Mexican Bark Paper: Evidence of History of Tree Species Used and Their Fiber Characteristics[1]

Citlalli López Binnqüist*[,2], Alejandra Quintanar–Isaías[3], and Marie Vander Meeren[4]

[2]Centro de Investigaciones Tropicales, Universidad Veracruzana, Veracruz, México
[3]Universidad Autónoma Metropolitana-Iztapalapa, Ciudad de México, México
[4]Instituto Nacional de Antropología e Historia, Ciudad de México, México
*Corresponding author; e-mail: citlalli_lb@yahoo.com

Mexican Bark Paper: Evidence of History of Tree Species Used and Their Fiber Characteristics. The use of bark fibers (secondary phloem) for the manufacture of the Mexican bark paper called *amate* can be traced back to the pre–Hispanic period. This paper was used extensively during this period, and for the last four decades has been produced as a handicraft by the Ñahñus of San Pablito village in the Sierra Norte de Puebla region of México. Due to the high demand for this product, new species are now used as a source of bark and specific phases of the traditional production technique have been modified. The focus of this study was to register all the species that have been used for bark paper manufacturing, both traditionally and more recently, and to analyze their fiber characteristics, mainly fiber length and lignin content. The main questions addressed by this study were: a) Which species have been used for bark paper production, both prior to and following its commercialization as a handicraft? b) Which anatomical and histochemical fiber characteristics of these species enable their use for bark paper production, regardless of taxa? And c) is there a relationship between the adoption and use of new species and recent changes in traditional paper making techniques? Based on an ethnobotanical study, a list of 13 species used for bark paper production was compiled and bark samples from each species were collected for phloem anatomical and histochemical analysis. Artisans and local healers were also asked to determine the main characteristics of each fiber and paper type. The results demonstrate that bark from currently used species differs anatomically and histochemically from species used during the pre–Hispanic period and until a few decades ago, and in terms of the quality assessed by local healers and artisans. Among other characteristics, the fibers of the new species have higher lignin content than the traditional ones, and this constitutes the main reason behind the modification of certain phases of the traditional paper making process.

Papel mexicano de corteza: evidencias históricas de las especies utilizadas y características de sus fibras. El uso de fibras de corteza (floema secundario) para la manufactura del papel mexicano de corteza llamado *amate*, se remonta a la época prehispánica. Este papel se utilizó extensamente durante la época prehispánica, y desde hace cuatro décadas es manufacturado como producto artesanal por los Ñahñus de la comunidad de San Pablito, en la región de la Sierra Norte de Puebla, México. Debido a la alta demanda de este producto, nuevas especies están siendo utilizadas para obtener corteza y algunas fases específicas de la manufactura tradicional han sido modificadas. El objetivo de este estudio fue registrar todas las especies que han sido utilizadas para la manufactura de papel de corteza, las tradicionales y las más recientes, y analizar las características de sus fibras, especialmente su longitud y contenido de lignina. Las principales preguntas de este estudio fueron: a) ¿cuáles especies han sido utilizadas para la manufactura de papel de corteza, antes y después de su comercialización como artesanía?, b) ¿cuáles características anatómicas e histoquímicas permiten su uso para la manufactura de papel de corteza, independientemente de su taxa?, y c) ¿existe alguna

[1] Received 29 September 2010; accepted 4 April 2012; published online 15 May 2012.

Economic Botany, 66(2), 2012, pp. 138–148

posible relación entre las nuevas especies adoptadas y los cambios más recientes en la manufactura tradicional de este papel?. Basándose en un estudio etnobotánico, se logró integrar una lista de 13 especies utilizadas para la manufactura de papel de corteza y se colectaron ejemplares de fibras de cada especie para realizar los análisis anatómicos e histoquímicos del floema secundario. También se pidió a los a artesanos y curanderos locales que determinaran las principales características de cada una de las fibras y papeles. Los resultados demostraron que la corteza de las especies utilizadas en la actualidad, difieren anatómica e histoquímicamente de las especies utilizadas durante la época prehispánica y hasta hace algunas décadas, así como también en términos de la calidad determinada por los artesanos y curanderos. Entre otras características, las nuevas especies tienen fibras con mayor cantidad de lignina que las especies tradicionales, y esta constituye la razón principal por la cual se han modificado ciertas fases del proceso de manufactura tradicional.

Key Words: Bark paper, México, fiber, histochemistry, handicrafts.

Introduction

Bark Paper in Mesoamerica

Bark paper (known as *amate* in Mexico) is part of the history of Mesoamerican cultures, closely embedded in religious, sacred, and political life. Certain Spanish missionaries, such as Fray Bernardino de Sahagún (1969), who described the traditions and knowledge of indigenous people in detail, report the existence of different objects made from bark and their use closely linked to ritual activities. The diversity of bark paper pieces, found in the year 2000 at the archeological site called the 102nd offering in *Templo Mayor* in the center of Mexico City, are a faithful testimony to this practice carried out by the Aztecs. Seeman-Conzatti (1990) analyzes the use of paper in Aztec rituals, mainly from the Florentino and Borbónico codices, and describes the essential role of bark paper in most pre–Hispanic ceremonies. Bark paper was decorated, rolled up and offered to the gods, made in different shapes and sizes, and used in garments and decorations for the priests. It was used in representations of gods, and of those sacrificed to them. Bark paper was also used as a writing surface (e.g., the codices), a practice frequently mentioned in written sources from the colonial period.

Even though bark paper was used extensively in Mesoamerica, it is not known exactly when its manufacturing began. Due to its organic nature, it is more prone to disintegration than other more tangible historic evidence and few archeological pieces remain. Moreover, large amounts of bark paper were destroyed during the Spanish conquest. Only the stone beaters used to pound the bark fibers during the paper making process survive, and these constitute the most important archeological evidence of this practice.

Linné (1934), in his study of the geographical distribution of stone beaters used for bark paper production, traces the use of paper in Mesoamerica back to around 500 CE, while Von Hagen (1945) and Lenz (1973), based on other evidence, suggest paper making is of Mayan origin and trace it back to approximately 300 BCE. To date, the oldest piece of bark paper that has been found was in the tomb of Huitzilapa in Jalisco (around 74 CE) (Ramos de la Vega et al. 1998).

At the beginning of the Spanish conquest, Spaniards prohibited paper making and ordered the destruction of every piece of paper, including the codices kept at the Real Biblioteca de Texcoco (Royal Library of Texcoco). The reason was the religious and political value of paper, which was used widely in the worship of native gods and for writing codices that preserved the historical and mythical memory as well as the domination of the ruling classes and priests. Despite this, some groups continued making paper clandestinely, particularly in areas distant from the Spanish settlements; this was the case of some communities located in the steep and inaccessible mountains of the states of Oaxaca, Puebla, and Veracruz (Galinier 1979; Lenz 1973; Starr 1900).

In the Sierra Norte de Puebla, the Ñahñu continue to produce bark paper. The Ñahñu ethnic group belongs to the Otomangean language group, one of the early complex cultures of Mesoamerica in the central Mexican highlands (Manrique 1969). During the pre–Hispanic and Spanish colonial period, they were constantly displaced from their territories, and some moved to the eastern mountainous where they settled in scattered and largely independent villages (Manrique 1969). According to Galinier (1987) and Dow (1990), when the Spaniards arrived, they had to contend with Ñahñu resistance and opposition as well as the vast geographical obstacles presented by the mountains. These conditions enabled the Ñahñu to continue the production and use of bark paper, even during the oppression of the colonial period.

Production of Bark Paper as a Handicraft

The production of bark paper as a handicraft began through the fusion of two cultural traditions: The bark paper from the Ñahñu of San Pablito in the State of Puebla and the traditional painting styles of the Nahuas who settled along the Balsas River catchment in the State of Guerrero. Nationwide, San Pablito is the only town where bark paper for the handicraft market is produced, while the hand–painted decoration of the bark paper has extended to eight towns located alongside the river Balsas in Guerrero (López 2003).

Until four decades ago, the Ñahñu produced bark paper only for cleansing ceremonies and rituals asking the gods for good crop yields, cures, and protection. For these ceremonies, healers make cutout bark paper figures from different barks, their meaning and use depending on the color of the bark. These paper figures have a prominent place in local rituals: They may represent the seeds of fruits or grains; the God of the Mountain or the God of the Earth; mythological animals or special characters such as the Sentinel and the Vigilant; and can also represent men, women, and children (Galinier 1979). The sacred use of bark paper figures continues to present day and is mainly used in curing ceremonies since agricultural activities have diminished in the face of handicraft manufacture and labor migration (López 2003).

Towards the end of the 1960s, the owners of an art gallery located in Mexico City (Max Kelow, Felipe Ehrenberg, and Manuel Felguerez), who were already working with Nahua potters, gave them plain bark paper sheets on which to paint the traditional patterns used to decorate their ceramic pieces. This initiative proved to be successful. The bark paper decorated with colorful and eye–catching patterns attracted the attention of urban people, mainly tourists (Marta Turok, pers. comm.) (Fig. 1). Initially, all the bark paper produced by the Ñahñu was sold to Nahua painters; however, over time the Ñahñu have diversified their designs and have opened their own marketing channels. For the first few years, they only produced 40×60 cm sheets, but today they produce a wide range of paper, including sheets measuring up to 1×2 m that are used to cover walls or furniture, lamp shades, envelopes, letter paper, booklets, book separators, boxes, and invitation cards.

Fig. 1. Sample of a bark paper handicraft product produced by the Ñahñu and painted by Nahua artisans.

Both the bark paper products of the Ñahñu and the pieces decorated by the Nahuas are sold commercially in stores, marketplaces, and bazaars located in the main cities and touristic sites of Mexico, and abroad. The eye–catching colors, multiple uses and textures, as well as their transportability, makes them one of the handicrafts most purchased by tourists (López 2003).

Species Employed in Bark Paper Making

From historical documents such as the chronicles written by Pedro Mártir de Anglería (1944), Fray Diego de Landa (1982), and Fray Toribio de Benavente (1984), it is known that the raw materials for paper making during the pre–Hispanic period included the skins of some animals (such as deer and rabbit), maguey fibers, some palms, as well as the bark of certain trees. One of the first Spanish explorers to travel across "New Spain" was Francisco Hernández, sent by the Spanish Crown to register the use of every single plant in the territory. In 1570, Hernández observed the production of bark and described the use of different fig trees (*Ficus* spp.) as the primary source of raw material for bark paper making (Hernández 1942).

Ever since bark paper began circulating as a handicraft, the Moraceae/*Ficus* trees traditionally used for bark paper making and only found in San Pablito and surrounding areas have been unable to satisfy the growing commercial demand (López 2003; Peters et al. 1987). Consequently, new species found over a wider area within the Sierra Norte de Puebla have become the main source of bark over the last 30 years (López 2003).

In total, 13 tropical tree species belonging to four families and found from cloud forest to low and medium semi–evergreen forest types of the Sierra Norte de Puebla have been used by the Ñahñu for bark paper production (López 2003). Of all the species recorded, *Trema micrantha* (L.) Blume, first identified by Peters et al. (1987), is the most used since the 1980s. *T. micrantha* is a pioneer tree of rapid growth that is widely distributed throughout the temperate and sub-tropical areas of Mexico (Vázquez-Yanes 1998). It is an abundant species, common in young secondary forests, abandoned fields, and shaded coffee plantations of the Sierra Norte de Puebla. Due to its physiological characteristics, this is the only species from the total used for bark paper that can be harvested all year round.

Within the Sierra Norte de Puebla, the common name given to this tree is *jonote* and people from different villages along the Sierra Norte de Puebla who harvest its bark are known as *jonoteros*. It has been nearly 30 years since *jonoteros* became involved in this activity and they are now the main suppliers of the bark used by artisans in San Pablito (López 2003; Peters et al. 1987).

Pre-Hispanic and Current Bark Paper Production Technology

In one of his chronicles, Fray Bernardino de Sahagún (1969) produced some of the most detailed descriptions about Mesoamerican beliefs, culture, and history, and recorded that pre–Hispanic paper making techniques included caring for the trees. Bark was extracted only from the thickest branches to avoid damaging the main trunk. The bark was softened by immersing it in a river overnight; afterwards, the inner bark was separated from the outer bark and a portion of this inner fiber was pounded to form a sheet of paper.

At present, bark is extracted from branches and trunks of new species (mainly *Trema micrantha*) but only from branches when extracted from traditional species (mainly *Ficus* spp.). Strips of the inner bark are separated from the outer bark and are left to dry in the sun to preserve them until use. To soften the fibers, artisans boil them in large metal saucepans with water, lime, and ash; although, in order to speed up the process, they frequently replace lime and ash with caustic soda, reducing the boiling time by almost a half. After the fibers have been softened, artisans rinse and separate them into thin strands. Next, the fiber strands are placed in a grid formation over a wooden board and are beaten with a stone until they blend together (Fig. 2). The boards with the moist bark sheets are placed outside in the sun and left to dry. Afterwards, the paper can be lifted off the board.

According to Vander Meeren (1999, 1990) and evidence found in the present study, paper makers pound the bark to take advantage of the soft traits of the fiber cell walls and the natural adhesive properties of parenchyma and sieve elements such as starch grains, water soluble sugars, pectins, and latex, all of which help to bring the fibers together. Regarding the boiling

Fig. 2. Bark paper manufacturing. Stone beaters have been used since the pre–Hispanic period to pound bark fibers and form the bark sheets.

process used to soften the fibers, Fray Bernardino de Sahagún (1969) did not mention the requirement for this practice. As Vander Meeren (1999, 1990) notes, this underscores the differences between traditional and current production techniques.

The focus of this study was to recognize the anatomical and histochemical characteristics of the bark fibers of all the species used since the pre–Hispanic period and to recognize the possible relationship that exists between bark fiber characteristics and the changes that have occurred over the last 30 years in bark paper production. Four species that were tested by the Ñahñu artisans but rejected as unsuitable for paper making were also integrated into the anatomical and histochemical study. This was carried out in order to understand the common characteristics of the species in use, in contrast to the other species that did not present the required characteristics.

The anatomical and histochemical observations focused mainly on fiber length and lignin content. In the modern paper industry, the mechanical resistance and final quality of paper depends on the length of the fibers, with more resistant paper resulting from the use of longer fibers. The efficiency in the unification or blending of fibers depends on the amount and quality of lignin retained at the fiber surface.

Methods

Ethnobotanical Study

To identify the species employed for paper making and to study the anatomical and histochemical characteristics of their bark, we carried out an ethnobotanical survey (Alexiades 1996; Cunningham 2001) incorporating local knowledge and the collection of botanical and bark samples followed by laboratory observations. Botanical samples were identified and placed in the herbarium of the Instituto de Ecología A.C., in Xalapa, Veracruz.

Based on preliminary studies (López 2003; Peters et al. 1987) and information found in historic documents, an updated list of the species used since the pre–Hispanic period for bark paper was generated. The list identifies the two main types of species: Traditional and newly adopted in the last 30 years as well as four species tested by Ñahñu artisans that proved to be unsuitable for paper making.

This list was used during open interviews with Ñahñu elder artisans and healers, the keepers of the knowledge about the different plants used for bark paper making in San Pablito. Interviews included questions concerning the type and number of plants recognized by the person interviewed, local plant names, bark extraction periods, and the main characteristics of the fibers and/or resulting papers, particularly in terms of flexibility of the final product. Bark harvesters, or *jonoteros*, and owners of the shaded coffee plantations, where most of the bark is now extracted, were also interviewed in order to determine the harvest period of the species they extract. Direct observation of production techniques was conducted in the houses of four artisans.

Bark sampling was carried out during the collection of botanical specimens, together with Ñahñu healers and elder artisans for the traditional species, and with bark extractors for the new species. This ensured that the trees sampled had the physical characteristics and age required for bark paper making. All bark samples were obtained at breast height and were collected in the spring, which corresponds to the flowering season and also the time during which most of the bark is obtained from the species identified. Bark samples consisted of pieces approximately 2 cm wide, including the inner and outer bark, which were fixed in FAA (ethanol–formol–acetic acid) and water.

Anatomical and Histochemical Observations

For anatomical and histochemical observations, cross, tangential, and radial sections were stained as described by Krishnamurty (1988) using Toluidine blue O to stain lignin (turquoise), cellulose (blue), and pectins (lilac), and a Zinc–Chloride–Iodine solution to stain water soluble polysaccharides and starch grains (blue gray) and lignin (yellow). Fibers were separated using Jeffrey's reagent, and permanent slides were prepared following Johansen (1940).

Bark paper is made from the inner bark called the secondary phloem. According to Roth and Cova (1969), the secondary phloem comprises fibers and other types of cells whose walls show different degrees of lignification. Lignin is a natural polymer, which settles between cellulose chains and reinforces cell walls, mainly those of wood and bark fibers. The quantity of lignin present in cell walls depends on the plant species. Lignin content was semi–quantitatively assessed based on reactivity to specific dyes shown in a color intensity response, in the following categories: – no evidence, + slight lignification, ++ moderate lignification, and +++ strong lignification (Quintanar-Isaías et al. 1997). The length, diameter, and wall thickness of fiber cells were measured and a Stata (2001) statistic package was used to perform Kruskal–Wallis tests and obtain unvaried statistics and standard deviations (SD) at $p<0.05$.

Results

Ethnobotanical, Anatomical, and Histochemical Observations

Table 1 contains the total number of species registered as sources of bark, both the traditional species used since the pre–Hispanic period and the new species introduced 30 years ago in response to increasing handicraft demand. This table integrates information recorded in historical sources with the results of an ethnobotanical survey carried out with the Ñahñu healers and elder artisans responsible for conserving traditional knowledge (López 2003; Rebolledo-Morales 2012).

Table 2 records information regarding fiber sizes and lignin content for each species. The first group of species, corresponding to the traditional species type (*Ficus* spp. and *Morus celtidifolia*), shows fibers distributed within the soft tissue and demonstrates no evidence of lignification. The second group, comprising the new species used over the last 30 years, shows a difference in lignin content. In this case, the fibers from *Trema micrantha*, *Ulmus mexicana*, and *Brosimum alicastrum* show some evidence of lignification. However, it is interesting to note that in the view of the artisans, paper made from *T. micrantha* is of much better quality than that obtained from the other two species (Table 1). In *Sapium oligoneuron* and *Sapium aucuparium*, the structure is basically cellulosic with abundant starch grains, and the cell walls of these species are stratified showing moderate lignification. Fibers of *Urera caracasana* and *Myriocarpa cordifolia* are strongly lignified with cells containing raphides and starch grains, and abundant laticiferous channels in the case of *U. caracasana*. Among the four non–suitable species, the two *Heliocarpus* species, containing abundant parenchyma and mucilaginous channels, show strong evidence of lignification. *Triumfetta* sp. and *Trichospermum mexicanum* are also unsuitable; *Triumfetta* presents a cellulosic structure with druses and polyphenol, while *T. mexicanum* has a structure with scarce starch and gum content. The cell walls are strongly lignified in both species.

In relation to fiber sizes, the nomenclature proposed by the International Association of Wood Anatomy Committee (1939) was adopted and the measurements were analyzed according to statistical procedures. The results show that the bark of *Ficus* spp. contains long and very long fibers (3,000–4,500 μm) of thin diameters (13–20 μm) and with thin cell walls, while species introduced in the last 30 years differ substantially in fiber length (from 1,500 to 5,296 μm). The unsuitable species feature medium to short fibers (<3,000 μm) relative to those of *Ficus* spp. However, the traditional and new species show similar values in terms of fiber diameter and cell wall thickness.

Anatomical and histochemical observations suggest that the fiber characteristic that dictates the selection of species used in pre–Hispanic paper making is lack of lignification of cell walls rather than the fiber length and diameter (Tables 1 and 2, Fig. 3). This is especially clear in the case of *Ficus* fibers, which show no evidence of lignin deposits in the cell walls but are of similar length to the strong lignified fibers of *U. caracasana* and *M. cordifolia.* Vander Meeren (1990) reports that bark fibers of *Ficus* and *Morus* used in pre–Hispanic period were apparently without lignin, in contrast to those of *T. micrantha* and *U. caracasana.* This is consistent with the results of the present study, which show no evidence of lignification of the soft tissue and cell walls of *Ficus* spp. and *M. celtidifolia.*

The results suggest that the secondary phloem of *Morus celtidifolia* or any *Ficus* spp. may be softer, and therefore more manageable for paper making than other species. They also present abundant starch grains and pectin that contribute to the adhesion of all cell types when pounding the fibers to form paper sheets. In addition to the above, artisans and healers who have tested the resistance and flexibility of each paper report that the paper made from Moraceae fibers have proven to be the best quality. Its flexibility facilitates the

TABLE 1. SCIENTIFIC AND COMMON NAMES OF TRADITIONAL, NEW, AND UNSUITABLE SPECIES AND A DESCRIPTION OF THE FIBER AND/OR PAPER CHARACTERISTICS ACCORDING TO ÑAHÑU ARTISANS AND HEALERS (BASED ON AND UPDATED FROM LÓPEZ 2003).

	Species/Family	Local name*	Fiber and/or paper characteristics
Traditional species	*Ficus pertusa* L. Moraceae	Xalama limon negro Amate	Very sticky fibers Flexible paper (does not break easily)
	Ficus padifolia H.B.K. Moraceae	Xalama limon blanco Amate	Flexible paper (does not break easily)
	Ficus cotinifolia H.B.K. Moraceae	Xalama hoja gruesa Amate	Flexible paper (does not break easily)
	Ficus goldmanii Standl. Moraceae	Xalama hoja pahua Amate	Resembles the *Morus* species
	Morus celtidifolia H.B.K. Moraceae	Tzhazucua (ñ) Mora	Very soft fibers The most resistant and flexible paper; folds without breaking
New species (last 30 years)	*Trema micrantha* (L.) Blume Ulmaceae	Coni (ñ) Jonote, chaca	Moderately resistant and flexible paper
	Ulmus mexicana (Liebm.) Planch. Ulmaceae	Sxifi-tzha (ñ) Tortocal, cueruda	Little flexibility; thick sheets break easily
	Brosimum alicastrum Swartz. Moraceae	Uini coni (ñ) Ojite	Very brittle paper
	Sapium oligoneuron K. Schum Euphorbiaceae	Coni pathi (ñ) Palo brujo	Very brittle paper
	Sapium aucuparium Jacq. Euphorbiaceae	Coni pathi (ñ) Palo brujo	Very brittle paper
	Urera caracasana (Jacq.) Griseb. Urticaceae	Tzhanna (ñ) Chichicaxtle	Resistance similar to that of *Morus*
	Myriocarpa cordifolia Liebm. Urticaceae	Husna (ñ) Hortiga	Flexible paper (does not break easily)
Unsuitable	*Heliocarpus donnell-smithii* Rose Tilaceae	Jonote baboso	Unsuitable
	Heliocarpus appendiculatus Turcz. Tilaceae	Jonote baboso	Unsuitable
	Triumfetta sp. Tiliaceae	Jonote gallina	Unsuitable
	Trichospermum mexicanum (DC) Baill. Tiliaceae	Jonote ratón	Unsuitable

*(ñ) Ñahñu name

TABLE 2. FIBER DIMENSIONS (LENGTH, DIAMETER, AND CELL WALL THICKNESS) AND LIGNIN CONTENT OF FIBERS AND OTHER CELLS.

	Species	Fiber length (μm)	Fiber diameter (μm)	Cell wall thickness (μm)	Lignin content of fibers and other cells*
Traditional species	*Ficus pertusa*	3016 (±920) (long)	16±2 (thin)	3±.5 (very thin)	–
	Ficus padifolia	4143 (±800) (very long)	16±2 (thin)	5±.5 (thin)	–
	Ficus cotinifolia	2962 (±588) (medium)	18±2 (thin)	5±.5 (thin)	–
	Ficus goldmanii	4416 (±788) (very long)	18±2 (thin)	6±.5 (thick)	–
	Morus celtidifolia	1306 (±347) (short)	17±2 (thin)	4±.5 (very thin)	–
New species (last 30 years)	*Trema micrantha*	1501 (±480) (short)	20±2 (thin)	4±.5 (very thin)	+
	Ulmus mexicana	1659 (±487) (short)	13±2 (thin)	3±.5 (very thin)	+
	Brosimum alicastrum	1603 (±427) (short)	15±2 (thin)	3±.5 (very thin)	+
	Sapium oligoneuron	3007 (±705) (long)	26±2 (medium)	9±.5 (thick)	++
	Sapium aucuparium	5296 (±836) (very long)	24±2 (medium)	8±.5 (thick)	++
	Urera caracasana	4176 (±883) (very long)	16±2 (thin)	6±.5 (thick)	+++
	Myriocarpa cordifolia	4726 (±911) (very long)	19±2 (thin)	4±.5 (very thin)	+++
Unsuitable	*Heliocarpus donnell–smithii*	2407 (±482) (medium)	16±2 (thin)	6±.5 (thick)	+++
	Heliocarpus appendiculatus	1751(±381) (short)	13±2 (thin)	5±.5 (thin)	+++
	Triumfetta sp.	1436 (±329) (short)	18±2 (thin)	7±.5 (thick)	+++
	Trichospermum mexicanum	2231 (±641) (medium)	22±2 (thin)	5±.5 (thin)	+++

*Semi–quantitative assessment of lignin content: – no evidence, + slight lignification, ++ moderate lignification, +++ strong lignification.

cutout of traditional figures and the production of diverse bark paper handicrafts (López 2003), and this might be the reason why bark paper in pre–Hispanic period could be used for distinct purposes in many different conditions, such as rolled, crumpled, and folded.

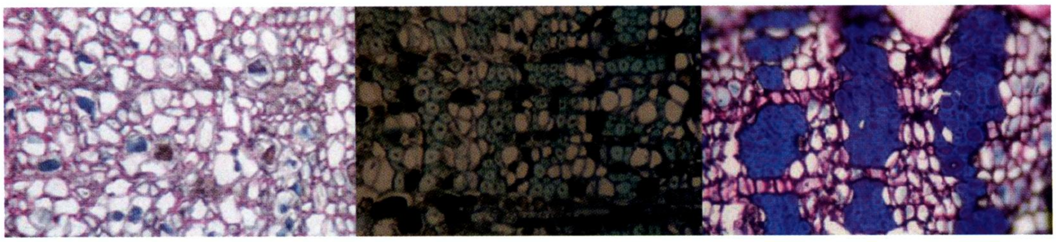

Fig. 3. Cross sections of secondary phloem of *Ficus padifolia* (left), *Trema micrantha* (center), and *Heliocarpus donnell–smithii* (right).

Changes in Production Technology and Their Impact on Bark Paper Quality

Although pre–Hispanic paper production dictated that bark fibers were immersed in water and pounded with stone beaters using techniques that deformed the spatial distribution of the cell group (formed by different types of parenchyma cells), the cell walls were preserved. In the pre–Hispanic and colonial codices, the tangential alignment of *Ficus* and *Morus* fibers produced by pounding them to obtain the paper sheets is visible on the surface (Vander Meeren 1999). Pounding the fibers with stone beaters allowed the reservoir and conducting cells to fit along the grain adding structural support to the paper sheets, so that thickness, shape, and texture is unique to each sheet when the fibers have not been boiled. However, in those species introduced over the last 30 years, the packaging of parenchyma cells, conducting cells and fibers is very different, such that deformation of the tissue by boiling and crushing produces a distinct shape and texture, especially when the paper is made with barks other than those of Moraceae family. As Vander Meeren (1999, 1990) and Quintanar-Isaías et al. (2004) point out, one of the main differences between pre–Hispanic and modern bark paper is the visible fiber arrangement of the end product.

Current production involves processes of aggressive boiling that dissolve the excess of lignin, as well as the remainder of the cell components and natural glues that maintain the cell structural integrity. Adoption of these procedures, which can be linked to the partial elimination of starch grains, pectin, and mucilage, result in cell wall fragmentation, producing a paper that is more fragile and prone to mechanical or biological deterioration.

Conclusions

Based on anatomical and histochemical observations of the fibers as well as on historic documentation of bark paper production, we were able to identify the key fiber characteristics that facilitate their use in paper making regardless of genus and family. We conclude that pre–Hispanic production techniques were adapted to and suitable for barks with a soft cell structure from trees of the Moraceae tree species. With the adoption of new species, production techniques were modified to employ bark of harder cell structure from diverse species with greater lignin content. This study therefore elucidates the close relationship between production techniques and the fiber characteristics of the species used. It is also consistent with the results of a previous study carried out by Peters et al. (1987), whose observations using a scanning electron microscope showed that fibers of *T. micrantha* were thicker and wider than those of *Morus celtidifolia* and *Ficus tecolutensis*, and therefore required a longer time for boiling.

Our results also indicate that although the adoption of new species has solved the problem of limitations in the supply of raw materials, it has had effects on the quality of the final product. The impact also extends to the welfare of the artisans and the environment due to the use of aggressive production techniques. This situation is becoming common within artisan communities in Mexico; they are under pressure to produce more craft pieces in a shorter time while facing problems with the supply of raw materials due to overharvesting and competition with other users as well as changes in land use (Cruz et al. 2009).

To conclude, we suggest the need to assess new bark paper making techniques according to current ecological, cultural, and economic contexts. We also suggest that it is not only the aesthetic aspect of this traditional paper making process that should be commercially appreciated, but also the value of the practice as part of an intangible cultural heritage of the Ñahñus of San Pablito involving local and traditional knowledge of plants and constant innovation in designs and paper types. These are aspects that should be more realistically reflected in the commercial value of the various bark paper handicraft products made by the Ñahñus of San Pablito.

Acknowledgments

The information was obtained over the last ten years and updated with funds from Universidad Veracruzana, Universidad Autónoma Metropolitana–Iztapalapa, Fondo Nacional para el Fomento de las Artesanías, and Instituto de Artesanías e Industrias Populares de Puebla during 2009 and 2010. The authors would like to give thanks to José Luis Contreras from the herbarium of the University of Puebla for discussing the ecological aspects of the trees used in paper making; to Leticia Escárcega, teacher at the San Pablito High School, for assisting during fieldwork; to Mariana Velázquez Núñez for her collaboration in the laboratory. Special thanks also go to Peter Hietz and Marta Turok for their review of this manuscript.

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