Sustainable use of the pseudostem and rachis of banana *Musa* sp.

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ABSTRACT
Currently, plastics are the most diversified materials with the highest volumes of consumption worldwide, reinforced with synthetic fibers. However, the environmental repercussions related to the accumulation of plastics have led to the search for alternatives that allow the establishment of a development attached to sustainability. Around the world, various research is being carried out with the aim of taking advantage of the use of natural fibers as a substitute for plastics. The objective was to establish sustainable techniques for the processing and staining of banana rachis and pseudostem fiber in order to diversify its use. It was found that solar dehydration allows fibers to be obtained with better characteristics than in an electric dryer. The dried fibers are useful for making various handicraft items with decorative, cultural and agricultural uses, compostable. The dyeing of the fibrous pieces was achieved using natural sources. The use of these techniques for the use of by-products of banana production will allow local artisans to have processes that allow them to improve their production and take advantage of the by-products of the environment while being environmentally friendly, which will have an impact on the development of communities dedicated to the elaboration of traditional handicrafts.

Keywords: Agricultural by-products, Bananas, Artisanal, Natural fibers.

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INTRODUCTION

In the last sixty years, the most diversified materials with the highest volumes of consumption worldwide are plastics reinforced with synthetic fibers: thermoplastics and thermosets reinforced with carbon fibers, aramid and glass fibers (Rodríguez *et al*., 2014). Most of the synthetic polymer fibers used in everyday life are obtained from petroleum; the decline of which has led to increased environmental concern, causing sustainable fibres to become important; leading to further research into materials such as cellulose, lignin and silk, as well as polymeric fibers synthesized from raw materials derived from natural resources (Chang *et al*., 2017).

In countries such as Brazil, Ecuador and Colombia, fibers from the by-products of the banana agro-industry are used, whose residues are considered organic, since they are mainly composed of cellulose, hemicellulose and lignin; Its management is costly and difficult, as well as being a source of pests that are harmful to crops (Saval, 2012).

An example of these technologies is the production of various products from the use of local resources, such as natural fibers such as juta, sisal, coconut fiber, flax, banana fiber and some other agricultural and industrial waste materials that are being used for many applications due to their advantages over their synthetic counterparts (Rodríguez *et al*., 2014).

In Mexico, the states of Chiapas, Tabasco and Veracruz together account for 72% of banana production (Agricultural and Fisheries Information Service, 2016), however, these resources have not yet been exploited. The banana is a herbaceous plant of which only 30% of its biomass is used after harvest, being able to find around 625 to 3,030 plants per hectare in one hectare, generating a usable source of resources after the harvest (Álvarez, 2010).

The banana agro-industry generates large amounts of organic vegetable waste made up of the pseudostem, leaves and pinzote (Canché-Escamilla *et al*., 2005; Sosa *et al*., 2010; Calle *et al*., 2014). When the banana bunch is harvested, only 20 to 30% of its biomass is being used (Álvarez, 2010), leaving 70 to 80% to be used. This waste has generated one of the main environmental problems because, in most cases, it is incinerated or dumped into the receiving sources without prior treatment, contributing to the degradation of the ecosystem (Mazzeo, 2010).

Untreated waste deposited in the soil generates leachate that can reach aquifers, favoring the transport of bacteria due to runoff to other areas of the crop (Saval, 2012). The high volume and weight of these by-products also makes them difficult to handle and more expensive to dispose of; while their accumulation contributes to the production of insects, fungi and odors inside or outside the crops when they are stored in an uncontrolled manner (Quinchia and Uribe, n.d.).

Agro-industrial waste represents one of the major problems and challenges faced by banana producing and exporting countries, which generates high costs in terms of the environment and finances (Gaona, 2015). Because Tabasco is one of the three banana-producing states in the country

(Agri-Food and Fisheries Information Service, 2016), it has to solve several challenges, including the negative impact on the environment. For this reason, it is a priority to develop products that do not cause damage to the environment or are made using reusable material, with the aim of having sustainable ecosystems and a society that is more aware of the benefits of a healthy environment today and in the future (Cortés, 2014).

Industries also need to gradually improve their technological development for the use of alternative resources, because of the growing demand for food, energy and other essential needs of the population. In this sense, the Food and Agriculture Organization of the United Nations (FAO, 2015) indicates that it is important to produce more food, but in a sustainable scheme; This implies for industries and producers to generate cleaner technologies and production chains.

Banana-producing regions in Mexico produce a high amount of plant residues (Sosa *et al*., 2010; Calle *et al*., 2014; Gaona, 2015), which forces them to look for alternatives for the sustainable use of these by-products, as is the case in other countries such as Colombia, where they are used to make handicrafts and paper, including the textile industry (Artesanías de Colombia, 2008). The use of the pseudostem can contribute to reducing the existence of pests in crops, such as: bacteriosis, screwworm, black or striped weevil (SIAP, 2016).

Considering the importance of developing products with fewer environmental impacts, in order to achieve a more sustainable ecosystem and a society more aware of the benefits of a healthy environment, today and in the future, there is a need to contribute to generating techniques for the use of these materials available in the locality (Cortés, 2014). In this context, this work presents a sustainable alternative for the use of the banana pseudo-stem, through the production of handicrafts, paper, biodegradable packaging and containers for agricultural use, including natural dyeing using available local resources.

THEORETICAL FRAMEWORK

(a) Agro-industrial by-products. The presence of man on the planet has caused the generation of various solid, liquid or gaseous wastes, which tend to increase permanently, as well as their quantity and complexity; This is done as the population increases and the development of technology; thus making it more difficult for the environment to degrade, assimilate or reuse the materials that compose them (Quinchia and Uribe n.d.).

In his documents, Saval (2012) describes agro-industrial by-products as: solid or liquid state materials that are generated from the direct consumption of primary products or their industrialization that are no longer useful for the process that generated them, but that are susceptible to use or transformation to generate other products with economic value. of commercial and/or social interest.

The new products generated from agro-industrial waste may have different characteristics, but be composed of similar elements, mainly lignin, cellulose, pectin and hemicellulose, to which they confer the name of *organic waste*; for which there is no adequate management, nor the technological or economic capacity to give them a destination, including a lack of specific legislation to promote the management of this type of waste. waste (Saval, 2012).

Gaona (2015) indicates that banana production produces high pollution due to the harvest waste generated after the fruit is cut, since it is deposited in the soil without any treatment, which does not reduce the impacts on the environment; This is a problem that those who engage in this activity must face.

On the other hand, Canché-Escamilla *et al*. (2005) also agree that there are large amounts of waste in banana crops, after harvest, since only the fruit is used, having to dispose of the other parts of the plant such as pseudostem, leaves and pinzote or rachis (part of the plant that supports the bunches of fruit).

These untreated vegetable wastes cause problems mainly related to their volume and weight, as well as difficulties in handling them, which makes them more expensive to dispose of; while their piling contributes to the production of insects, fungi and odors, specifically when stored in an uncontrolled manner (Quinchia and Uribe n.d.).

b) Morphology of the banana plant. According to Sandoval and Müller (1999), the banana tree is a herbaceous plant of the Musaceae family, which has an underground stem (corm or rhizome) from which an aerial pseudostem is born; the corm emits roots and lateral buds that will form the offspring or offspring (Álvarez, 2010). The root system of the banana tree has the main function of absorbing and transporting water, as well as transferring nutrients from the soil to the plant. Banana plants have both a primary and an adventitious root system. Primary roots originate from the rhizome and secondary and tertiary roots originate from primary roots.

The rhizome is the true stem of the banana plant and is found underground, although it is usually referred to as corm, the correct botanical term is rhizome. The growing point of the rhizome is a flattened dome where the leaves are formed and then the inflorescence arises at the top of the plant.

The pseudostem is the part of the plant that resembles a trunk, it is a false stem formed by a tight set of overlapping leaf sheaths, fleshy in texture, formed mainly by water, which can support a cluster of 50 k or more. As the leaves emerge, the pseudostem continues to grow upward, reaching its maximum height when the true stem, the flowering stem that supports the inflorescence, emerges at the top of the plant.

The inflorescence is supported by the floral stem, a structure that contains the flowers, which will be the future fruits. The flowering stem, produced by the terminal growing point of the rhizome, grows through the pseudostem and emerges at the top of the plant after the last cigar leaf has sprouted. As the female flowers develop into fruits, the distal portion of the inflorescence elongates and produces a second set of male (staminate) flowers, each under a bract. Male flowers located on the male bud produce pollen, sterile or fertile.

The leaves are the main photosynthetic organ of the plant; These emerge from the center of the pseudostem like a coiled cylinder. The distal end of the elongating leaf sheath contracts to form a petiole, more or less open depending on the cultivar. The upper part of the leaf is called the adaxial surface, while the lower part is called the abaxial surface. The first basic leaves that are born from a growing child are called flakes. Mature leaves, which are called true leaves, consist of sheath, petiole, midrib, and blade.

The cluster is the set of fruits that appear along the rachis. The individual fruits, also called fingers, are grouped into structures called hands. The male bud contains the male flowers enclosed in their bracts, sometimes called "bells", which, together with the rachis, continue to grow as the fruits ripen. In some crops, the male bud stops growing when the fruits have formed and may be more or less exhausted by the time the bunch reaches maturity. The presence or absence of male bud is one of the characteristics used to differentiate between crops.

On the other hand, the rachis is the stem of the inflorescence. Starting from the first fruit to the male bud, it may be devoid or covered with persistent bracts. The spine has nodules; These are scars that indicate where the bracts were attached.

(c) Banana by-products. Several studies found (Abad *et al*., 2012; Canto and Castillo, 2011; Cortés, 2014; Flotats, 2015; Gaitán *et al*., 2016; Gonzalez *et al*., 2016; Grisales and Giraldo, 2004; Linares *et al*., 2008; Mazzeo *et al*., 2010), among others, propose various alternatives for the sustainable use of these by-products, demonstrating in their work their versatility for the production of components of construction materials, biodegradable packaging, handicrafts and paper.

In the Americas: Brazil and Costa Rica, both banana producing countries, are already making various products based on banana fiber such as: paper, diaries, cargo bags, wallets, mats, bread baskets, dolls, hats, among others. Similarly, in Costa Rica, Japan and Australia in 2015, products obtained from banana fiber were also industrially produced, exporting their production to the markets of Europe and the United States (Gaona, 2015).

At a global level, great advances have been made for the use of bananas and their by-products (peels, leaves, pseudostem, stem and inflorescence) whose applications range from food products for people or animals as well as for non-food products related to the use of natural fibers, natural bioactive compounds and bio-fertilizers (Padam *et al*., 2014).

One of the current discoveries is the use of the pseudostem for the production of laminate material known as *Green Blade*, discovered in 2016 in France (Ecocosas, 2017). Agro-industrial banana residues have been evaluated for the production of activated carbon by Quinchia and Uribe (n.d.) in Colombia, whose study concludes that it is feasible for this purpose.

Studies have also been found on the components of the pseduostem juice of the banana known as dominico, carried out by Vargas and Martínez (2015), a residue also studied three years earlier for the production of wine by Guarnizo-Franco *et al*. (2012) in Colombia. Another study by Álvarez (2010) evaluated the feasibility of banana residues for animal feed. In addition, leachates have been shown to be efficient for the control of crop-related diseases and as promoters of plant growth, in addition to not containing pathogenic microorganisms for plants, humans and animals (Blasco *et al*. 2014).

Based on the works found, it is important to emphasize that one of the countries that predominates in the study and use of this waste is Colombia, although some were also found in Venezuela, Ecuador, Brazil and India, countries where it was even found that there are small companies dedicated to the production of paper and handicrafts using these resources. composed mainly of women.

Thus, the alternatives for the use of these by-products for the production of paper, agglomerates, lamination and cellulose extraction require sophisticated equipment and greater financing. In other cases, they can be used in an artisanal way for the production of handicrafts and paper; In both situations, there is the prospect of obtaining economic benefits, taking advantage of a low-cost resource available in banana growing areas.

The recycling of the huge quantities of by-products from this crop represents a valuable source of high-value raw materials for industries, avoiding the waste of this biomass, as well as providing additional income for small-scale agricultural industries, without compromising quality and safety in competition with other commercial products (Padam *et al*. 2014)

The prospects and challenges in the future, in the use of these materials, are the important key factors, given the association with sustainability and the feasibility of the use of these by-products (Padam *et al*., 2014). As far as Mexico is concerned, few examples of research or the application of technologies for the use of this material have been found:

- Nanocellulose obtained from agro-industrial waste from plantains. Held in Morelos, Mexico, in 2016.
- Musa balbisiana *finzon* and *Musa acuminata* as a source of paper fibers. Held in Jalisco, Mexico, in 2009.
- Elaboration of ecological paper and other products carried out by students of the Instituto Tecnológico Superior de Tierra Blanca in the state of Veracruz, Mexico.

Similarly, in Tabasco, Mexico, work was found carried out by high school students related to the use of banana stem fiber to manufacture biodegradable sheets and tablets and bioplastic by students from the State Technological University. The few studies found indicate that alternatives for the use of banana residues, considered one of the most important crops in Mexican agriculture, are still being explored in Mexico (García *et al*., 2013).

At the international level, researchers Armas *et al*. (2016), carried out several tests with different fibers extracted from the banana stem, in combination with polyester resin as a matrix, applying two treatments; one consisting of pre-curing the fibres with 10% sodium hydroxide (NaOH) and the other using the untreated fibre. They found that the mechanical properties of this compound are better compared to the behavior of polyester resin. The fibers that were chemically treated with NaOH in combination with the resin possess improved mechanical properties, including the property of working in saline environments without affecting their properties.

The high strength, compression and tensile strength of polyester resin composites in combination with banana fiber allows their use in multiple applications such as body elements, aircraft or boat parts, insulating structures, tool accessories, among others, based on the fact that the integration of the fiber to the resin increases its mechanical properties by approximately 272.55% at maximum tensile stress. 292.46% in the modulus of elasticity and 442.51% in the average bending stress (Armas *et al*. 2016).

METHODOLOGY

a) Obtaining banana fibre. The fiber was obtained based on the techniques described by Abad *et al*. (2012) and Artesanías de Colombia S.A. (2008), according to the following indications:

1. The pseudostem was cut to a height of 80 cm from the corm or base of the plant, depending on its height, pieces of 1 to 1.5 m in length were cut.
2. The surface was cleaned and the layers were separated until the center was reached. Then 4 cm was cut from the edges of each layer.
3. The central part of the layer was filleted to obtain three different textures: mesh-like, hard fiber, and soft layer, as shown in Figure 1.

Figure 1. Pseudostem layers, from top to bottom: mesh type, hard fiber and soft layer.

4. To obtain the dry fiber, two methods were evaluated: solar dehydration and oven drying. Sun drying was carried out during the months of May to September. The mesh-type fibers, silk and those obtained from the edges of each layer, were placed on a circular rod of 4cm in diameter approximately suspended 1.70 cm from the ground, while the rest were laid neatly on a zinc sheet roof; exposed during the day and night, except on rainy days.

6. Oven drying was carried out in the laboratory using an oven at 45°C, with inspections every 30 minutes.

(b) Fibre dyeing. Three natural sources of dyes were evaluated: mahogany husk (*Swietenia macrophylla* King), hibiscus flower (*Hibiscus sabdariffa*) and beet tuber (*Beta vulgaris*). The dyeing with the husk of the mahogany stem was carried out cold, as indicated by Martínez *et al*. (2010) proposing a modification at the time of adding the fibers, which were added at the same time as the dyeing material and not after 24 hours. Three treatments and two levels of peel were performed (T1, water at room temperature, 10 and 20% dry peel; T2, Water at room temperature, 10 and 20% green shell; and water at 90 °C, 10 and 20% dry mahogany) and three repetitions of each. 3 strips of each type of fiber of 10 x 1 cm (9 in total) were added for each repetition, weighing approximately 2 to 3 g, leaving at rest for 24 h. They were monitored every 12 h until color change was observed.

For the dyeing of the fibers with hibiscus flower, two treatments were evaluated with three replications: T1, 250 ml of water at room temperature with 6 g of dried hibiscus flower; T2, 250 ml of water at 90 °C with 6 g of dried hibiscus flower. In the dyeing with beets, the pieces of the tuber were added in the container where the strips of fibers were placed. In both treatments, coloration was evaluated in the same way as in mahogany shell treatments.

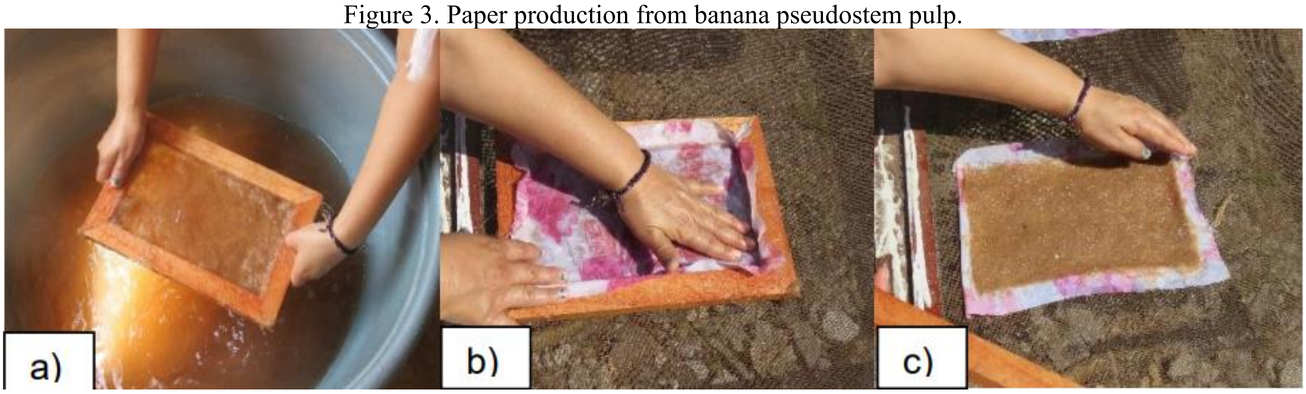
(c) Making handicrafts from dry fibre. The sun-dried fibers were evaluated, and the air was extracted using a glass container used as a roller. Subsequently, they were cut into strips 1cm wide and various fabrics were made, interlaced, and spliced until a handmade product was obtained, as shown in Figure 2. A bioglue-based sealant was applied to the finished handicrafts.

Figure 2. Elaboration of handicrafts with different weaving techniques.

(d) Papermaking. The technique proposed by Gaona (2015) was used. The raw material was obtained from the pseudostem, cut into slices and cooked with water for 1.2 hours. The pulp at room temperature was crushed in an industrial blender for 2 min. Four 1 k portions of the paste obtained were weighed and placed in separate containers, where treatments were applied to give color. Mahogany husk (10%), hibiscus flower (10%) and commercial sodium hypochlorite (1%) were evaluated for the dyeing of the paste.

The paper was made by placing water in a container to which the paste was added and dispersed homogeneously. Using a 20 cm x 40 cm frame, covered with metal mosquito net, the fiber contained inside the container was trapped to form a homogeneous sheet (Figure 3). Finally, it was dehydrated in the sun until it was obtained into dry paper sheets.

Figure 3. Paper production from banana pseudostem pulp.



(e) *Production of compostable containers*. For the production of compostable plates, pots and masks, the same procedure used in the production of paper was carried out, until the pulp was obtained. To provide firmness to the fibre paste, a bio glue based on cornstarch was designed, made with 300 ml of water plus 10% of corn starch and 10% of vinegar as a preservative; The mixture was stirred until the ingredients were homogenized, then simmered until it reached a change from white to transparent. For each kilo of dry fiber, 20% bioglue was added and mixed by manual kneading; the paste was molded in the different containers, to which paper or plastic was placed to facilitate unmolding (Figure 4).

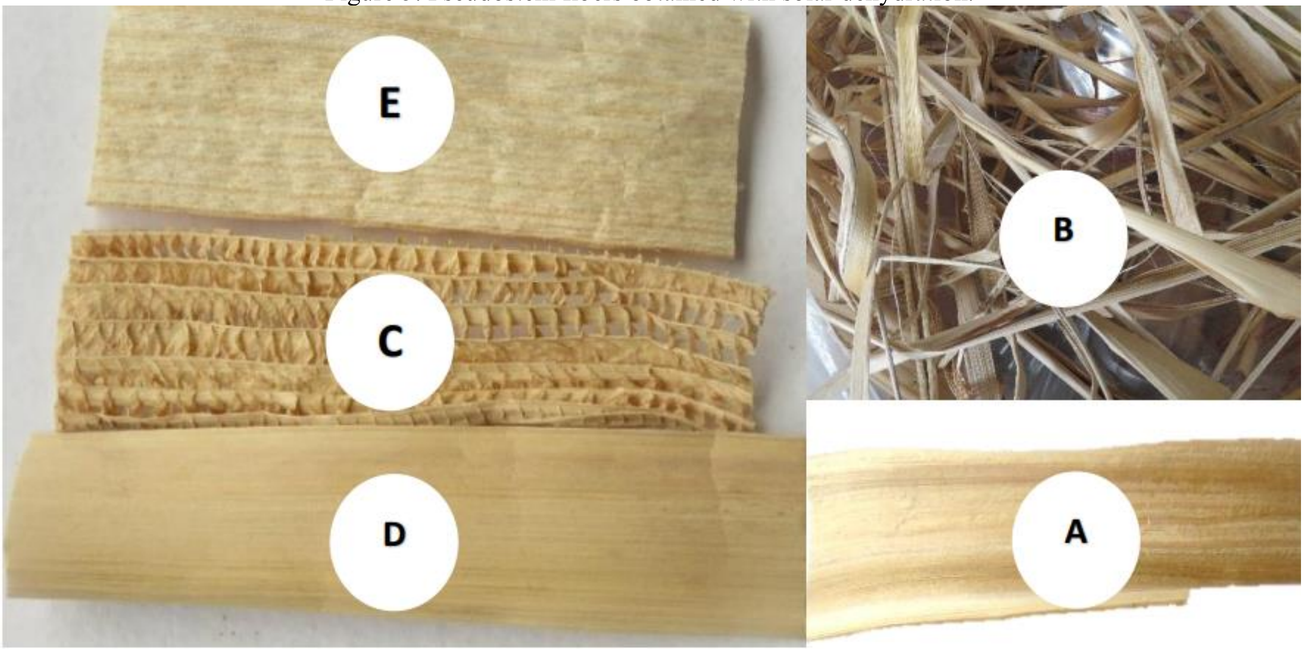
Figure 14. Moulding of bio packaging and handicrafts.

RESULTS AND DISCUSSION

The use of by-products of banana cultivation is an opportunity to contribute to sustainable development by adding value to products made from natural fibers. The objective of this work is to present sustainable alternatives for processing the pseudostem and rachis of the banana plantation; Provide tools that allow artisans to make crafts, paper, packaging and compostable containers that add value, take care of the environment and promote the development of sustainable communities.

a) Drying. Two methods of drying, solar dehydration and oven drying were evaluated; Five types of fiber were obtained. With solar dehydration, during sunny days the drying time of the thin and flexible layers was one to two days, while the thick fibers were 3 to 5 days (D, A and B), as shown in Figure 5.

Figure 5. Pseudostem fibers obtained with solar dehydration.



The dry fibers obtained during hot days had a light brown color. On these days, temperatures around 48 °C were reached inside the fiber, with a relative humidity of 72-96%. The dehydrated fibers on sunny and rainy days took 7 to 8 days to dry, presenting a dark brown color and fungal spots on more than 30% of the material. According to Abad *et al*. (2012) indicate that it is possible to remove fungal stains with a 10% chlorine solution, the stains are removed. However, it is not recommended for use on materials with more than 30% stains, as when applied it was observed that the fiber loses its shine and it is more difficult to remove stains.

As for kiln drying, no favorable results were obtained with this method in any of the five types of fibers. The thinnest layers (the mesh and silk fiber) dried after half an hour, however, the flexibility characteristics were not adequate, since they broke when handled during the folds to make the handicrafts; these results are similar to the drying work carried out by Artesanías de Colombia S.

A. (2008). However, the temperature of 45 °C is given as unsuitable for drying. As for the other thicker fibers, they began to dehydrate from the banks after two hours; They became brittle when pressed with the fingers. A change in the color tone of the fibers was also observed, turning dark brown, an effect probably related to the caramelization of sugars or enzymatic browning (Belén-Camacho *et al*., 2007).

The results obtained in both drying techniques indicate the importance of this step during the process to obtain fibers with suitable characteristics for the elaboration of handicrafts both in color and flexibility; solar dehydration is the technique that makes it possible to obtain fibers with the best characteristics for the production of handicrafts; However, its disadvantage lies in its seasonality, with the months of January to August being the most suitable, while the rest are not recommended due to the problems of fungal appearance. However, tests indicate that it is possible to dry the fibers, but they should be prevented from getting wet with rainwater.

To avoid the inconveniences of the rainy months, it is recommended to dry fiber during the sunny months and store them in closed bags in a dry place. If required, it is recommended to build solar dryers to carry out drying in the rainy months, as is done by working groups in other countries.

(b) Staining. Three treatments were evaluated in the mahogany shell staining, the best being the treatment consisting of hot water at 90°C + 10% dry mahogany shell; where a dyeing time of 24 h was obtained, unlike those immersed in cold water that took 48 h. However, after 36 hours, all three treatments added color to the fiber, in visually similar shades. It was observed that the longer the submerged fibers take, the more the color intensifies. It should be noted that only the thinnest fibers, such as mesh and silk, showed more intense homogeneous coloration; unlike the hard fibers, which were only dyed on the edges. Subsequently, Mayan fiber was dyed to make handicrafts, which was observed for a year, a period in which the color remained visually constant.

The results obtained indicate that mahogany shell is a dyeing plant material suitable for dyeing Mayan banana fiber and silk, whose color remains for a long time; which justifies its use to dye materials with rustic textures. Fibers dyed with beets and hibiscus failed to permanently dye the fiber. However, after 24 hours, both added color to the wet fiber.

The fibers of the top layer (hard) when wet gave the appearance of being dyed homogeneously, not just from the edges as in mahogany shell dyeing. Although both provided a rosewood-like color when dried, the beetroot-dyed fiber discolored after a week; Causes of discoloration include lack of pH control and instability to light and oxygen. It was found that the stability of these dyes depends directly on the pH, which ranges from 3 to 7, with an optimal pH between 4 and 5; in addition to being unstable in the presence of light and oxygen (Antigo, 2018).

Likewise, the loss of the color of hibiscus may be due to the use of high temperatures, since the increase causes the loss of glycosylant sugar, resulting in chalcones that are totally colorless, in addition to the presence of oxygen and water activity (Ordoñez & Saavedra, 2016).

(c) Obtaining paper. Although initially the production of paper using rachis and pseudostem was considered; The low availability of the spine limited its use in the other products. Handmade paper was obtained using both fibers. Paper made with pinzote was more rustic as the fibers are thicker and shorter than those of the pseudostem (Canche *et al*., 2005). Figure 6 shows the paper sheets obtained.

Figure 6. Handmade paper obtained from the pseudostem and rachis.

Although there are other methods that contribute to obtaining paper with better textural characteristics, this involves the use of other products that are not environmentally friendly, such as sodium hydroxide, to remove up to 90% of liginine. In rachis paper, even the hairs of the fibers are detached when you run your finger over the surface of the paper. On pseudostem paper, the hairs do not come off and the paper can be folded without difficulty, unlike rachis paper that breaks when folded.

On the other hand, it is possible to dye the paste of the moist banana fiber with beet extract and hibiscus flower. The paste was also bleached using 10% commercial chlorine. However, during drying, the dyes obtained from hibiscus and beets were lost, possibly due to enzymatic reactions or bacterial consortia (Antigo, 2018). The dyeing material that gave color and permanence to both wet and dry fibers was mahogany shell extract. As for bleaching with chlorine, it is possible to obtain a yellowish paper.

(d) Handicrafts and compostable packaging. Handicrafts made of paper pulp and bioglue were made as a new technique for making use of fibres. Compostable pots and masks were obtained and used in the Danza del Pochó, a dance of Mayan origin performed in southeastern Mexico, where around 1,000 dancers participate, during several days of carnival; With this alternative, it is proposed to replace wood to avoid the felling of trees. With this alternative, the elements of the dancers' costumes are provided and the cultural and tourist activity of the municipality is promoted. These elements are shown in Figure 7.

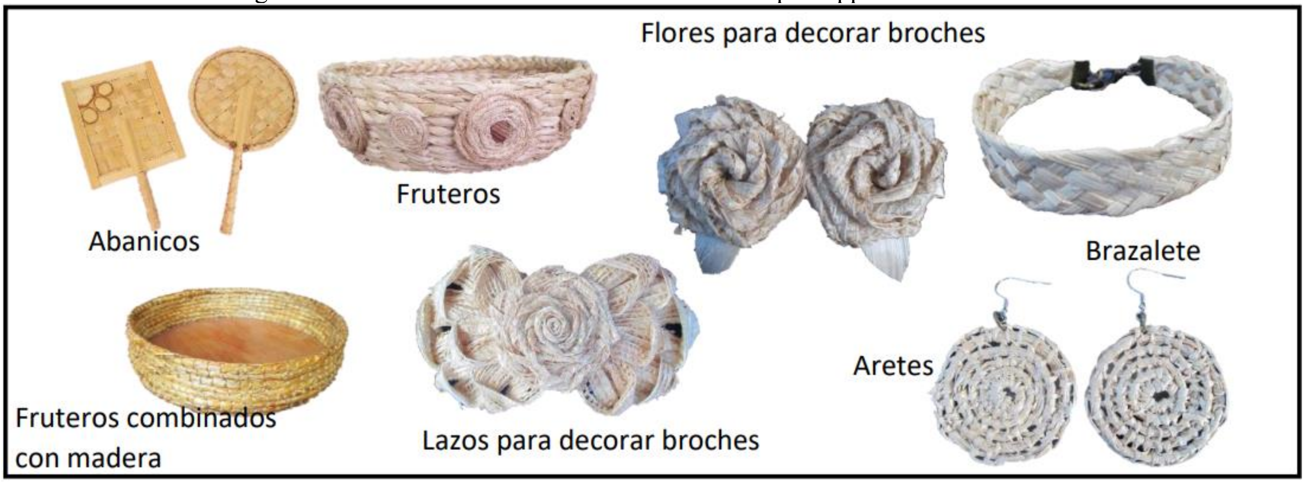
Figure 7. Bio handicrafts obtained from the molding and drying in the sun of pulp for paper.

An alternative technique of molding and drying the paper pulp in the sun obtained biopackaging and biodegradable plates (Figure 8). With this, an alternative for the use of paper pulp obtained from the same pseudostem is proposed. Further studies may contribute to consolidating a proposal for biocontainers and biopackaging through the use of banana fibre.

Figure 8. Bio packaging and containers obtained by molding banana fiber paste.

Finally, the five types of dry fibres were used to make various handicrafts (Figure 9), demonstrating the versatility of banana fibre for the production of products in an artisanal way.

Figure 9. Handicrafts obtained with various techniques applied to banana fibre



CONCLUSIONS

From the banana plant, versatile fibers are obtained for the artisanal production of various products. It was found that fibers with better color and flexibility characteristics are obtained when dried in the sun in the months of January to May, from which different types of fiber can be obtained, depending on their final use. Drying times vary from 2 to 4 days depending on the type of fiber. It is not recommended to dry in the rainy season, unless it is avoided to get wet.

Various handicrafts were obtained from the dry fibre by applying different techniques, including weaving. Compostable containers were also made by adding 20% bioglue to support the reduction of plastics in sustainable agriculture. There is also a new proposal for the use of fiber, consisting of the production of masks that promote the culture and tourism of a region.

Of the three natural dyes used in banana fiber, it was found that the only dye material that provided color in the shortest time to the banana fiber was mahogany peel (*Swietenia macrohpyla*) in a concentration of 10%, by immersion in water at 90 °C with a time of 24 hours, followed by immersion at room temperature for 48 hours; demonstrating that the fiber can be dyed with specific natural dyes.

The use of these techniques for the use of by-products of banana production will allow local artisans to have processes that allow them to improve their production and take advantage of the by-products of the environment while being friendly to the environment, which will have an impact on the development of communities dedicated to the production of traditional handicrafts by promoting added value. innovation and waste reduction in the banana production chain.

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