

# Comprehensive Methodology for the Identification of Liberian Flax and Hemp Fibers in the Supports of New Spanish Paintings

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Translated by Richard Addison

## SUMMARY

This RESEARCH ARTICLE presents the results from the application of a complementary analysis methodology for the accurate identification of Liberian fibers, specifically linen and hemp, used in the textile supports of easel paintings. The research focuses on six paintings attributed to various representative authors of New Spanish recognized plastic arts over a wide-ranging time frame spanning from the last third of the XVI century–until the end of the XVII century. During this paper we discuss the continuance detected in the process of intentional selection of canvases used for viceregal paintings in Colonial Mexico.

## KEY WORDS

liberian fibers, flax, linen, hemp, New Spanish painting, optical microscopy, modified Herzog test, Schweitzer's reagent

## PRESENTATION

In the vast array of aspects that make up the analysis of techniques and materials used in the creation of an easel painting, knowledge on the nature of its supports is fundamental. In this RESEARCH ARTICLE we present the results from the application of an integral and complementary methodology for the identification of the organic fibers that constitute the painting's supports, in six paintings produced in workshops established in the capital of the viceroyalty of New Spain between 1610 and 1683 (Figure 1).

Code	Description	Name and author
NE235 M1	canvas	Baltasar de Echave Orio (attributed), <i>El Pentecostés (The Pentecost)</i> , ca. 1610, oil on canvas attached to board, 259.5 x 174.5 cm; Gallery of the Temple of San Felipe Neri, La Profesa, Mexico City.
NE229C M5	canvas	Sebastián de Arteaga, <i>Cristo en la Cruz (Christ on the Cross)</i> , ca. 1643, oil on canvas, 245 x 190 cm; collection: Museo Nacional de Arte, Mexico City.
NE229B M5	canvas	Sebastián de Arteaga, <i>Los desposorios de la Virgen (The Betrothal of the Virgin)</i> , ca. 1645, oil on canvas, 223 x 171 cm; collection: Museo Nacional de Arte, Mexico City.
NE245C M6	canvas	Sebastián de Arteaga (attributed), <i>El levantamiento de la cruz (The Raising of the Cross)</i> , n. d., oil on canvas, 270 x 202.5 cm; collection: Episcopal Gallery of the Cathedral of Durango, Mexico.
NE233 M4	canvas	Baltasar de Echave Rioja, <i>El lavatorio de pies (Foot Washing)</i> , 1681, oil on canvas, 195 x 245 cm; Temple of Santo Domingo de Guzmán, Izúcar de Matamoros, Puebla, Mexico.
NE232 M4	canvas	Cristóbal de Villalpando, <i>El lavatorio de pies (Foot Washing)</i> , ca. 1683, oil on canvas, 196 x 252 cm; collection: Sacristy of the Temple of Nuestra Señora del Carmen, Puebla, Mexico.
NE245C M7	sewing	Sebastián de Arteaga (attributed), <i>El levantamiento de la cruz (The Raising of the Cross)</i> , ca. 1640, oil on canvas, 270 x 202.5 cm; collection: Episcopal Gallery of the Cathedral of Durango, Mexico.
NE233 M5	sewing	Baltasar de Echave Rioja, <i>El lavatorio de pies</i> , 1681, óleo sobre tela, 195 x 245 cm, Templo de Santo Domingo de Guzmán, Izúcar de Matamoros, Puebla, Mexico
NE232 M5	sewing	Cristóbal de Villalpando, <i>El lavatorio de pies (Foot Washing)</i> , ca. 1683, oil on canvas, 196 x 252 cm; collection Sacristy of the Temple of Nuestra Señora del Carmen, Puebla, Mexico.

FIGURE 1. List of analyzed samples (Table: Ana Laura Avelar-Carmona, 2021).

We distinguish between the use of linen and hemp in canvases and stitching since these materials were the most commonly used in the manufacture of paintings on canvas in the viceregal period, and we emphasize the physical properties of these fibers to contribute new data enabling for a better understanding of the processes used by local artists when selecting raw materials, con-

fronting the material identification of specific cases with the scarce documentary data recorded on the artistic technology used in Novo-Hispanic paintings.

### **CONTEXT: THE USE OF LIBERIAN FIBERS IN NOVO-HISPANIC PAINTING**

In the Mexican context, the use of fabrics for the manufacture of cultural artifacts dates to pre-Columbian cultures where early pieces were made from cotton fabrics usually boasting geometric designs that hint at a well-established textile culture from as least as early as 1200 BC. Although the country's climatic conditions at the time had been unfavorable for the preservation of organic materials such as the Liberian fibers we reference here, we know from historical sources that there was a wide diversity of textiles present in the culture of Mesoamerican indigenous peoples (Ramírez, 2014, pp. 68-69).

After the Conquest, the range of textile fibers used for the production of decorative objects diversified due to transatlantic trade and the increasing demand for such goods from foreign populations. Archival sources reveal complete lists of the materials used on a daily basis in an art workshop. Such is the case of the payment account dated January 18<sup>th</sup>, 1585 by means of which Rodrigo Dávila, maestro mayor of the Old Cathedral of Mexico, gave the painter Andrés de Concha (active in New Spain between 1568 and 1611) 27 pesos and 6 tomines for the materials he used in the work for the main altarpiece: “ten rods of ruan [sic] to canvas [sic] many pieces and trimmings of the tabernacle”<sup>1</sup> and “six rods of angeo [sic] for the finishes of the said altarpiece” (Archivo General de la Nación [AGN], Historia 112, in Zárate, 2020, p. 518). Both types of fabrics, despite slight differences in cost, were coarse weaves of simple bindings, made with linen or hemp threads; the name of the former derives from the production region in Europe (Bruquetas, 2002, p. 234).

Between 1979 and 2009, Rita Sumano's research systematized and interpreted the information concerning the supports of the Novo-Hispanic paintings restored by the Escuela Nacional de Conservación, Restauración y Museografía (ENCRYM, National School of Conservation, Restoration and Exhibition Design), using statistical methods, which revealed that the fabrics used by the painters' guild were, for the most part, low quality linen fabrics and, in many cases, were re-purposed (Sumano, 2010, pp. 4-5).

<sup>1</sup> Editorial translation. This quote and all quotes and description of terms where the original text is in Spanish are also editorial translations.

JULIO-DICIEMBRE 2022  
 JULY-DECEMBER 2022

Examples, such as the fabric that reinforces the pine board in *El Pentecostés* (*The Pentecost*), attributed to Baltasar de Echave Orio (Guipúzcoa, 1558-New Spain, 1619), provide compelling evidence of the need to obtain the maximum benefit from every scrap of coarse fabric available to a workshop in New Spain during this period. Here, radiography allowed us to confirm the placement of strips of fabric of different thicknesses and textures, stretched horizontally on the planks that make up the panel. It seems that the use of textile scraps to reinforce the boards was a common practice in Echave Orio's workshop, as we detected a similar reinforcement in the painting *El martirio de san Ponciano* (*The martyrdom of Saint Pontian*) from 1605 (Cuadriello et al., 2018, p. 196) (Figure 2).



FIGURE 2. *The Pentecost*, 242 x 152 cm (ca. 1610), oil on panel by Baltasar de Echave Orio. A. Work seen with visible light and B., with X-rays. The work is in the collection of the Oratorio de San Felipe Neri, in the Casa Profesa in Mexico City. (Photograph: Eumelia Hernández, 2018; X-ray: Oscar de Lucio; courtesy: A. Laboratorio de Diagnóstico de Obras de Arte [LDOA]-Instituto de Investigaciones Estéticas [IIE] and B. Instituto de Física [IF], both of Universidad Nacional Autónoma de México [UNAM]/D. R. Secretaría de Cultura and Instituto Nacional de Antropología e Historia [INAH]).



FIGURE 3. Canvas details of Cristóbal de Villalpando's *Moses and the bronze serpent, and the transfiguration of Jesus*, 856 x 427 cm (1683), oil on canvas. Work located in the collection of the Cathedral of Puebla, Puebla (Photograph: Eumelia Hernández, 2017; courtesy: D. R. Secretaría de Cultura and INAH).

Similarly, we have noticed the use of fabrics with irregularities in the monumental scene of *Moisés y la serpiente de bronce; y la transfiguración de Jesús* (*Moises and the bronze serpent, and the transfiguration of Jesus*), painted by Cristóbal de Villalpando (Mexico City, ca. 1649-1714) for the Cathedral of Puebla, where complete linen canvases from the same lot were used, sewn by the selvage “overcast stitch”, to form the central areas of the work, being complemented—at each end of the lunette—with defective fragments that have small holes distributed according to a quadrangular pattern (Arroyo, 2017, p. 7) (Figure 3).

Although most of the canvases used in viceregal paintings have been identified as belonging to the linen genre, it is important to point out that hemp fiber was also used, as well as maguey fiber, which, in the case of the pictorial works, seems to have been used to make the threads for the seams. In his opuscle on the Virgin of Guadalupe, Miguel Cabrera observed that the painting conserved in the hill of Tepeyac was made on a canvas composed of two fragments of a “crude” fabric of a very open weft, whose color and texture “is similar to the rough canvas or Bramante of Europe, that here we call Cotenze”<sup>2</sup> (Cabrera, 1756, p. 3). According to the *Diccionario de autoridades* (1726), the word bramante referred to a thick cloth made of hemp. It is not strange then that, as a result of his observations of the miraculous image, Miguel Cabrera decided to use cotenze in his two versions of the Virgin of Guadalupe paint-

<sup>2</sup> Editorial translation from the Spanish version.



ed in 1756, one for the Jesuit college in Tepotzotlán and the other for the chapel of the same denomination in the Cathedral of Puebla (Ángeles & Arroyo, 2021, p. 200).

### PHLOEM OR LIBERIAN FIBERS

Several types of fibers are extracted from plants, including soft fibers, Liberian fibers or, more precisely, phloematic fibers (known also as bast fibers). These are part of the phloem, a conductive tissue that forms the inner cortex of plants, and provides stems with their resistance to mechanical stress Azcárraga et al., 2010, p. 93). Linen fibres (*Linum usitatissimum* L.) and hemp fibers (*Cannabis sativa* L.) have similar characteristics, so there is a high risk of misidentification (Luniak, 1953, p. 129; Kvavadze et al., 2009, p. 1359), even more so if they come from textiles that have suffered a high degree of deterioration.

Taxonomic identification allows the recognition of features, traits or intrinsic properties that a specimen under study shares with one or another taxon (e.g., family, genus or species), and is regularly carried out by means of descriptions, identification keys, atlases or comparison specimens (Mishler & De Luna, 1997, p. 46; Iriondo, 2000, p. 2).

The taxonomic identification of fibers present in cultural objects has traditionally been carried out by means of qualitative techniques, read, the observation of their morphology in the optical microscope (Mirambell & Sánchez, 1986, p. 34) or combustion, staining or microchemical tests, where their behavior is observed before chemical reagents of various kinds. However, these procedures are not able to precisely differentiate between types of bast fibers (Suomela et al., 2017, p. 415).

### THEORETICAL FOUNDATIONS OF THE ANALYSES PERFORMED

#### Morphology

A plant fiber is an elongated, narrow cell, with sharp ends; it has a lumen or cavity and a wall constituted, in turn, by two walls, an external one, called primary wall, and an internal one, called secondary wall Azcárraga et al., 2010, p. 93); it can present cross-linking markings and dislocations or nodes. Such marks are striations transverse to the fiber's surface—sometimes also presenting longitudinal striations—so much so that it is possible to observe their faint or strong markings (Catling & Grayson, 2004, p. 3; Suomela

et al., 2017, p. 413). Dislocations are visible as ring-shaped marks, coarsening or knots that are generated by a change in fiber direction due to external or internal stresses (Catling & Grayson, 2004, p. 1; Suomela et al., 2017, p. 413) (Figure 4). It should be added that there is no consensus in literature on the origin and definition of these markings.




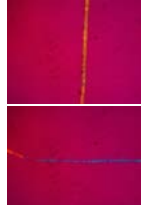
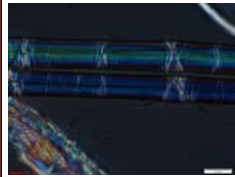


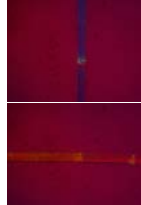
Pattern	Section type		Microchemical with Schweitzer's reagent	Modified Herzog test
	Longitudinal	Cross		
	A	B	C	D
Linen				
	Fibers with "X" X-shaped dislocations and crossover marks	Thick-walled, four-, five-, and six-sided fibers with flat surfaces with reduced lumens	Spiral fiber contraction	Color change at 90° yellow and at 0° blue
Hemp				
	Fibers with well-marked dislocations and some crossing marks	Thick-walled fibers and small lumens	Fiber shrinkage in folds	Color change at 90° yellow and at 0° blue

FIGURE 4. Photomicrographs of standard fibers: flax and hemp (Optical microscopy and microchemistry: Victor Santos Vázquez, 2020; micrographs of modified Herzog's test: Ana Laura Avelar-Carmona, 2020; courtesy: Laboratorio de Biología, Escuela Nacional de Conservación, Restauración y Museografía [ENCRYM] and Instituto Nacional de Antropología e Historia [INAH]).

**Linen**

Linen is a shrubby plant of Asian origin, specifically from south-eastern Turkey (Fu, 2005, p. 1084), whose uses date back to ancient Egypt (Elsharnouby & Ahmed, 2015, p. 3). Its filaments may be grouped in bundles or bunches with 12 to 40 useful fibers (Hall & Davies, 1968, p. 23). The average length of flax fibers is between 1.6 mm and 24.0 mm, or even up to 30 cm, while the diameter

ranges from 11.7 to 32  $\mu\text{m}$ , or even up to between 40 to 80  $\mu\text{m}$  (Campo et al., 2009, p. 18). It should be noted that these dimensions vary according to the consulted author and the processes of crimping, debarking and stranding of the yarns (Houck, 2009, pp. 3-14 and 247). The width is usually uniform along its entire length (Campo et al., 2009, p. 18; Florian et al., 1994, p. 49); its wall has cross-linking marks and X-shaped dislocations (Campo et al., 2009, p. 18; García, 2007, p. 137; Florian et al., 1994, p. 49; Hall & Davies, 1968, p. 23; Matthews, 1934, p. 750); they are generally located at a more or less fixed distances, a feature that, according to Hall & Davies (1968, p. 23), is particular to flax. Its lumen is observed as a thin, dark line (Florian et al., 1994, p. 49; Hall & Davies, 1968, p. 23; Matthews, 1934, p. 750) and discontinuous, as the cell walls thicken in sections, until the lumen closes completely, a peculiarity that, according to some authors (Campo et al., 2009, p. 19; García, 2007, p. 137), can separate flax from hemp. Transversely it shows triangular, pentagonal or hexagonal shapes, and the contours are slightly rounded, with oval lumens (Matthews, 1934, p. 750; Von Berger & Krauss, 1942, p. 27; García, 2009, p. 137) (Figure 4).

### **Hemp**

Hemp is a type of shrub native to Central Asia (Hillig, 2005, p. 170). It can reach heights of up to 2 m (García, 2007, p. 133) and the morphological characteristics of its fibers, although similar to those of flax, are less transparent and more rigid (Campo et al., 2004, p. 19; Catling & Grayson, 2004, p. 22; García, 2007, p. 134). They are 5 to 55 mm long and 10  $\mu\text{m}$  wide (Florian et al., 1990, p. 49). The lumen, regular, wide and continuous, covers half or three quarters of the wall (Campo et al., 2004, p. 19; Catling & Grayson, 2004, p. 22; García, 2007, p. 134) and diminishes towards the ends of the filaments (Campo et al., 2004, p. 19); its width is irregular, as it varies along the fiber (Florian et al., 1990, p. 49). X-shaped dislocations are frequent, pronounced and irregularly arranged along the filaments; some specimens have lines, striations or folds parallel to the fiber axis (Campo et al., 2004, p. 19; Catling & Grayson, 2004, p. 22; García, 2007, p. 134). It should be noted that sometimes they are bifurcated at each end (Catling & Grayson, 2004, p. 22; García, 2007, p. 134.), although this feature can be observed in other types of fibers, including flax (Catling & Grayson, 2004, p. 22).



**Differences between linen and hemp**

Transversely, they are polygonal, with angular edges of four, five or even six sides; in other cases, they are oval or circular. Their lumen may be observed as broad, if the walls are thin, or as narrow, if they are wide (Catling & Grayson, 2004, p. 22) (Figure 4).

The presence of calcium oxalate crystals is also a feature that is useful to differentiate between linen fibers, which do not contain them, and hemp fibers that do, showing rhombohedral, prismatic or druse shapes (Catling & Grayson, 2004, p. 23). Since their presence is subject to various factors, e.g., the age of the plants and the environmental conditions in which they grow, and whether they have been bleached or boiled (Hall & Davies, 1968, p. 25; Florian et al. 1990, p. 49; Bergfjord & Holst, 2010, pp. 1192-1193), failure to detect them in microscopic analysis is not definitive in identifying them.

The shape of cross-sections, cross-linking marks and X-shaped dislocations have been used to identify Liberian fibers; however, previous studies have shown that they are not a feature that contributes to effective differentiation between them (Lukesova & Holst, 2020, p. 9).

**TESTS FOR THE IDENTIFICATION OF LIBERIAN FIBERS****Modified Herzog test or delayed filter test ( $\lambda$ )**

This analysis is based on the fact that plant fibers are composed of a lumen or cavity and a cell wall containing various chemical compounds, mainly cellulose, and, among others, lignin and hemicellulose: for example, flax contains 71% cellulose and 2% lignin, and hemp, 75% and 4% respectively (Avérous & Le Digabel, 2006). The cell wall, in turn, is made up of a primary and a secondary wall (three different layers make up the latter), both of which are formed by microfibrils, and these in turn by more microfibrils-cellulose chains with birefringent<sup>3</sup> properties; those of the thickest layer of the secondary wall have a helical arrangement and can rotate either to the right (forming S helices) or to the left (forming Z helices), determining the microfibrillar orientation according to the letters S or Z, which is the path taken by the microfibrils with respect to the

<sup>3</sup> Birefringence: different absorption of light, diachronism, depending on whether the light vibrates along the axis of the fiber or perpendicular to it. The greatest difference between the ordinary and extraordinary refractive indices in the same material is called birefringence, which translates into a difference in speed of light beams when traveling through the interior of these materials.

observer (Strasburger et al., 2004, p. 95). Flax has a characteristic S twist, while hemp has a Z twist (Strasburger et al., 2004, p. 95; Haugan & Holst, 2013, p. 160; Suomela et al., 2017, p. 414), varying the birefringent properties of each.

This property allows the Herzog test to be applied using a microscope with a polarizer. If the type of fiber present has a Z-twist, as in the case of hemp, when parallel to the polarizer (vertical) it will turn blue, when parallel to the analyzer (horizontal), yellow, and then the opposite will be true: yellow vertically and blue horizontally, when the fiber has an S-twist, as is characteristic of flax (Figure 4. Flax D and Hemp D) (Haugan & Holst, 2013, pp. 166-167). For the accurate execution of this test, it is necessary to first set the microscope parameters using reference fibers (Suomela et al., 2018, p. 418) (Figure 4).

#### **Microchemical analysis: Schweitzer's reagent test**

This analysis technique is specific for vegetable fibers and has a destructive effect, so it is only recommended to be used as an alternative to optical microscopy, if a sufficient amount of the sample is available. It is useful to differentiate between linen and hemp fibers, mainly when the state of deterioration of the specimens prevents observing the morphological features of the fibers by means of optical microscopy.

In this test the fiber is put into contact with an ammoniacal solution of cupric hydroxide capable of dissolving the cellulose, after which a cellulose-copper complex is formed. Once the cell wall is dissolved, the resulting filament acquires feature shapes depending on the cellulose distribution. When a flax fiber is subjected to this test, the lumen contracts forming a spiral, whereas, in hemp, the internal cavity forms transverse folds (Campo et al., 2009, p. 25) (Figure 4. Flax C and Hemp A). Here we follow the methodology of T. A. Geissman (1974) applied effectively on heritage objects (Juanes et al., 2008, p. 75). Figure 4 shows the microphotographs of two standard samples analyzed by the three methods described.

#### **APPLIED METHODOLOGY**

The application of the three methods of identification of Liberian fibers was performed on bundles or individual fibers (Figure 5).

Method of sampling and preparation of samples in the laboratory
<p>Sampling was carried out in accordance with the techniques for global analysis of works of art, as well as with prior careful observation of the case study, in order to remove only the material necessary to answer the research question (Gómez, 2000, p. 183). A sample was extracted from each work under study (a thread less than 5 mm in length was sufficient) trying to damage the artistic object as little as possible, these were taken from the edges of each painting, near the area of union between fragments or around of tears. The samples were placed inside vials and in hermetically sealed plastic capsules to guarantee their safety during transport to the laboratory. Each one was labeled with a number that begins with the identity of the analyzed painting (inventory of works analyzed in the Laboratorio de Diagnóstico de Obras de Arte, del Instituto de Investigaciones Estéticas (LDOA-IEE-UNAM)).</p>
Shredding and mounting of samples
<p><i>Preliminary registration.</i></p> <p>The loose fibers were observed under the Carl Zeiss XZ10 stereoscopic microscope with tungsten light, in the LDOA-IEE-UNAM. Its physical properties were described: color, texture, firmness and conservation status. A photographic record was made with the Carl Zeiss Axiocam camera in both directions of the fibers: transverse and longitudinal.</p>
Longitudinal view
<ul style="list-style-type: none"> <li><i>Preliminary registration.</i></li> </ul> <p>Defibrillation and selection of fibers for assembly.</p> <p>This process was carried out dry with the help of a scalpel, dissection needle and under the light of the stereoscopic microscope. Depending on the state of conservation of the selected fiber, they were subjected to an aqueous cleaning process by immersion in hot water for 5 min (without agitation).</p>
<ul style="list-style-type: none"> <li><i>Permanent mounting in longitudinal section.</i></li> </ul> <p>A bundle of fibers was placed on a transparent glass slide and a second stripping was carried out under a stereoscopic microscope in order to obtain isolated filaments. Afterwards, McCrone® Cargille Meltmount mounting medium was added, a polymer that melts at 25°C and whose refractive index is 1.662.</p>
Cross view
<ul style="list-style-type: none"> <li>A bundle of fibers was adhered to the lateral face of a resin polyhedron that is embedded in a silicone mold filled with Struers' Clarocit® acrylic medium, thus ensuring the total impregnation of the specimen. Once solidified, the surface of the sample was polished with 200 mm diameter, 5 micron diamond film sandpaper, of various grits (800, 1000, 1200) to mirror point.</li> </ul>

FIGURE 5. Sampling and sample preparation method in the laboratory (Table: Victor Santos Vázquez, 2020).

### A. Optical microscopy (OM) with polarized light (PLM) and transmitted light (TL).

Morphological analysis of the fibers (length, walls, dislocations, cross-linking marks, lumen and general shape) was performed with an Olympus BX51 optical microscope equipped with an Olympus DP72 high-resolution camera. The images were processed using Olympus Cell-Sens Dimension software®. The aforementioned equipment is located in the facilities of the Chemistry-Biology Laboratory of the National Coordination for the Conservation of Cultural Heritage (CNCPC) of the National Institute of Anthropology and History (INAH).

# Intervención

JULIO-DICIEMBRE 2022  
JULY-DECEMBER 2022

Sample	Morphology			Schweitzer's	Herzog's	Identification
	Shape and borders	Dislocations	Lumen			
NE235 M1	Pentagonal Hexagonal Straight	No defined pattern	Discontinuous	Fold	90° blue 0° yellow	Hemp·
NE229C M5	Pentagonal Hexagonal Straight and rounded	No defined pattern	Continuous and reduced	Spiral	90° yellow 0° blue	Linen·
NE229B M5	Pentagonal Straight and rounded	Regular distances	Discontinuous	Inconclusive	90° yellow 0° blue	Linen·
NE245C M6	Pentagonal Straight and rounded	Regular distances	Discontinuous, reduced and wide	Spiral	90° yellow 0° blue	Linen·
NE233 M4	Pentagonal Straight	Regular distances	Discontinuous	Spiral	90° yellow 0° blue	Linen·
NE232 M4	Square, Pentagonal Straight and rounded	Regular distances	Discontinuous	Spiral	90° yellow 0° blue	Linen·
NE245C M7	Pentagonal Hexagonal Straight and rounded edges	Regular distances	Continuous and wide	Inconclusive	90° yellow 0° blue	Linen*
NE233 M5	Squares Pentagonal Hexagonal Straight and rounded	Regular distances	Discontinuous	Fold	90° blue 0° yellow	Hemp*
NE232 M5	Squares Triangular Pentagonal Straight and rounded	No defined pattern	Discontinuous	Fold	90° blue 0° yellow	Hemp*
		Properties related to flax.		· Canvas		
		Hemp related properties.		* Sewing		

FIGURE 6. Results of the three techniques used and their identification (Table: Ana Laura Avelar-Carmona, 2021).

### B. Modified Herzog test

This analysis was performed based on the Herzog test, modified by Haugan and Holst (2013, p. 166), for which an Olympus BX43 petrographic microscope with an Olympus EG20 integrated camera was used. The images were processed using AxioVision software.

To conduct this test it is necessary, to first perform a search using the 10X lens the fiber on which the analysis will be carried out. Once located, it must be positioned, with the help of the rotating plate, at an angle  $\alpha = 0^\circ$ . Subsequently, the objective is changed to 40X: the fiber is then observed with crossed polars/nicols and the analyzer is set until the fiber is brought to the extinction angle, which is achieved when it, or a fragment of it, is extinguished, i.e., it “disappears” or darkens.

Then, the compensator or  $\lambda$ -foil is inserted, at which time the background should appear magenta or pink, then focusing our attention on a small segment of the fiber. Next, we rotate the stage at an angle of  $\alpha = 90^\circ$  and note the color change of the same section observed before  $\alpha = 0^\circ$ .

### C. Preparation of Schweitzer's reagent

The reagent for identification is prepared by dissolving copper sulfate in hot water. Then a 28% ammonia solution is added drop by drop, until the pale blue color of the copper sulfate is diminished, and the solution becomes transparent. This solution is then rinsed with water, filtered, and from the precipitate two or three drops of ammonium hydroxide are added, which gives an intense dark blue color. It is important to mention that this reagent is functional when freshly prepared before crystallization; after that occurs, it loses its effectiveness. Once the drop of the reagent is applied to the fiber, the shrinkage of the material is observed under optical microscopy (OM) and using polarized light (PLM), the images are captured.

### Discussion of results

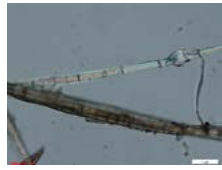
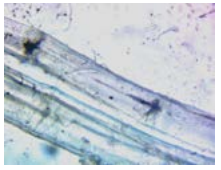
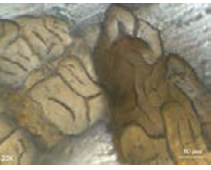
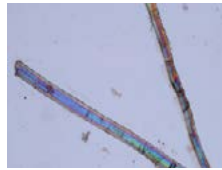

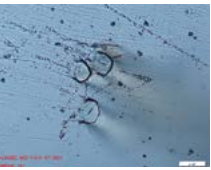


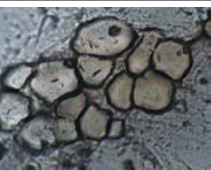
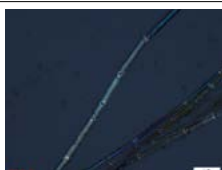
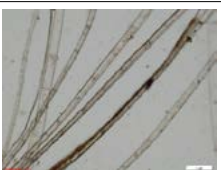




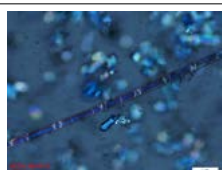


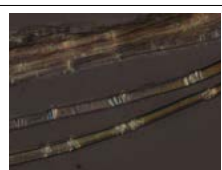
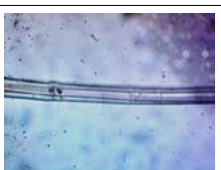

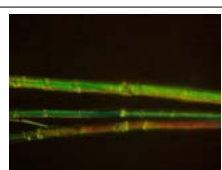
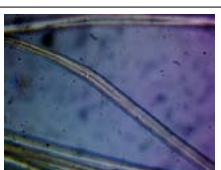
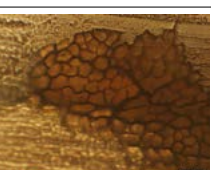


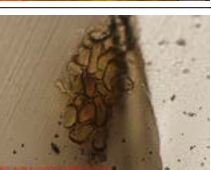
Figure 6 summarizes the results of the three complementary techniques used in this research for the precise identification of Liberian fibers. The yellow color highlights the properties assigned to flax according to the literature consulted, and in green, those related to hemp. The above shows that most of the analyzed fibers observed characteristics—especially—morphological characteristics of both flax and hemp, so that the correct interpretation of the constituent material of the analyzed paints was conducted by comparing the



Intervención

JULIO-DICIEMBRE 2022  
 JULY-DECEMBER 2022

FIGURE 7.  
 Morphology  
 (Micrographs: Victor  
 Santos Vázquez,  
 2020; courtesy:  
 Laboratorio de  
 Química, Research  
 area of the CNCPC-  
 INAH).

Painting	Longitudinal section		Cross section
	A	B	C
NE235 M1			
NE229C M5			
NE229B M5			
NE245C M6			
NE233 M4			
NE232 M4			
NE245CM7			
NE233 M5			
NE232 M5			

results obtained from both the modified Herzog test and with the chemical reaction of Schweitzer.

Figures 7 and 8 show the evidence of the results obtained in each of the tests performed on the samples of the fibers of the support of the New Spanish paintings.

All the samples of Liberian fibers analyzed presented dislocations or X-shaped nodes; therefore, this morphological feature does not allow a precise identification of the material used as support in the paintings (Figure 7. A and B).

Of the nine samples studied, only three: NE229BM5, NE232M4 and NE233M4, presented in their entirety morphological characteristics reported in the known properties of flax, that is, equidistantly distributed dislocations and reduced and discontinuous lumen that closes in sections (Campo et al., 2009: 18; García, 2007, p. 137; Florian et al., 1994, p. 49; Hall & Davies, 1968, p. 23; Matthews, 1934, p. 750). Additionally, they came up positive for flax in the modified Herzog and microchemical tests.

Samples NE235M1 and NE232M5 presented dislocations without any specific distribution, which is indicative of hemp fibers (Campo et al., 2004, p. 19; Catling & Grayson, 2004, p. 22; García, 2007, p. 134); however, their lumen went from continuous to discontinuous and reduced, as it is supposed to occur with flax fibers. Finally, these samples tested positive for hemp with Schweitzer's reagent and the modified Herzog's test, highlighting the importance of using a combined methodology for their correct identification.

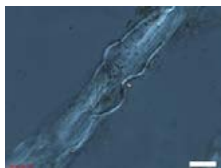

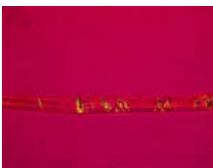


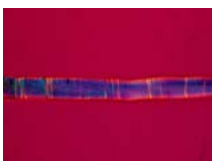


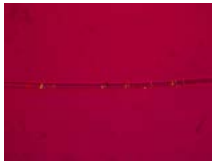




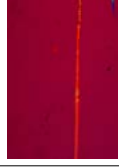
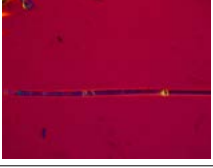

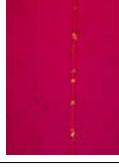





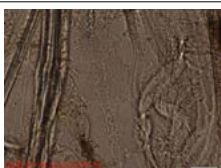

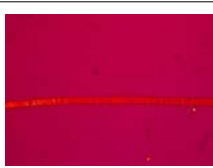
In fact, samples NE229CM5, NE233M5, NE235M1, NE232M5, NE245CM6 and NE245CM7, i.e., more than half of the fibers under study, were representative examples of the problems faced by a researcher during the process of analyzing heritage materials. Under the optical microscope they presented morphological elements corresponding to flax, hemp or even both fibers. Only by applying the complementary tests of Herzog and microchemistry with Schweitzer's reagent were results obtained that helped to make a correct identification. For example, sample NE245CM7 presented X-shaped dislocations at regular distances, as would flax, and its lumen was wide and continuous, a characteristic associated with hemp. The microchemical test was inconclusive, as the fiber contracted in an unidentified form, and only the Herzog test was positive for flax.

The shape of the fibers in cross section did not present an important value for their identification, since both hemp and flax fibers observed triangular, square, pentagonal, hexagonal, straight and rounded edges (Figure 7. C), which corresponds with Lukesova

# Intervención

JULIO-DICIEMBRE 2022  
 JULY-DECEMBER 2022

FIGURE 8. Results of microchemical tests and the Herzog test (Optical microscopy and microchemistry: Victor Santos Vázquez, 2020; micrographs of modified Herzog's test: Ana Laura Avelar-Carmona, 2020; courtesy: Laboratorio de Biología, Escuela Nacional de Conservación, Restauración y Museografía [ENCRYM], Instituto Nacional de Antropología e Historia [INAH]).

Sample	Microchemistry Schweitzer's reagent	Herzog test	
	A	B	
NE235M1			
NE229C M5			
NE229B M5			
NE245C M6			
NE233 M4			
NE232 M4			
NE245C M7			
NE233 M5			
NE232 M5			

& Holst (2020, p. 9), who also found no significant differences between the cross-sections of the two organic materials.

By carrying out a complementary analysis methodology with microchemistry and the Herzog test, it was possible to establish a different identification of the resulting morphology. Only the combination of analyses can guarantee reliable results, especially considering that in ancient paintings both the state of conservation of the material and even the process of plant growth, extraction and the complete processing of textile production modify the physical characteristics of a fiber.

In the identification methodology we used, we considered it a necessary criterion that at least two analyses should match, and to validate the results further it was necessary to apply the tests to more than one fiber. Regarding the test performed with Schweitzer's reagent, it rarely matched with the other analyses, due to the amount of fiber used, the speed of the reaction and the degree of subjectivity involved in the interpretation of the resulting contractions. In all the cases analyzed, the Herzog test also linked



FIGURE 9. Sebastián de Arteaga, *Christ on the Cross*, 245 x 190 cm (ca. 1645), oil on canvas. Museo Nacional de Arte. D. R. Secretaría de Cultura. INBAL, Mexico (Photographs: Eumelia Hernández, 2019; courtesy: D. R. Secretaría de Cultura and Instituto Nacional de Bellas Artes y Literatura [INBAL]).



with the other techniques used and was considered decisive in achieving the identifications. Therefore, its effectiveness in differentiating between flax and hemp was confirmed, even considering the thickness and deformations that the fibers may undergo, either by deterioration, by the growth of the fibers themselves or due to the textile manufacturing process.

## CONCLUSIONS

This research has shown that, in order to carry out the taxonomic identification of Liberian hemp and flax fibers, it is necessary, as already suggested by other authors, to apply a complementary analysis methodology, especially if morphological analysis is included, since both fibers present similar characteristics, even the X-shaped dislocations (Hall & Davies, 1968, p. 23), and their distribution along the filaments and the shape of the lumen (Florian et al., 1994, p. 49; Hall & Davies, 1968, p. 23; Matthews, 1931, p. 750; García, 2009, p. 137; Campo et al., 2009, p. 19). This work demonstrates that based on morphology alone there is a high possibility of misidentification.

From the analysis of six New Spanish paintings, whose period of manufacture extends from the end of the 16<sup>th</sup> to the 17<sup>th</sup> century, we conclude that linen was the material most used in the supports. Its presence is associated with both the fabrics and the stitching (Figure 9). On the other hand, in the example of paintings on panel selected in the set, hemp is present in the reinforcements of the panels (Figure 2).

The preference to use linen as a support for the New Spanish viceregal paintings may be explained by its chemical composition, since, compared to hemp, linen has more cellulose. This confers to the vegetal cells their traction force—be it Liberian or Xilema fibers—that is to say, it makes them resistant when they are submitted to two forces that act in opposite ways. Linen fiber stands are more tolerant to fluctuations in environmental conditions.

According to García (2007, p. 137), the strength properties of flax depend on the dislocations in its fibers, since when under tension, the knots disappear, and when the fiber relaxes, they reappear. And although other bast fibers, such as hemp, also exhibit dislocations, the lignin content of each fiber type also directly influences its strength. For example, the percentage elongation at break, i.e., the increase in length of a fiber before it breaks, is higher in flax (2.7-3.2) than in hemp (1.6), which is due to the fact that the lignin content in hemp makes it a stiffer and less flexible fiber.



In sum, the physicochemical properties of the fibers could explain the preference of flax as a constituent material of the supports and linings of the New Spanish paintings.

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