industrial waste (fique fiber, banana fiber, and goose feathers) from the Boyacá region of Colombia. The composite materials studied in this study were exposed to xylophagous fungi for 90 days under constant humidity and controlled temperature that favor fungal proliferation. The results showed that composite materials, including fique fibers, are the most promising substitute for wood in hive construction. These materials proved 80.00% more resistant to pathogen attack and more durable in weight loss than pine wood. These durability results may be important for future implementation in beekeeping production units. They have the potential to impact not only the sustainable development of rural communities but also to make a great ecological contribution by reducing the need to cut down trees and maintaining the health of hives (Rubiano et al., 2022).

In another order of ideas, develop the composition of a thermo-acoustic insulator, implementing Mycelium, Fique, and Hay, from analysis of thermal conductivity, thermal reflectance, and soundproofing; adapting to the hygrothermal standards by the Colombian Council of Energy Efficiency (CCEE) and the distinctive analysis of the bioclimatic diagram of Baruch Givoni in the year 1969; in addition to offering environmentally friendly characteristics, it will determine the sustainable influence by which it will be compared to the composition of existing thermal insulators in the Colombian context (Gil et al., 2021). A comprehensive characterization of the Fique fiber, including chemical composition, thermal degradation, crystallinity, topographical and mechanical properties, surface chemistry and interactions, macromolecule distribution, and quantification of previously unreported extractives, is carried out. The fact that extractives were quantified reduces the possibility of reporting non-structural sugars as part of the macromolecule distribution. The results indicate that fique fiber is mainly composed of macromolecules such as cellulose (42.10% by weight), hemicellulose (13.00% by weight), and lignin (18.20% by weight). The extractive content was 15.30% by weight. Thermal degradation indicates a maximum degradation temperature of 360 °C. Chemical characterization of the surface indicates that the fiber is mainly acidic with various functional groups (carboxylic, phenolic, hydroxyl, and hemiacetal) determined by ATR-FTIR and a weakly hydrophilic attribute. Mechanical characterization shows a Young's modulus of 24.31 GPa. These characteristics reveal that fique is an intermediate fiber, not as hard as sisal but not as soft as jute, with a thermal chemical composition, volume of crystallinity, and surface area attractive for a wide range of applications (Bastidas et al., 2022).

In another direction, the morphology, mechanical, and thermal properties of biocomposites based on epoxy-EP resin and fique (Furcraea Andina), a crop native to South America, were examined. The EP-fique biocomposites were prepared using fique-FP powder, an industrial waste generated during fique, non-woven fique fibre-NWF processing, and unidirectional fique fibre-UF meshes oriented at 0° and 90°. The addition of fique to the EP matrix restricts the movement of EP macromolecule chains and improves the thermal stability of EP. SEM images showed that the form of fique used (powder or fiber) and the arrangement of the mat can generate changes in the morphology of the biocomposites. Mechanical characterization shows that the fique powder and 90° oriented fique fibers act as fillers for the epoxy matrix. In comparison, the 0° oriented fique fibers reinforce the EP matrix, increasing the tensile and flexural modulus up to 5700.00% and 1100.00%, respectively, and the tensile and flexural strength up to 277.00% and 820.00% compared to pure EP. The results obtained may increase interest in research and product development from fique powders and other by-products of natural fiber processing, thus reducing the abundance of waste in soil and landfills and environmental concerns and suggest that EP-fique biocomposites are promising for use in the automotive industry (Centeno et al., 2022).

On the other hand, the ballistic performance of the multilayer armor system (MAS) with ceramic tile front, followed by a laminate of up to 50.00% vol. epoxy matrix reinforced with fique fabric and 5062H34 aluminum alloy backing, was evaluated. The back face signature (BFS) caused by the bullet in a witness clay block behind the target was used to evaluate the ballistic performance of the MAS by international standards. The results with 7.62mm high-velocity ammunition show a similar BFS to a MAS of second layers of KevlarTM laminate with the same thickness. Weibull analysis provides statistical reliability of the BFS test results. Scanning electron microscopy (SEM) fracture examinations revealed that the epoxy-fique fabric composite has different energy dissipation mechanisms. It is the same capture of ceramic fragments by embedding mechanics presented in KevlarTM laminate. Among the materials tested, the 40.00% by volume fabric composite was a better alternative to replace KevlarTM. The lower cost of the epoxy-fique fabric composite is an additional advantage that favors its substitution for the aramid fabric (Souza et al., 2019).

However, a bio-nano composite's fabrication and advanced oxidation capabilities were analyzed based on cellulosic fique fibers (FF) decorated with magnetite (Fe3O4) NPs. The assembly of the composite material was monitored using FESEM, XPS, ATR-IR, XRD, and TGA. The cellulose in FF undergoes alkaline treatment, resulting in a heterogeneous and positively charged microstructure with channels and cavities acting as nanoreactors, which facilitates size control, dispersion, and stabilization of the Fe3O4 NPs through an ultrasound-assisted co-precipitation method. The nanocomposite material (FF/Fe3O4) promotes color removal from indigo carmine (IC) solutions through heterogeneous Fenton-type reactions. UV-vis and MS data show the removal of up to 90.00% of the color in model aqueous samples spiked with IC through oxidation reactions within 5 min for up to 10 cycles. The catalytic performance of the nanocomposite is significantly affected by pH and oxidant concentration (H2O2). Furthermore, after treating a real effluent from a denim factory with the FF/Fe3O4 nanocomposite for 120 min, we observed reductions of 24 % in chemical oxygen demand (COD), 100.00 % in surfactant content, 99.00 % in surfactant and apparent color, and 99.00 % in turbidity (Ravelo et al., 2023).

On another note, the feasibility of using agricultural residues from fique plantations (genus Furcraea microphylla) as an alternative to Northern Bleached Softwood Softwood Fibres (NBSK) in high-performance hygiene tissue applications is demonstrated. Fiber residues were mechanically cleaned and transformed into tissue pulp by simply pulping and bleaching. The tissue paper properties (bulk, softness, water absorption, tensile strength) were fully characterized and compared to NBSK market pulp. In addition, fique waste pulp was blended with Bleached Eucalyptus Kraft (BEK) to match the performance of a selected benchmark consisting of 70.00% BEK and 30.00% NBSK (Kumar et al., 2022).

The mechanical behavior of a VAWT (Vertical Axis Wind Turbine) vertical axis wind turbine made of natural composite, a blade made of fique and epoxy, was analyzed. The analysis was carried out by FEM (Finite Element Method) applying wind forces. Using materials to reduce the solid waste produced by typical fiberglass and epoxy composites. Using biodegradable materials provides a solution to reduce environmental impact. For example, fique composite is being studied and analyzed as an option for manufacturing VAWT blades. For example, fique composite is studied and analyzed as an option for manufacturing VAWT blades. The objective

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is to provide a computational model to analyze the stress and strain distribution, confirm a VAWT blade design using a computational model to analyze the rain and stress distribution and confirm a VAWT blade design using a composite of fique and epoxy subjected to wind forces. A computational model was generated in ANSYS software, including the anisotropic properties of the material. The numerical model recreates a VAWT leaf geometry and a composite of fique and epoxy subjected to wind forces. ANSYS software generated A computational model, and the number of layers was varied to obtain an acceptable stress-mass ratio. The stress distribution was obtained by including the anisotropic properties of the material. The numerical model recreates a VAWT sheet geometry and the VAWT sheet geometry using a fique-epoxy composite. Principal stresses were contrasted to determine the critical stress.

In another direction, the number of layers was varied to obtain an acceptable stress mass. The stress distribution was obtained over the region. A stiffener was implemented to reduce peak stresses, the VAWT sheet geometry using fique-epoxy composite. The main braids were contrasted to determine the critical region. A reinforcement to reduce peak stresses was implemented (Castro et al., 2022). However, the fique fibers were modified with zinc oxide (ZnO) nanoparticles to remove the color of the indigo carmine (IC) solutions. The ZnO nanoparticles were synthesized by precipitation method, and the fibers were modified ex-situ and in situ. The fibers and nanoparticles were characterized using different techniques such as X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), visible light spectroscopy (UV-vis), and scanning electron microscopy (SEM). The rate of color removal was monitored using a UV/Vis spectrophotometer. Nanoparticles with an average diameter in the nanoscale and a typical hexagonal structure were obtained and effectively deposited on the fibers. The highest color removal obtained with ex-situ fibers (ZnO-Ex / fique) was 90.00% in 180 minutes. The color removal by in situ fibers (ZnO-In / fique) was 70.00% after 180 min. From the results, ZnO nanoparticles can be an excellent catalyst for removing aqueous IC dye solutions under UV-C light (Llano et al., 2020).

On the other hand, the removal capacity of Reactive Black 5 from original and enzyme-modified natural fibers was evaluated. A fiber extracted from a Colombian fique plant (Furcraea sp.) was used. The effects of protonation of the fique fiber with different solvents and pH of the dye solution on the removal of RB5 were evaluated. The chemical composition of the biosorbent was modified using the commercial enzymes pectinase, ligninase, and xylanase. The point of zero loading (PZC) of the original and modified material was measured, and the dye removal capacity of the three enzyme-modified fibers was determined. Protonation of fibers with 0.1 M HCl and a dye solution at pH 2.4 increased the removal of RB5 to 49.10%. The change in fiber chemical composition reduced the PZC from 5.50 to a range of 4.70 to 4.90. The pectinase pre-treated fique fibers showed the highest dye removal with 66.29%, representing a 36.00% increase in RB5 dye removal. Although the original fique fiber showed RB5 dye removal capacity, its enzymatic modification changed the fiber surface's charge distribution, improving the dye molecules' capture. The enzymatic modification can be applied to obtain new functionalities for plant fibers as biosorbent materials (Muñoz et al., 2022).

However, a research program was launched to study the development and application of Natural Fiber Composites (NFC) as potential substitutes for foamed plastics. Also, a research program explored using maize (Zea mays) crop waste and fique (furcraea andina) plant fibers to develop new NFC and their applications. Six new nFCs were developed, and a collection of about a dozen products in which the new materials were applied. These products were targeted at the three industries that consume the most plastic foams, i.e., construction, packaging, and automotive. On an experimental level, these new materials have shown beneficial properties for these industries as they have high impact resistance, low thermal conduction, high acoustic insulation capacity, and low weight. The preliminary results of the materials testing and market validation are promising for further developing and expanding the production of these materials and their applications (Téllez et al., 2022).

In another vein, a brief review was conducted to shed light on the importance of some novel high-performance green fibers, such as bamboo, curaua, jute, kenaf, among others, in ballistic applications. Fibre architecture and configurations and manufacturing processes also greatly influence the high energy absorption potential. The importance of bio-influence woven, multi-layer, and hybrid fabrics and the impact of polymers in manufacturing personal protective armor, helmets, or other articles is highlighted. The various prevailing factors, such as toughness, ductility, thickness, and strength of composite materials, are also analyzed to improve ballistic performance (Kar et al., 2022).

However, an evaluation of notch toughness was performed by Izod and Charpy impact tests of epoxy matrix composites reinforced with different volume fractions of fique fabric, up to 50.00% vol. Statistical analyses indicated significant differences between composites with different amounts of fique fabric. The failure mechanisms were analyzed by scanning electron microscopy (SEM). The results revealed that the composite reinforced with 40.00% vol. of fique fabric had the best performance in notch toughness. The composites with 15.00% and 30.00% by volume of fique fabric show predominantly brittle fracture associated with lower impact energies. With a higher amount, 50.00% vol., of fique fabric reinforcement, both Izod and Charpy impact energy suffered a small decrease, according to Roger and Plumtree's model (Souza et al., 2019). The fabrication and mechanical characterization of fique fiber-reinforced mortar sheets were carried out in another direction. The influence on the mechanical properties of the composite material of two different fiber treatments was evaluated: a surface coating with liquid paraffin and an alkalinization with sodium hydroxide. The efficiency of both treatments was characterized chemically and mechanically. It was concluded that both treatments efficiently protect the fiber surface and have no significant influence on the mechanical strength. Paraffin coating seems to negatively affect the energy absorption capacity of the composite material (Coudert, 2020).

On the other hand, the research studied the behavior of sinewy walls under the external imposition of lateral loads, either monotonic loads or loading and unloading cycles. The tendon wall system consists of frames on which semi-flexible panels are placed. The frames can be wood, guadua, metal, or reinforced concrete. On the other hand, the panel is assembled with barbed wire tendons, tensioned symmetrically around the perimeter of the portico, and on top of which are stretched sacks of sisal, mesh, and guadua matting, among others, thus achieving a network, which will be covered with traditional mortar. In the development of this research, a series of 12 scale tests were carried out with three types of walls; a wide difference was found between the maximum drift percentage allowed by the Colombian Regulation of Earthquake Resistant Construction 2010, NSR-10 for wood and guadua structures and the results obtained in the laboratory; where the values exceeded almost double and triple the values allowed by regulations, without major damage to the wall spacing, punishing in the case of guadua, the flexibility of this material as a raw material for construction (Mora, 2022).

On the other hand, the evaluation and study of meshes woven with fibers extracted from the Furcraea or fique plant determined their effectiveness in protecting slopes and reducing laminar erosion in soils, as the latter can affect infiltration, storage, and drainage of water in the soil, systematically affecting its fertility and reducing its ecosystem services, decreasing its productivity, reducing its stability and amplifying the hydrogeological risk such as landslides or floods, thus causing significant socio-economic losses. Two tests were carried out, one in the field on slopes located in the department of Cesar in the municipality of San Diego, approximately 26.23 km from Valledupar, which are subject to natural conditions of erosion, precipitation, and humidity, and the other, using artificial slopes built-in transparent tanks, simulating rainfall with the help of an irrigation system. In both cases, a mesh was installed on one slope, and the other was left completely uncovered, measuring the runoff, infiltration, and soil loss for subsequent analysis and comparison. As a result, it was observed that the plot covered with the mesh showed a significant decrease in runoff and soil loss, moisture retention, and changes in vegetation growth compared to the uncovered plot (Mejía et al., 2021).

3.3 Experiments with fique bagasse

To evaluate the effect of incorporating bagasse microparticles (FBM) in a cassava starch-based foamed material. First, the extraction conditions of FBM by acid hydrolysis were established, for which the effect of acid concentration (5.00%, 10.00%, and 15.00% H2SO4), temperature (70, 80 and 90 ◦C) and extraction time (3, 5 and 7 h) were analyzed. The particle size, functional groups, color, and thermal properties were evaluated. Next, the addition of FBM to the foamed material was performed. A completely randomized design was evaluated with five treatments (0.00%, 0.50%, 0.75%, 1.00%, and 1.25% FBM). The response variables were bulk density, expansion and spring rate, compressibility, water absorption, thermal properties, and FTIR. The results showed that acid concentration, temperature, and time affected the morphological, chemical, and thermal properties of FBM, with 10.00%, 70 ◦C, and 7 h being the conditions that yielded the smallest particle size (61.69 ± 12.88 μm2). Furthermore, FBM concentration significantly affected the foam's physical and mechanical properties, triggering the 0.75% treatment properties, indicating that FBM could be used in obtaining bio-based materials (Parra et al., 2022).

On the other hand, ABS is one of the most used polymers in 3D printing, and the study of composite materials with matrix in this polymer is of interest for footwear applications. In this study, 4 composite filaments were obtained in a mixture of different compositions with PLA, PP, cassava starch, and fique. The filaments were manufactured by 3D printing and analyzed mechanically, morphologically, and chemically. They found that the adhesion between ABS layers is a determining factor for the final properties of the product to be as expected (Quiroga et al., 2022).

However, the slow pyrolysis of a low-value-added agricultural waste, bagasse, was carried out to obtain biochar. The prepared biochar was then activated or modified by chemical or physical processes to produce six types of biochar. The bagasse biochar (FBB) was characterized using different analytical techniques. In addition, FBB was studied as an adsorbent for the emerging pollutants caffeine and diclofenac sodium. Therefore, FBB can be seen as a win-win condition and an approach to valorize this waste and include it in a circular economy. The adsorption tests showed that the pH studied did not have a significant difference in the adsorption capacity.

In contrast, adsorption time, temperature, and concentration affected the adsorption capacity of caffeine and diclofenac on the six biochars used. Furthermore, the biochar prepared by slow pyrolysis at 850 °C, with a residence time of 3 h and activated with NaOH (FB850- 3Na), was the best adsorbent evaluated, with adsorption capacity values of 80.65 and 57.13 mg g-1 at 20 °C, for caffeine and diclofenac, respectively. It was also shown that the experimental data

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of FB850-3Na fit very well with the Sips isotherm model and followed a pseudo-first-order kinetic model for both caffeine and diclofenac. These results demonstrate that biochars from fique bagasse are an option for treating contaminated water and an alternative to reducing waste from fique fiber production (Correa et al., 2022).

On the other hand, pharmaceuticals, including caffeine (CFN) and diclofenac sodium (DCF), are a group of emerging pollutants that can cause harmful effects on flora and fauna, even at relatively low concentrations. Furthermore, NFC is one of the most ubiquitous active compounds in the natural environment. At the same time, DCF is a widely used non-steroidal anti-inflammatory drug detected in environmental sources worldwide. In contrast, fique is a plant of the Agavaceae family and genus Fucraea. In Colombia, two native species, Furcraea cabuya, and Furcrae macrophylla, are cultivated to extract their fiber, but this process produces much waste. In this study, fique residues were thermochemically treated, and 5 biochar samples were obtained, colourimetrically characterized, and used to investigate their behavior in the competitive adsorption of DCF and CFN. The results of the calorimetric studies show that the biochar prepared from fique bagasse has different porous and chemical characteristics, which are related to the different treatments used at the time of its preparation. In addition, it was established that the results of adsorbate-adsorbent interactions determined by calorimetry allow for correlating the adsorption processes of the molecules under study (CFN and DCF). The results show that the fique NaOH biochar (FB850-3Na) presents the highest adsorption capacity in simple and competitive tests (Correa et al., 2023).

On the other hand, biochar obtained from agricultural residues is increasingly recognized as a multifunctional product, a porous solid for multiple applications. This study produced bagasse biochars from fique bagasse at different temperatures. These materials were investigated for their physicochemical properties and caffeine adsorption capacity. The pH of the solution was an influential parameter, and it was determined that pH = 2.0 for washed biochar and pH = 6.0 for unwashed biochar were the best conditions for adsorption. The Langmuir, Freundlich, and Redlich-Peterson isotherm models fit the experimental data well, indicating surface and multilayer adsorption. From the equilibrium adsorption capacity of the fique bagasse biochars, it was concluded that pH-dependent interactions, hydrogen bonding, and π-π stacking interaction were responsible for caffeine adsorption. The results allow visualizing the biochar obtained from fique bagasse as a sustainable alternative to waste derived from cabuya production (Correa et al., 2019).

3.4 Experiments with juice and with fique cellulose nanofibres

Composite cellulose hydrogels are the result of physical or chemical cross-linking processes. The unique three-dimensional architectures, which arise from the interactions of the hydrogel components, make these materials ideal for designing function-based structures. We follow the development of cellulose nanofibre/silver nanoparticle (Ag NP) hydrogels in aqueous media. TEMPO-oxidized cellulose nanofibres (TOCN), extracted from fique waste biomass, acted as reducing and protecting agents for the in situ synthesis of Ag NPs. Temperature and COONa: AgNO3 molar ratios influence hydrogel formation. Increasing temperatures (60 8C) resulted in shorter reaction times (28 h) compared to the behavior at lower temperatures (25 8C), which required longer reaction times (192 h). High COONa: AgNO3 molar ratios (1:3) produced stiffer and darker Ag TOCN/NP hydrogels at the expense of forming large cubic Ag NP clusters (1 lm).

In contrast, lower COONa: $AgNO_3$ molar ratios (1:1) resulted in softer hydrogels with spherical Ag NPs exhibiting diameters between 15 and 80 nm. The Ag NP formation and cross-linking processes depend highly on the unreacted aldehydes on the TOCN surfaces after the TEMPO oxidation reaction. IR spectra indicated a bridging bidentate interaction between the COO- and Ag+ ions. These carboxylate-metal complexes could weaken the hydrogen bonding system by increasing the distance between the cellulose molecules and decreasing the crystallinity index of the material, as observed by XRD analysis. TGA analyses showed that Ag NPs significantly increased the thermal stability of TOCN/Ag NP hydrogels compared to TOCN hydrogels. Rheological probing of the hydrogels clarified the role of Ag NP distribution and loading in the elastic response to cyclic deformations, suggesting various uses for these materials, particularly in medicinal applications (Ovalle et al., 2020).

Cellulose nanofibres were obtained from Colombian fique (Furcraea Bedinghausii), and acrylic hydrogels (H) and acrylic hydrogels reinforced with fique nanofibres (HRFN) were synthesized using the solution polymerization method. The extraction was done using a combined method (chemical procedures and ultrasound radiation). The raw material (NAT-F), bleached fibers (B-F), hydrolyzed fibers, and ultrasound-treated fibers (US-F) were characterized by infrared spectroscopy (FTIR) and thermal stability analysis, and a commercial sample of microcrystalline cellulose (CC), which demonstrated extraction of fique cellulose, was analyzed for comparison. The surface morphology of NAT-F and B-F was determined by scanning electron microscopy, and the average particle size of the nanofibres was determined by transmission electron microscopy. At H and HRFN, the strain percentage and compressive strength (Rc) were measured. The average diameter and length of the fique nanofibres were 25.20 ± 6.20 nm and 483.80 ± 283.20 nm, respectively. The maximum degradation temperature was 317 °C. HRFN presented higher compressive strength (16.39 ± 4.30 kPa), and this strength was 2.5 times higher than the strength of H (6.49 ± 2.48 kPa). The results indicate that the lignocellulosic matrix of fique has potential application for obtaining polymeric composite materials (Guancha et al., 2020).

Conclusions

It can be observed that there are several products made with fique with high technical demands, aesthetic and symbolic value, innovation, and commercial competition in the market, giving a satisfactory response to all the stimuli granted by public and private entities that made it possible to reach the final product. It can be established that each product developed has posed personal and professional challenges for the artisan or the person responsible, where, with the help of material and immaterial tools, they have managed to elaborate innovative and quality products.

A variety of experiments have been carried out with fique fiber as a thermal insulator, ballistic armor for personal protection, composite materials that include fique fibers as a substitute for wood in the construction of beehives, thermo-acoustic insulation, toilet paper applications, the impact of the structure of natural fabrics on ballistic function. With specific enzymatic treatments targeting the removal of pectin in the chemical composition, fique fibers can become a promising biosorbent for removing azo dyes by surface modification. They may be particularly important for textile wastewater treatments in terms of improving water quality before discharge.

One of the investigations resulted in a family of six new natural fiber composites using maize residues and fique fibers and designed a collection of products for various industries such as packaging, construction, and automotive. At the experimental level, these new materials have beneficial properties for these industries as they have high impact resistance, low thermal conduction, high acoustic insulation capacity, and low weight. The fabrication and mechanical characterization of fique fiber-reinforced mortar sheets was carried out, a sufficiently interesting material for the civil construction industry, which is cheap, suitable for construction in seismic risk areas, and durable over time. The mechanical properties of the composite material must be improved by studying the reinforcement-matrix compatibility, developing optimal treatment processes for the fibers, and analyzing the material's durability over time.

Meshes woven with fique fibers were developed, evaluated, and studied in order to determine their effectiveness in protecting slopes and reducing laminar erosion in soils, as the latter can affect infiltration, storage and drainage of water in the soil, systematically affecting its fertility and reducing its ecosystem services, decreasing its productivity, reducing its stability and amplifying the risk of landslides or floods, thus causing significant socio-economic losses. Based on a circular economy model, revaluing up to 7500 tonnes per year of waste from the Colombian fique agro-industry is proposed. Colombia uses approximately 40 billion cubic meters of water in the agricultural sector. This demand is unsustainable, so it is worth considering technologies aimed at reducing water use for irrigation, increasing its availability in the soil for longer, and enabling the efficient use of fertilizers.

The hydrogel reinforced with 3.00% w/w fique nanofibres (AHR3) presented the best swelling capacity and used the least amount of fique, representing better economic benefits for industrial-scale production. The proposed superabsorbent hydrogel (AHR3) could be used as an alternative to improve the water retention capacity of soils, reducing irrigation frequency by up to 90.00%. It would also help to improve soil compaction and reduce water loss through infiltration, and fertilizer loss would improve seed germination, thus increasing plant growth and delaying wilting in drought conditions, which is common in some areas of Colombia. One of them is the department of Cesar, a problem that will worsen over the years due to the climate emergency.

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