A TALE OF TWO *CORCHORUS* SPECIES: JUTE AND ITS SUBSTITUTES IN COMMERCIAL GOODS

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ABSTRACT

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Natural fibers from jute (*Corchorus capsularis* and *C. olitorius*) are common in commodities such as cordage, sacking, and textiles. Currently neither chemical nor microscopic methods exist to differentiate fibers or the single-celled fiber ultimates from these two jute species. Observation of physical and optical properties in this work, including a comparison of the measured length, width, and area of ultimates, revealed no differences between the species. A novel, rapid, and simplified investigation of cellulose orientation-specific Raman bands was also insufficient to identify potential differences in the angle of cellulose microfibril orientation in the cell walls.

Jute can be identified and distinguished from other common vegetable fiber on the basis of its microscopic characteristics. Furthermore, other natural fibers and some synthetic fibers may be substituted in commercial goods advertised as jute. Twenty of 113 (18%) of commercially obtained jute goods analyzed herein contained non-jute fibers, the most frequent of which was polyester. Non-jute fibers appeared in textiles, sacking, and flooring products but not in geotextiles, cordage, or miscellaneous products advertised to contain jute. Photomicrographs of the commercial goods will be assembled into a publicly accessible database. A summary of products containing non-jute fibers from the database may also help guide fiber examiners toward a more thorough examination of the jute product types known to more frequently contain non-jute fibers, resulting in a more efficient use of time and resources. Further, this visual database can help standardize interpretation of vegetable fiber features among fiber analysts.

Dedicated with great love to my parents,
Patricia Leahy Fallon and Peter Barry Fallon,
for their selfless sacrifices, love, and encouragement.

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TABLE OF CONTENTS

LIST OF TABLES ix

LIST OF FIGURES x

KEY TO ABBREVIATIONS xii

CHAPTER 1: Introduction 1
1.1 The need for vegetable fiber identification 1
1.2 The botanical origins of jute fibers 2
1.3 Obtaining fiber from jute plants 4
1.4 The jute economy 6
1.5 Analysis of fibers in the modern crime laboratory 7
1.6 Microscopy of vegetable fibers 8
1.7 Raman microscopy of vegetable fibers 11
1.8 Aims of the present study 13

CHAPTER 2: Materials and Methods 14
2.1 Reference samples 14
2.2 Commercial samples 14
2.3 Sample preparation 15
2.4 Reference slide preparation 15
2.5 Microscopic observations 15
2.6 Measurement of ultimates 16
2.7 Qualitative test for degree of lignification 16
2.8 Macroscopic photography 16
2.9 Photomicrography 17
2.10 Raman spectroscopy of cell wall cross sections 18

CHAPTER 3: Results and Discussion Part 1: Microscopic and spectroscopic attempts to differentiate ultimates of *C. capsularis* and *C. olitorius* 19
3.1 General morphology of *C. capsularis* and *C. olitorius* ultimates 19
3.2 Measurement of *C. capsularis* and *C. olitorius* ultimate dimensions 21
3.3 Optical properties of *C. capsularis* and *C. olitorius* ultimates 23
3.4 The Herzog test for the cellulose twist direction of *C. capsularis* and *C. olitorius* ultimates 28
3.5 Raman spectroscopy of *C. capsularis* and *C. olitorius* ultimate cell walls 31
3.6 New considerations for the Herzog test 35

CHAPTER 4: Results and Discussion Part 2: Microscopic analysis of commercial jute goods 38
4.1 Rationale for the analysis of commercial goods analysis 38
4.2 Acquisition and summary of commercial goods 38

4.3 Features used to identify jute and non-jute fibers 39
4.4 Analysis of textile samples 44
4.5 Analysis of geotextile samples 48
4.6 Analysis of cordage samples 49
4.7 Analysis of flooring samples 49
4.8 Analysis of sacking material samples 49
4.9 Analysis of miscellaneous samples 52
4.10 Trends in jute fiber substitution in commercial goods 52
4.11 Difficulties encountered in the analysis of commercial goods 54
4.12 Photography of commercial goods samples for the future development of a jute fiber database 56

CHAPTER 5: Conclusions and Future Work 58
5.1 Efforts to identify a method to discriminate jute fibers from *C. capsularis* and *C. olitorius* 58
5.2 Evaluating the frequency with which goods advertised to contain jute are composed of other fibers 59

APPENDIX 62

BIBLIOGRAPHY 94

LIST OF TABLES

Table 1.	Comparison of ultimate dimensions reported in this work and in a representative sample of published literature .	22
Table 2.	Summary of commercial goods analysis by product type.	39
Table 3.	Summary of the results of the phloroglucinol test for relative degree of lignification for reference samples depicted in Figure 14.	41
Table A.1.	Description of items in the commercial goods collection and results of microscopic analysis.	63
Table A.2.	Observations of fibers from the commercial goods collection.	84

LIST OF FIGURES

Figure 1.	A multi-scale representation of jute fibers.	3
Figure 2.	Enlarged photomicrograph of a representative ultimate of flax (*Linum usitatissimum*, Sample B-30008), a common bast fiber, to demonstrate the appearance of nodes, dislocations, and cross markings.	10
Figure 3.	Representative ultimates from reference samples of *C. olitorius* (A, Sample B-30059) and *C. capsularis* (B, Sample B-30025).	20
Figure 4.	Measurement of ultimates from *C. capsularis* and *C. olitorius* reference samples.	21
Figure 5.	Optical properties of a representative ultimate from a reference sample of *C. capsularis* (Sample B-30026).	24
Figure 6.	Optical properties of a representative ultimate from a reference sample of *C. olitorius* (Sample B-30007).	25
Figure 7.	Enlarged photomicrograph of representative ultimates from *C. olitorius* (Sample B-30007) to demonstrate the appearance of nodes, dislocations, and cross markings.	26
Figure 8.	Enlarged photomicrograph of crystals in an ultimate from a jute coffee bean sack (Sample BF-009).	27
Figure 9.	Photomicrographs of a representative ultimate of *C. capsularis* (Sample B-30026) to demonstrate the Herzog test for a Z twist fiber.	29
Figure 10.	Schematic illustration of how the Herzog test for a Z twist fiber can result in either a definitive or uncertain determination of the twist direction.	30
Figure 11.	Structure of cellulose.	33
Figure 12.	Average Raman spectra of *C. capsularis* and *C. olitorius.*	34
Figure 13.	A new hypothesis to explain why some ultimates produce clear colors and others produce ambiguous colors during the Herzog test.	36
Figure 14.	Photograph of the results of the phloroglucinol test for relative degree of lignification for reference samples of jute, some jute substitutes, and some common vegetable fibers.	40

Figure 15.	Ultimates from a sample of jute flooring (Sample BF-012) to demonstrate the variability in lumen morphology observed in many of the commercial goods.	44
Figure 16.	Blend of polyester fibers from a swatch of fuchsia textile advertised as “Vintage Burlap” (Sample BF-023).	45
Figure 17.	Photomicrography series of a polyester fiber from a textile swatch advertised as “Vintage Burlap” (Sample BF-024).	46
Figure 18.	Blend of macerated fibers from coffee bean sacking (Sample BF-005) and comparison to macerated coir fibers (Sample B-30002).	51

KEY TO ABBREVIATIONS

DSLR	Digital single-lens reflect
GC	Gas chromatography
IJSG	International Jute Study Group
IR	Infrared
MSU	Michigan State University
n	Refractive index
$n_{\parallel}$	Refractive index parallel to the length of the fiber
$n_{\perp}$	Refractive index perpendicular to the length of the fiber
NE-SW	Northeast-southwest
NW-SE	Northwest-southeast
PLM	Polarized light microscopy
PPL	Plane polarized light
SEM	Scanning electron microscopy
SWGMAT	Scientific Working Group for Materials Analysis
TLC	Thin-layer chromatography
XP	Crossed polars

CHAPTER 1: Introduction

1.1 The need for vegetable fiber identification

Forensic fiber examinations frequently attempt to associate a questioned fiber with a known source (1, 2); this involves identifying the fibers present in each sample. Aside from noting the general prevalence of fibrous materials in the everyday environment, very few published works comment on the frequency with which fiber evidence is encountered in casework (1, 2). One trace evidence analyst noted that of 506 cases he examined between 1977 and 1983, 100 cases, or nearly 20%, yielded fiber evidence of investigative value (3). While often overlooked and not collected at crime scenes, such trace evidence can be of particular value when other types of evidence have been exhausted or are absent (1, 4-8). Thus, accurate identification of fibers in casework can be exploited to provide helpful investigative leads.

Jute is the most abundant vegetable fiber in production after cotton (9, 10) and is used to make the well-known textile burlap. Currently neither microscopic nor chemical methods exist to differentiate fibers from the two jute species, *Corchorus capsularis* and *C. olitorius*. Distinguishing between jute species would provide a new level of discrimination when jute fibers are encountered in forensic casework. Furthermore, other natural fibers and some synthetic fibers are sometimes substituted in commercial goods advertised as jute. In labs with limited time and resources, knowing which types of products are more likely to be misidentified can guide examiners towards more thorough examination of particular product types. The experiments described herein represent one of the first attempts to discriminate fibers from the jute species and also determine the frequency of mislabeling of common commercial jute goods.

1.2 The botanical origins of jute fibers

Jute is the name for the fiber extracted from the bast (stems) of the jute plants, *C. capsularis* and *C. olitorius*. While approximately 80 species of plants belong to the genus *Corchorus* (11), only these two are commercially cultivated for fiber production (9, 12-17). Jute fibers from *C. capsularis* can range from pale cream to dull gray or brown to black in color and be finer than those from *C. olitorius*, which is often yellowish, silky, and softer than the former type, although the fiber color is substantially impacted by processing conditions (12, 13).

Jute plants are annual herbaceous angiosperms (10, 13) belonging to the family *Malvaceae* (11). Other fiber crops in this family include the seed fibers cotton (*Gossypium sp.*) and kapok (*Ceiba sp.*) as well as other bast fibers such as kenaf (*Hibiscus cannabinus*), roselle (*H. sabdariffa*), and aramina (*Urena lobata*) (11, 18). The high content of lignin in jute cell walls causes the fiber to be relatively coarser than other, softer bast fibers such as flax (*Linum usitatissimum*), hemp (*Cannabis sativa*), and ramie (*Boehmeria nivea*) (19-22).

In the jute plant, fiber bundles arise from the actively dividing procambium and cambium in the stem (**Figures 1A and 1B**) (23). These rings of tissue develop into the vascular tissues that serve as a transport system for the plant (24). The vascular tissues include water-carrying xylem and nutrient-carrying phloem (25, 26). The tissue that is harvested for commercial fiber products begins as phloem-associated fibers that eventually differentiate into sclerenchymatic support tissue (10). This occurs in part via the continuous deposition of lignin into the secondary cell wall (24). Lignins, a complex and diverse family of biopolymers, impart mechanical strength to the plant stem by thickening the cell walls of the mature sclerenchyma fibers (19, 24, 26). Nearby parenchyma cells, a thin-walled cell type that adds bulk to the stem, may infrequently remain attached to the final fiber product and be detected microscopically from scrapings (27).

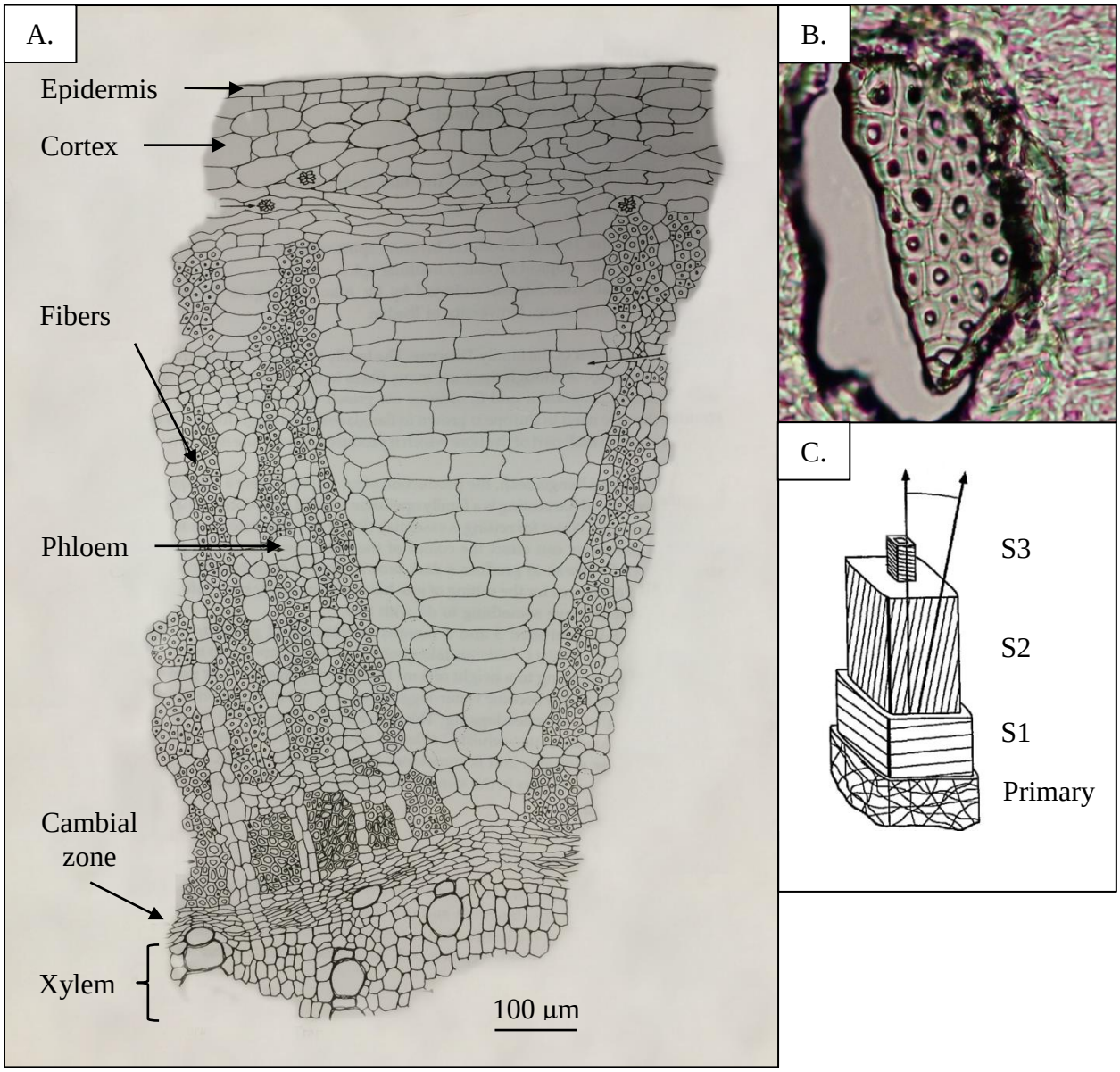

Figure 1. A multi-scale representation of jute fibers. A. Sketch of a transverse cross section of *C. olitorius* stem. Fibers are located in bundles primarily surrounded by phloem tissue. Modified from Catling and Grayson (27). **B**. Plane polarized light (PPL) photomicrograph of a transverse cross section of *C. olitorius* embedded in paraffin wax. Sample B-30059 from the Microtrace Vegetable Fiber Reference Collection (18). 400X total magnification. **C**. A longitudinal schematic representation of the cell wall layer structure typically found in bast and wood fiber cells. The striations indicate the typical direction of cellulose spiraling in each layer. The microfibril angle is the acute angle between the long axis of the fiber and the angle of cellulose in the S2 secondary cell wall layer. Modified from Ye *et al*. (28).

The cell walls of most angiosperms are broadly divided into two categories: primary and secondary cell walls. The former is present in all cell types and begins to form during plant cell division, and it is continuously synthesized and reformed as cells expand. In contrast, secondary cell walls are only laid down in sclerenchyma after the cell reaches its final size (29). Lignin is deposited on a scaffold of cellulose microfibrils (30). The secondary cell wall is divided into three layers based on cellulose orientation: S1, S2, and S3, with the outermost S1 adjacent to the primary cell wall and the innermost S3 adjacent to the lumen (**Figure 1C**) (29, 31). S1 and S3 are relatively thin with cellulose microfibrils laid down perpendicular to the long axis of the fiber (29, 31, 32). By comparison, the S2 layer is considerably thicker and the cellulose microfibrils spiral at a steep angle to the fiber axis (29, 31-37). This angle varies in fibers from different plant species in both degree of steepness and in S versus Z direction (31, 38-40). Multiple techniques can measure this spiraling angle, including two dimensional X-ray diffraction (38-40), scanning electron microscopy (SEM) of the exposed cell wall (32), ellipsometry (28), and Raman spectroscopy (33-35). As the first two techniques were not used in this research, they will not be discussed further. Raman spectroscopy will be addressed in **Section 1.7**.

1.3 Obtaining fiber from jute plants

The conditions in which jute plants are grown can impact the final quality of the resulting fiber. Jute is hand sown in loamy soil during the rainy season between February and May in India and Bangladesh (10, 12). Soil characteristics affect the fiber quality: sandy soils result in coarser fibers while clay soils result in shorter fibers that do not separate from the stem easily (12). Fiber quality also deteriorates if jute is grown repeatedly on the same land without crop rotation. Spacing between plants proves to be another consideration: plants too close will have

thin stems and poor fiber quality, while plants far apart will branch and also diminish quality. Thus, the crop must be weeded and thinned two to three times by hand during the growing cycle to ensure strength of the final product (12).

The ideal time to harvest the fiber crop is considered to be when the fruits ripen, often between early June and late October (12). Harvesting too early reduces the yield of fiber, while harvesting too late makes fibers overly coarse and difficult to separate from the stem (12, 13). Traditionally all plants have been harvested by hand using sickles to cut close to the ground or by pulling directly from water-logged areas (12, 13). The stems can then be defoliated, which increases the speed and uniformity of the next process, retting (13).

Retting frees the fibers from the stem by soaking tied bundles of stems in slow-moving water. Bacteria and fungi decompose pectins and hemicelluloses that attach the fibers to the rest of the stem (13). The flowing of the water removes dark-colored and acidic degradation products, resulting in higher grade fibers that are stronger and more lightly colored (13). In contrast, stagnant water permits deterioration of fiber color and luster due to the buildup of fermentation products (15). *C. capsularis* rets faster than *C. olitorius* because it supports a larger population of aerobic and anaerobic microorganisms, but the presence of a periderm layer on the exterior of the stem in *C. capsularis* decreases the uniformity of retting (13).

As soon as possible after retting, the fiber must be physically separated from the woody stem remnants. Stripping is also done by hand. In this process, the butt end of the fibers is gently beaten with a wooden paddle or mallet to loosen the fiber from the stems. Grasping and shaking the butt ends removes the bulk of the woody stem parts, while jerking the fibers through the water several times removes the final upper stem portions from the fiber. After a sufficient period of drying, the fibers are transported to a baling center. Here, fibers are sorted, given a

preliminary grade, and marked with the species and area of origin before being purchased for further processing or export (13).

1.4 The jute economy

The International Jute Study Group (IJSG) is an intergovernmental body comprised of India, Bangladesh, and the European Union. The group was established by the United Nations Conference on Trade and Development and seeks to promote the worldwide jute industry. IJSG data show that between 1994 and 2010, the only period for which centralized data are available, worldwide jute production has risen and fallen cyclically. Output fell to a minimum of 1.9 million kilograms in the 1995—1996 season and peaked at a maximum of 3.1 million kilograms in the 1997—1998 season (41). Most recently, in the 2009—2010 season, India and Bangladesh respectively produced 57.4% and 41.6% of the world's jute. Myanmar and Nepal supplied the remaining 1% of jute (41).

Second only to cotton in production (9, 10), jute has been used for a wide variety of goods. A non-exhaustive list of jute products includes cordage, sacking, textiles, draperies, upholstery, rugs, carpet backing, wall coverings, handicrafts, linoleum backing, soft luggage, mail bags, webbing, geotextiles/soil savers, agricultural mulching, tarpaulins, padding cloths, roofing materials, electrical insulation, backing for automotive carpeting, automotive seat backing, automotive composite materials, biocomposites, and fire-retardant garments (9, 10, 14, 15, 42). The production of jute goods by India and Bangladesh quintupled between 1991 and 2013, from 521.9M kilograms to 2,569M kilograms (41). In that time, the use of jute for sacking increased from 38.9% to 58.1% of all manufactured goods, while carpet backing declined from 11.6% to 0.5% as it has been largely replaced by synthetic materials. The significance of jute

evidence from carpet backing may therefore increase because it has become rarer in recent years. As the uses of jute in different goods shifts with time, such information may assist a forensic examiner in narrowing the time window from which a product is likely to have originated.

1.5 Analysis of fibers in the modern crime laboratory

Currently, the Organization of Scientific Area Committees Materials Subcommittee, overseen by the National Institute of Standards and Technology, is developing standards and guidelines for the forensic examination of fibers (43). While these recommendations for procedures and reporting are in progress, the retiring Scientific Working Group for Materials Analysis (SWGMAT) Fiber Subgroup's *Forensic Fiber Examination Guidelines* is still, for the time being, the widely accepted standard for fiber examination (44). Most recently updated in 2014, the *Guidelines* were originally published in 1999.

The *Forensic Fiber Examination Guidelines* is divided into chapters on microscopy, visible and infrared (IR) spectroscopy, thin-layer chromatography (TLC) of textile dyes, pyrolysis gas chromatography (GC), and analysis of bulk fabrics and cordage. The *Guidelines* recommend combining methods which provide complementary types of information. To perform the examination most efficiently, it is recommend that an analyst commence with techniques which provide the most exclusionary information.

As all samples handled in this research were intact specimens of different fibers or products, there was no need to determine if there was an association of one sample to any other. Techniques which could assist with such associations, but not necessarily in the definitive identification of the vegetable fiber itself, include the analysis of fiber color using visible spectroscopy or TLC of dyes, and analysis of bulk items for physical matches or shared class

characteristics such as warp and weft count. Of the remaining techniques, IR spectroscopy would be more appropriate for the identification of a man-made fiber, as the primary constituent of all vegetable fibers is cellulose. Next, pyrolysis GC would be most helpful for polymer fibers that do not char at high temperatures, as vegetable fibers would. With the various drawbacks of these techniques, microscopical analysis is the ideal choice for the identification of vegetable fibers.

1.6 Microscopy of vegetable fibers

Much has been written on the subject of using microscopes to identify the fiber type(s) present in a sample. Some of the earliest materials are reference books containing black and white photomicrographs with varying amounts of information on the chemical and physical characteristics of ultimates (16, 45-47). Various editions of *The Particle Atlas* have enumerated unique characteristics of the most common vegetable fibers along with color photomicrographs, with Volume V of the second edition containing a dichotomous guide to identification (22, 48, 49). Other reference texts and educational textbooks also suggest schemes for fiber identification using a variety of methods (20, 21, 50-52). The SWGMAT *Forensic Fiber Examination Guidelines* also describes an analytical scheme using microscopy, detailed below, primarily for the purpose of excluding or including a known fiber sample as a potential source of another sample (44).

The initial classification of a sample as a vegetable fiber, as opposed to a man-made, animal, or mineral fiber, may be made quickly based on observations while handling the sample, such as the texture, sheen, odor, and uniformity of the sample (20, 44). However, it is preferable to support such initial observations with low-magnification examination with a stereomicroscope. Overall construction of the sample should be recorded, along with physical

characteristics such as fiber length, relative diameter, luster, apparent cross section, damage, and adhering debris (44). If the fibers under examination appear similar after the preliminary examination, a comparison microscope may be used to observe physical characteristics such as diameter, color, presence of delusterant particles, surface characteristics, and apparent cross sectional shape (44). Cross sections may be taken of fiber bundles and viewed with a light microscope to note their shape (27, 44).

While the above applies to any fiber, vegetable fibers should additionally be searched for additional adhering plant tissues and cells, presence of crystals, and relative degree of lignification, nodes, dislocations, and cross markings (20, 44). While some authors do not distinguish between nodes and dislocations or sometimes describe only one or the other (17, 27, 45, 46), they are in fact separate features (53). Nodes are regions where ultimates appear to swell and often have a bend, akin to a knuckle or elbow joint (**Figure 2**) (53). Dislocations occur transverse to the length of the fiber and usually appear as bright, birefringent discontinuities in the shaft (**Figure 2**). The origin of dislocations is unclear and has been hypothesized to be due to tension or slippage resulting from compression; this disagreement by botanists on the subject has been succinctly summarized by Catling and Grayson (27). Dislocations occur more frequently in bast than leaf fibers and are absent from seed fibers (27, 53, 54). Another feature of vegetable fibers is cross-markings, which are thought to be the remains or impressions of adjacent cell walls no longer attached to the fibers (27). These appear most plainly as birefringent X's, Y's, or simple lines crisscrossing the width of the fiber (**Figure 2**) (27, 45, 46).

Most vegetable fibers at crime scenes are encountered as technical fibers, i.e. bundles of individual fiber ultimate cells that may also contain additional tissue from the plant (20, 27). In the laboratory, a maceration process is used to digest the lignin holding ultimates together,

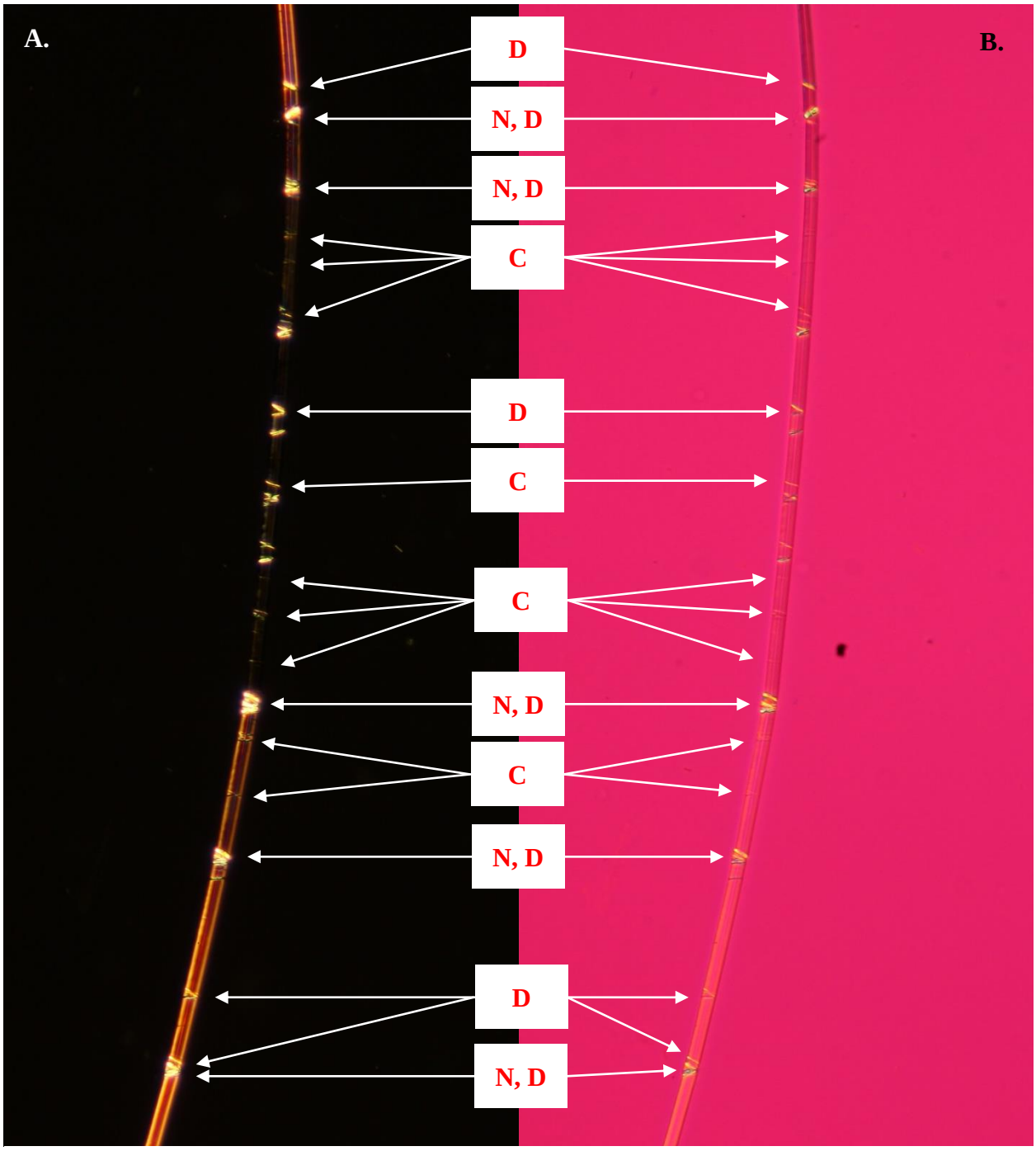

Figure 2. Enlarged photomicrograph of a representative ultimate of flax (*Linum usitatissimum*, Sample B-30008), a common bast fiber, to demonstrate the appearance of nodes, dislocations, and cross markings. A. The ultimate is first oriented to the vertical position of minimum brightness under XP. **B.** The first order red compensator may then be added to the light path to observe these features. Dislocations occur frequently; cross marking are fainter than dislocations. Letters indicate the following features: N = nodes, D = dislocations, and C = cross markings. Ultimates were mounted in glycerin jelly and photographed at 100X total magnification.

releasing them so that the single cells may be examined (20). For crime scenes where only one or a few technical fibers are recovered, the analyst can infer that characteristics of ultimates are representative of the entire sample. Maceration permits measurement or estimation of ultimate dimensions and observations of dislocations, cross markings, and relative lumen diameter to overall diameter (20, 44, 47). Next, a determination of optical characteristics is carried out using polarized light microscopy (PLM). For vegetable fibers, the most important properties include refractive index determination (either definitive or relative to the chosen mounting medium), sign of elongation, birefringence, retardation colors, and the Herzog test for cellulose twist direction (S or Z).

1.7 Raman microscopy of vegetable fibers

As mentioned briefly in **Section 1.6**, the Herzog test is used to determine the direction of a fiber's twist (20, 36). It is further possible to determine the angle of the cellulose twisting using a variety of methods (28, 32, 38-40), including Raman spectroscopy (33-35). This technique is based on single-wavelength excitation of ground state molecules in which inelastic scattering of photons from the sample induces vibrational transitions (33). Lignocellulosic samples have classically suffered from laser-induced fluorescence which swamps the Raman scattering signal (55-58), although this limitation has been mitigated by the use of near-IR lasers, Raman-inactive mounting surfaces, and interferometry (55-57). Despite this challenge, Raman microscopy provides useful information about the orientation of biological macromolecules, such as cellulose and lignin, which is not available through IR spectroscopy or other microscopic observations (55, 56). Specifically, Raman permits such examinations of individual cell wall layers from a

simple cross section, whereas SEM would require potentially damaging electron beam exposure or isolation of the layer of interest (32, 33).

The use of Raman microscopy for cellulose orientation determination is based on the presence of bands in the spectrum that are sensitive to cellulose orientation (33-35). In one study by Gierlinger *et al*. (34), Raman spectra were collected from the tangential surface of wood fibers rotated from -90° to 90° relative to the long axis of the fiber. Relative heights of peaks whose intensities varied most as orientation changed were used to develop a quadratic regression to describe the relationship between the peak height ratios and orientation angle. Multivariate analysis using partial least squares regression then identified the wavenumber regions of the overall spectrum that most contributed to the orientation-related variance. These regions were then used to develop a model which could predict the cellulose angle from the Raman spectrum of fiber cross sections. The validity of this model for predicting microfibril angle from cross sections of fiber samples was then tested and confirmed by comparing predicted angles with those experimentally determined by X-ray diffraction. While this method involved more statistical analysis than is typically performed in routine forensic fiber examinations, the most significant advantage of Raman spectroscopic determination of cellulose angle compared to historic two-dimensional X-ray diffraction is the reduction in sample preparation time and the simplicity of data acquisition. This achievement notwithstanding, an even more simplified procedure could aid forensic fiber examiners in using cell wall cellulose orientation to discriminate fibers from different species, a property that is not currently measured in forensic settings.

1.8 Aims of the present study

The accurate identification of vegetable fibers encountered in forensic casework can be useful to determine whether commercial goods contain the fibers indicated on their labels. Such information may be particularly useful in cases of suspected counterfeiting. While most vegetable fibers originate from only one plant species, jute is unique in that it is harvested from two species. Thus, the experiments describe herein aimed to devise a rapid, simple, and inexpensive method to discriminate between fibers from the two jute species with the hopes that such a method could then be used to determine whether commercial goods contained one or both jute species. Subsequently, the incidence of non-jute fibers in goods purporting to contain jute was determined regardless of the jute species present in an item.

Aim 1: Attempt to use microscopic and spectroscopic methods to distinguish jute fibers from *C. capsularis* and *C. olitorius*.

Aim 2: Ascertain the frequency with which commercial goods labeled as jute contain non-jute fibers.

CHAPTER 2: Materials and Methods

2.1 Reference samples

Reference samples and macroscopic photographs of jute and other vegetable fibers were a generous gift from the Microtrace, LCC Vegetable Fiber Reference Collection (18).

2.2 Commercial samples

Goods claiming to be fully or have a component fully comprised of “jute” or “burlap” were obtained from a variety of sources, as summarized in **Table A.1** in **Appendix A**. Briefly, samples were obtained from online craft product and home goods retailers, big box stores in Michigan (Meijer), professors from Michigan State University (MSU), Ebay, a Michigan coffee shop, a Michigan dollar store, and an online clothing and accessories retailer. Products were purchased or obtained by donation from brick-and-mortar stores in greater East Lansing, Michigan geographical region. To remain within a modest budget, only one or two stores of a particular type (e.g. home improvement stores) were visited and multiples samples of the same product were not purchased.

Textiles, defined as woven cloth for craft, clothing, or interior design purposes, were the largest group of samples (n = 85). Other samples included geotextiles for agricultural and conservation purposes (n = 7), cordage (n = 7), flooring (n = 6), sacking (n = 6), and novelty/miscellaneous items (n = 2).

2.3 Sample preparation

Approximately 1” cut or pulled technical fibers were collected from bulk reference and commercial samples for maceration to release fiber ultimates. Standard maceration conditions were utilized (20). Briefly, samples were boiled in a bath of equal parts glacial acetic acid and 30% hydrogen peroxide for 4-5 hours. After the maceration, the fluid was poured off and samples were rinsed twice with distilled water and twice with 70% ethanol. Macerated samples were stored in sealed, labeled glass vials in 70% ethanol.

2.4 Reference slide preparation

References slides were prepared using tungsten needles to spread ultimates across a slide with the aid of a stereomicroscope (Nikon SMZ645). Glycerin jelly (5 g gelatin, 30 ml deionized water, 35 ml glycerol, 0.5 ml phenol) was prepared and used as the mounting medium (n = 1.43). A cover slip was pressed down evenly over the sample, which was then allowed to cool and solidify. Three coats of nail polish were used to ring the edges of the cover slip to prevent drying and cracking of the mounting medium.

2.5 Microscopic observations

Samples were observed with a polarized light microscope (Olympus BH-2 or Olympus BX-51) under plane polarized light (PPL), between crossed polars (XP), and between XP with a 530 nm first order red compensator inserted into the light path. Observed physical and optical characteristics included overall morphology, surface texture, relative lumen diameter to overall diameter, interference colors, sign of elongation, direction of twist, and presence of nodes, dislocations, and cross markings. For synthetic fibers, refractive indices parallel and

perpendicular to the long axis of the fiber ($n_{\parallel}$ and $n_{\perp}$, respectively) were determined using the standard Becke line method using reference Cargille oils of known refractive indices. Birefringence was calculated as $n_{\parallel} - n_{\perp}$.

2.6 Measurement of ultimates

Length and area were measured with ImageJ (National Institutes of Health) from PPL photomicrographs by manually selecting the shortest path through the ultimate and around the perimeter, respectively. Average width was calculated by dividing area by length. Averages of the three measurements for each species were compared using two-tailed, unpaired student's t-tests performed with Microsoft Excel 2010.

2.7 Qualitative test for degree of lignification

Phloroglucinol reagent was prepared by dissolving solid phloroglucinol in the minimum amount of 190 proof ethanol necessary and adding an equal volume of concentrated hydrochloric acid. Cuttings of selected reference fibers and all commercial goods were placed individually in watch glasses. Upon the addition of phloroglucinol reagent, highly lignified fibers turn a deep magenta, partially lignified fibers turn lighter pink, and celullosic fibers do not exhibit a color change (20, 21, 50).

2.8 Macroscopic photography

Macroscopic photographs of commercial samples were captured using an EOS Rebel T3i 18.0 megapixel digital single-lens reflect (DSLR) camera with an 18-55 mm lens (Canon).

2.9 Photomicrography

Photomicrographs for the commercial goods database were collected with the same EOS Rebel T3i 18.0 megapixel DSLR camera connected to the Olympus BX-51 microscope using a 1.38X widefield T-mount adapter (Martin Microscope). Unless otherwise noted, samples are mounted in glycerin jelly (n = 1.43). Photomicrographs were collected with fibers oriented in multiple positions with the 10X objective for 140X total magnification. The EOS utility software's white balance was adjusted to the pre-programmed "cloudy" setting and a neutral density 25 filter was utilized for all 160X photomicrographs to achieve optimal illumination for photomicrography.

To improve the white balance of brightfield photomicrograph, a daylight blue filter was inserted into the light path and the camera's exposure compensation was set to zero. Photomicrographs of samples observed under XP utilized an exposure compensation set to $-3\,{}^{2}/_{3}$. Photomicrographs of samples observed under XP with the first order red compensator inserted used an exposure compensation of -1.

PPL photomicrographs were collected with ultimates oriented in the northeast-southwest (NE-SW) position of maximum brightness as determined by examination under XP. The XP and XP plus compensator photomicrographs were collected while the fiber was subsequently rotated into the northwest-southeast (NW-SE) position, vertical extinction, and horizontal extinction. As vegetable fibers only to go partial extinction, these positions were determined to be the positions of minimum brightness and were not always oriented at precisely 0° or 90° to the x-axis.

2.10 Raman spectroscopy of cell wall cross sections

Technical fibers of samples B-30058 (*C. capsularis*) and B-30059 (*C. olitorius*) were mounted in paraffin blocks. Thin (10 μm) sections were sliced with a microtome and mounted on glass slides. A tungsten needle was used to gentle remove an embedded fiber cross section from the paraffin for mounting on an aluminum slide. Spectra were collected from the 10 μm cross sections mounted on aluminum slides with an inVia Raman microscope (Renishaw) with a charge coupled device detector using the following conditions:

Objective:	100X (Numerical aperture = 0.9)
Spot size:	1.064 μm
Excitation wavelength:	785 nm
Exposure time:	1/10 s
Grating:	1200 lines/mm
Accumulations:	2

For each species, one spectrum was collected from four randomly chosen locations in the interior of the cell wall from a single cell for one reference sample of each species (B-30058 for *C. capsularis* and B-30059 for *C. olitorius*). Replicate spectra were individually baseline corrected (cubic spline interpolation method), zeroed, and averaged to generate a representative spectrum for the cell wall of that species.

CHAPTER 3: Results and Discussion Part 1: Microscopic and spectroscopic attempts to differentiate ultimates of *C. capsularis* and *C. olitorius*

3.1. General morphology of *C. capsularis* and *C. olitorius* ultimates

The reference collection contained five samples of *C. capsularis* (B-30006, B-30024, B-20035, B-30026, and B-30058) and four of *C. olitorius* (B-30007, B-30027, B-30028, B-30059) as well as an additional five samples from the genus *Corchorus* of undetermined species (B-30103, B-30120, B-30220, B-30221, and B-30222). Because the focus of the first part of the research effort focused on identifying potential differences between the two species, only the samples of known species are described in the following observations.

Much literature on vegetable fibers treats jute from *C. capsularis* and *C. olitorius* as interchangeable (10, 17, 21, 45, 46, 50, 59, 60), and it is true that they share many similarities. As with all bast fibers, the overall morphology of ultimate cells was not uniform but in general was characterized by a larger diameter in the middle part of the fiber which eventually tapered to both ends (**Figure 3**). One of the most characteristic features of *C. capsularis* and *C. olitorius* ultimates is the variability in the diameter of the lumen relative to the diameter of the overall cell, as illustrated in **Figure 3**. Within a single ultimate, a lumen may vary from occupying greater than 50% of the total diameter to being pinched so narrowly as to appear nearly closed. However, not every ultimate demonstrates this characteristic. Ultimates in every macerated sample have a lumen of more uniform diameter that occupies roughly one-fifth to one-third of the overall diameter (**Figure 3**). This is in agreement with observations published elsewhere (22, 27). In some ultimates of both species with particularly wide lumens, length-wise striations similar in appearance to the texture of wood grain could sometimes be observed (data not shown). Thus, gross morphology does not differ between *C. capsularis* and *C. olitorius*.

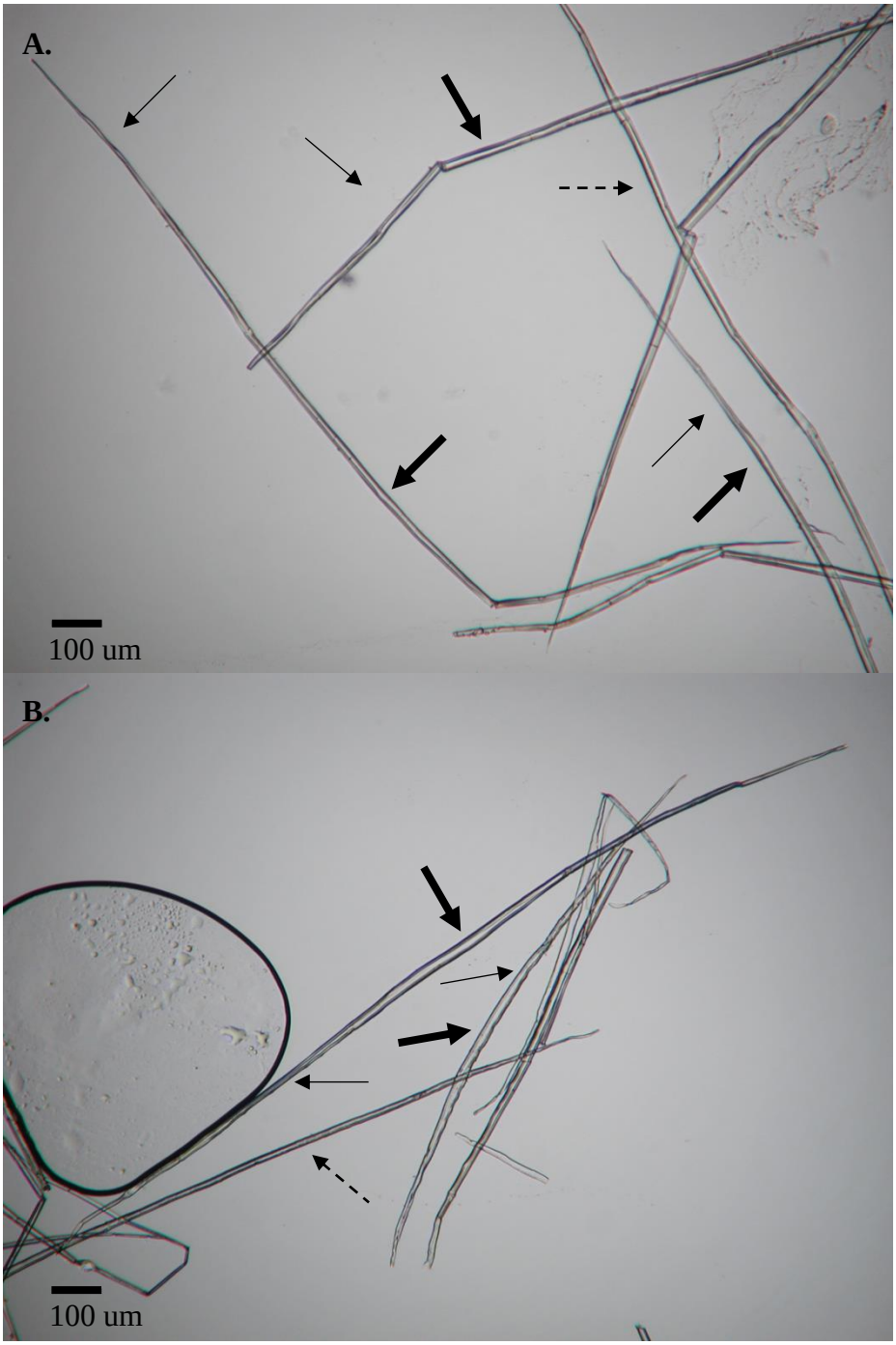

Figure 3. Representative ultimates from reference samples of *C. olitorius* (A, Sample B-30059) and *C. capsularis* (B, Sample B-30025). Overall, fibers were widest along the shaft and tapered toward the ends, unless one or both ends were blunt due to breakage. These ultimates demonstrated the variability in lumen diameter characteristic of jute ultimates. Thin arrows point to sections of narrow, pinched lumen while bold arrows point to sections of wider lumen. Dashed arrows point to ultimates with more uniform lumen diameter. Ultimates were mounted in water and photographed under plane polarized light (PPL) at 40X total magnification.

3.2 Measurement of *C. capsularis* and *C. olitorius* ultimate dimensions

Next, the length, apparent area, and average width of ultimates were measured from photomicrographs by calibrating ImageJ software to convert the number of image pixels into a physical distance or area. This was done to test whether such a rapid, simple, and inexpensive method could discriminate ultimates from the two jute species. Ultimates from each species did not significantly differ in length, apparent area, or width. (**Figure 4**, unpaired, two-tailed

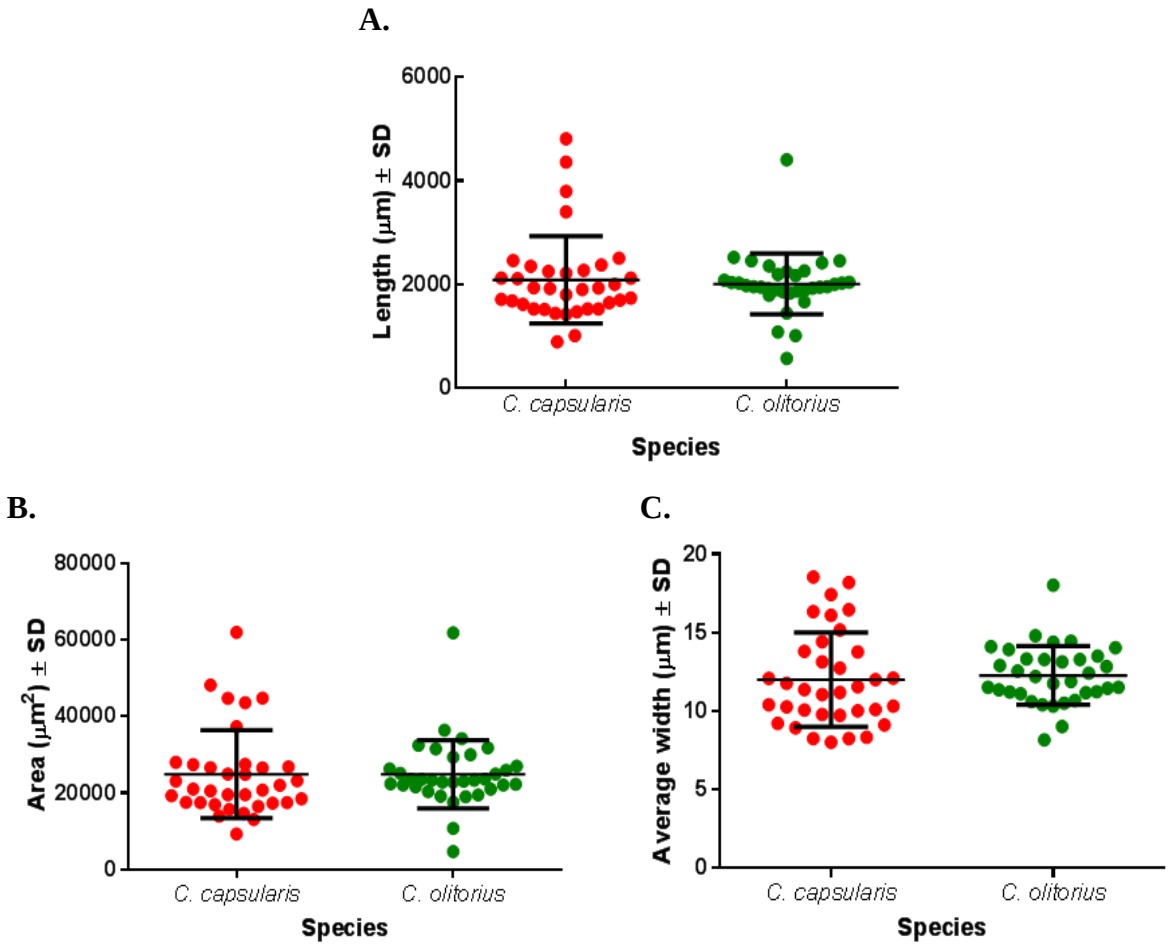

Figure 4. Measurement of ultimates from *C. capsularis* and *C. olitorius* reference samples. The ultimates from each species did not differ significantly in length (**A**), apparent area (**B**), or average width (**C**) (student's unpaired, two-tailed t-tests). Length was measured from photomicrographs using ImageJ to manually click the shortest path from one end of an ultimate to the other end. Apparent area was similarly measured by manually clicking around the perimeter of the ultimate. Average width was calculated by dividing the apparent area by the average width. Values are presented as mean ± standard deviation.

Table 1. Comparison of ultimate dimensions reported in this work and in a representative sample of published literature.

Author, Year	Reference	Species	Length, average (mm)	Length, range (mm)	Diameter, average (μm)	Diameter, range (μm)
This work	-	*C. capsularis* *C. olitorius*	2.09 2.01	0.9—4.8 0.6—4.4	12.0 12.3	8.0—18.5 8.2—18.0
Catling and Grayson, 2004		*C. capsularis* *C. olitorius*	2.17 2.04	0.6—5.3 0.6—5.3	18 20	9.6—26.6 9.3-32.6
The Textile Institute, 1975		*C. capsularis* *C. olitorius*	1.9—2.4 2.3—3.2	-	16.6—20.7 15.9—18.8	-
Franck, 2005		Not specified	2.5	0.75—6	18	5—25
Isenberg, 1958		Not specified	2.0	1.5—5.0	-	20-25
Luniak, 1953		Not specified	-	0.8—8	-	5—32
Montgomery, 1954		Not specified	2.03	1.5—5.1	23	20-25
von Bergen, 1942		Not specified	2.4	-	10	-

students' t-tests, $p > 0.05$) *C. capsularis* measured 2,089 ± 842 μm in length, 24,908 ± 11,492 μm^2 in apparent area, and 12.0 ± 3.0 μm in average width (mean ± standard deviation, n = 35). *C. olitorius* measured 2,008 ± 588 μm in length, 24,888 ± 8,954 μm^2 in apparent area, and 12.3 ± 1.9 μm in average width (n = 34).

Most prior reports of ultimate size do not distinguish between samples of each species (**Table 1**). For example, Catling and Greyson tabulate fiber ultimate measurements from four other authors, none of which treat the species as distinct (27). The range of lengths extends from 800 to 4,100 μm, while Catling and Grayson report 600 to 5,300 μm (average 2,170 μm) for *C. capsularis* and 600 to 5,300 μm (average 2,040 μm) for *C. olitorius* (27). **Table 1** compares the values found in this study with length and width measurements reported by other authors. The measurements reported herein for each species fall within the range of previously reported values

for jute. The large overlap in measurements for *C. capsularis* and *C.* olitorius seen both here and by Catling and Grayson indicates that measuring the dimensions of ultimates is not a reliable method for discriminating fibers of the two jute species.

3.3 Optical properties of *C. capsularis* and *C. olitorius* ultimates

When viewed in different positions between crossed polars (XP) and between XP with the first order red compensator, it is possible to observe the optical properties of the jute ultimates (61). The interference colors observed in samples between XP arise because light passing through the fiber vibrates at different speeds and wavelengths in two directions, parallel or perpendicular to the length of the fiber (61), due to the regular arrangement of cellulose chains in the cell walls (53). The arithmetic difference in the wavelengths, known as the retardation measured in nm, corresponds to a color on the Michel-Lévy chart of interference colors, where lower orders of colors correspond to samples with lower birefringence (62). If the thickness of the fiber is known, the wavelength of observed interference colors can be used to calculate a numeric value for birefringence (62). However, because jute cell cross sections are irregular polygons (27, 45), it is not possible to obtain an accurate value for the thickness at any given point on the fiber. Thus interference colors are described here only to give a qualitative idea of a sample's birefringence. All jute samples observed from both species demonstrated interference colors ranging from first order pale yellows or grays to second order vibrant blues, as seen in the representative photomicrographs in **Figures 5B** and **6B**. Further, all samples exhibited addition colors in the northeast-southwest (NE-SW) direction and subtraction colors in the northwest-southeast (NW-SE) direction indicating a positive sign of elongation (Figures **5C**, **5D**, **6C**, and

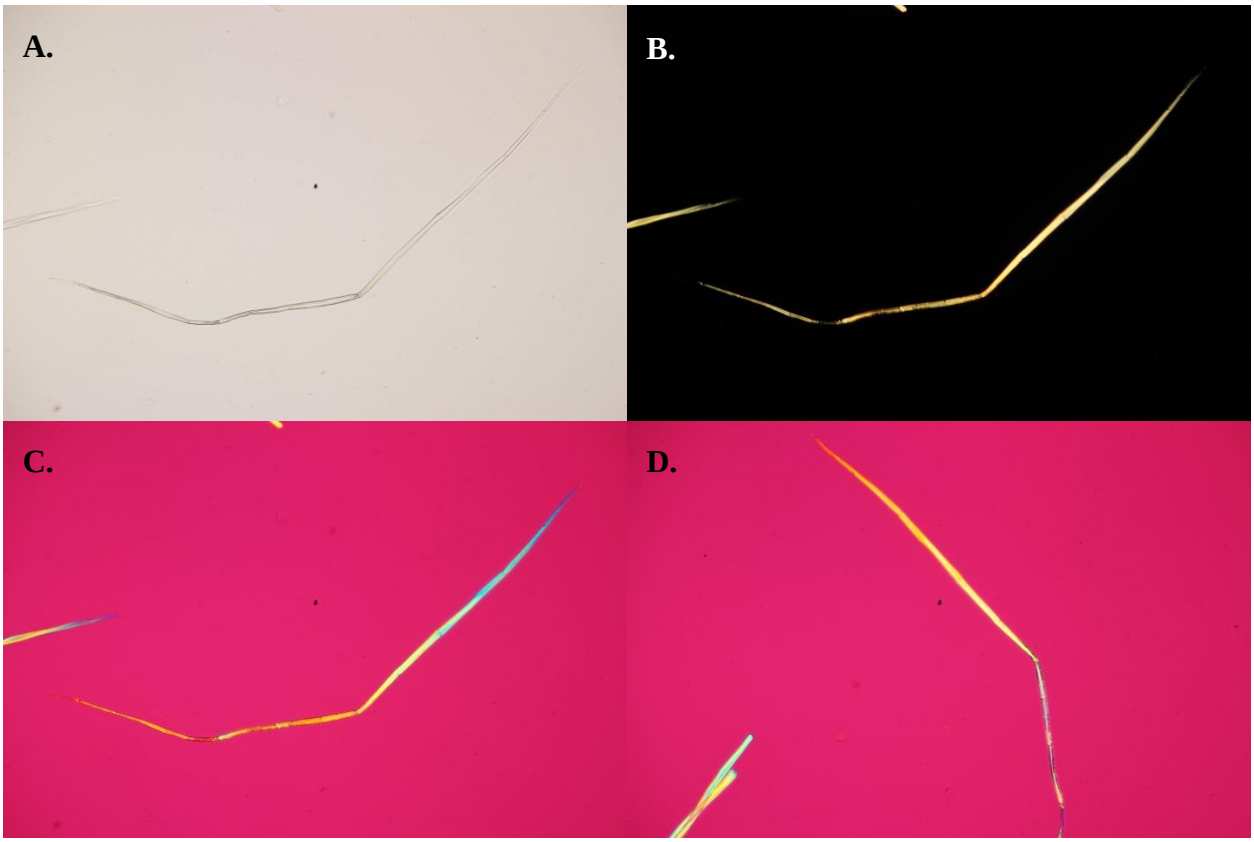

Figure 5. Optical properties of a representative ultimate from a reference sample of *C. capsularis* (Sample B-30026). A. Reference photomicrograph in PPL focused on the center ultimate pointing in the NE-SW direction. **B.** Ultimate in the center demonstrates pale yellow interference colors between XP. **C.** In the NE-SW position the ultimate exhibits addition of wavelengths into the second order bright blues and green-yellows between XP with the compensator in place. **D.** In the NW-SE position the ultimate exhibits subtraction of wavelengths to first order light-medium yellows. Together **C** and **D** illustrate that fibers of *C. capsularis* have a positive sign of elongation. Ultimates were mounted in glycerin jelly and photographed in PPL at 100X total magnification.

6D). Thus, these characteristics again do not permit differentiation of fibers from the two jute species.

Further examination of the ultimates between XP and with the compensator helps to enhance certain features which can also be observed in PPL, including nodes, dislocations, and cross-markings (**Figure 7**). In general, the jute reference samples contained these features as reported previously (17, 21, 27, 50). However, some authors have noted that neither nodes nor

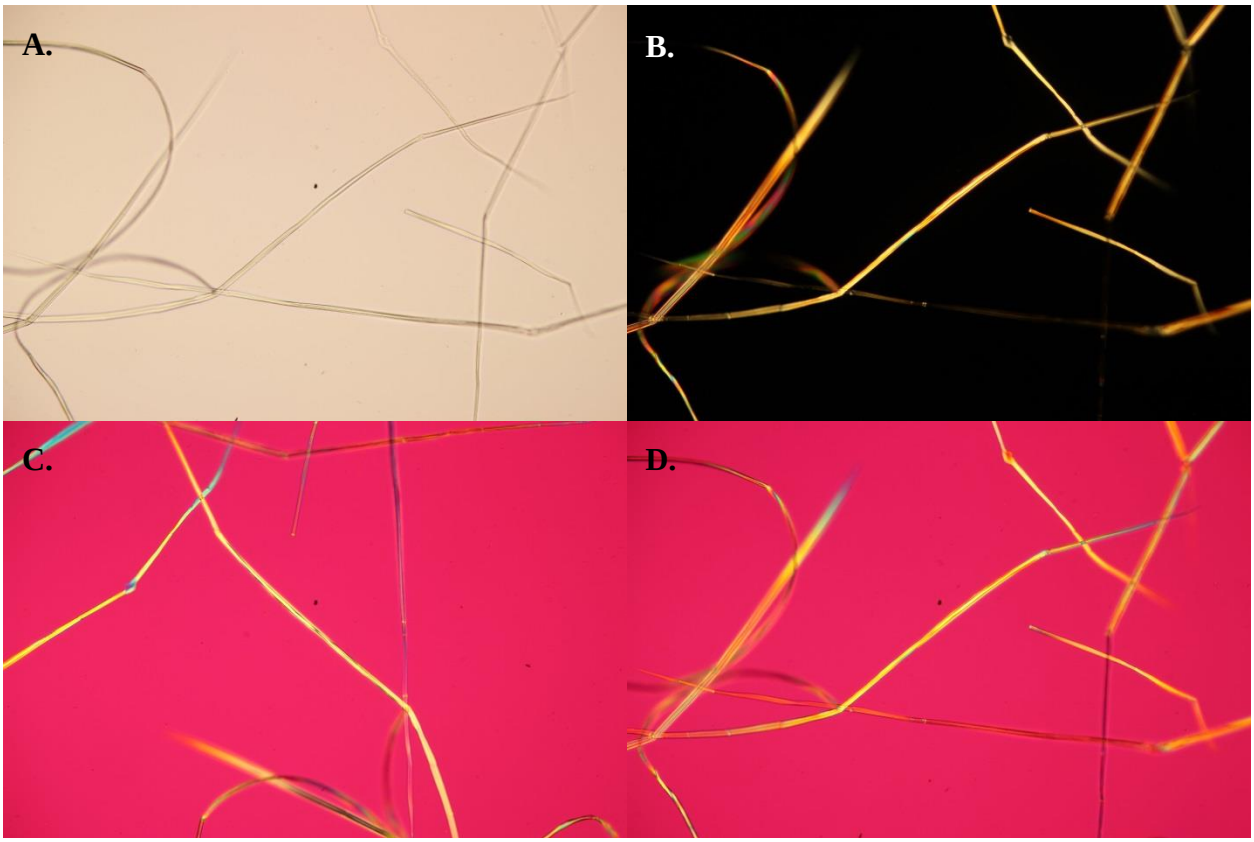

Figure 6. Optical properties of representative ultimates from a reference sample of *C. olitorius* (Sample B-30007). A. Reference photomicrograph in PPL focused on the center ultimate in the NE-SW position. **B.** Ultimate in the center demonstrates pale yellow interference colors between XP. **C.** In the NE-SW position the ultimate exhibits addition of wavelengths into the second order bright blues and green-yellows between XP with the compensator in place. **D.** In the NW-SE position the ultimate exhibits subtraction of wavelengths to first order light-medium yellows. Together **C** and **D** illustrate that fibers of *C. capsularis* have a positive sign of elongation. Ultimates were mounted in glycerin jelly and photographed in PPL at 100X total magnification.

cross-markings are common in jute fibers (17, 21, 27, 45, 46). Observations made in this work are not consistent with such reports; nodes were seen in all fibers and were common. In addition, cross-markings were noted to occur occasionally to very frequently. At present it is unclear if these discrepancies represent a difference in judgement between the authors or a true difference in the features of the fibers. Some of the same jute specimens examined by Catling and Grayson were examined as reference samples for this work, demonstrating that subjectivity in

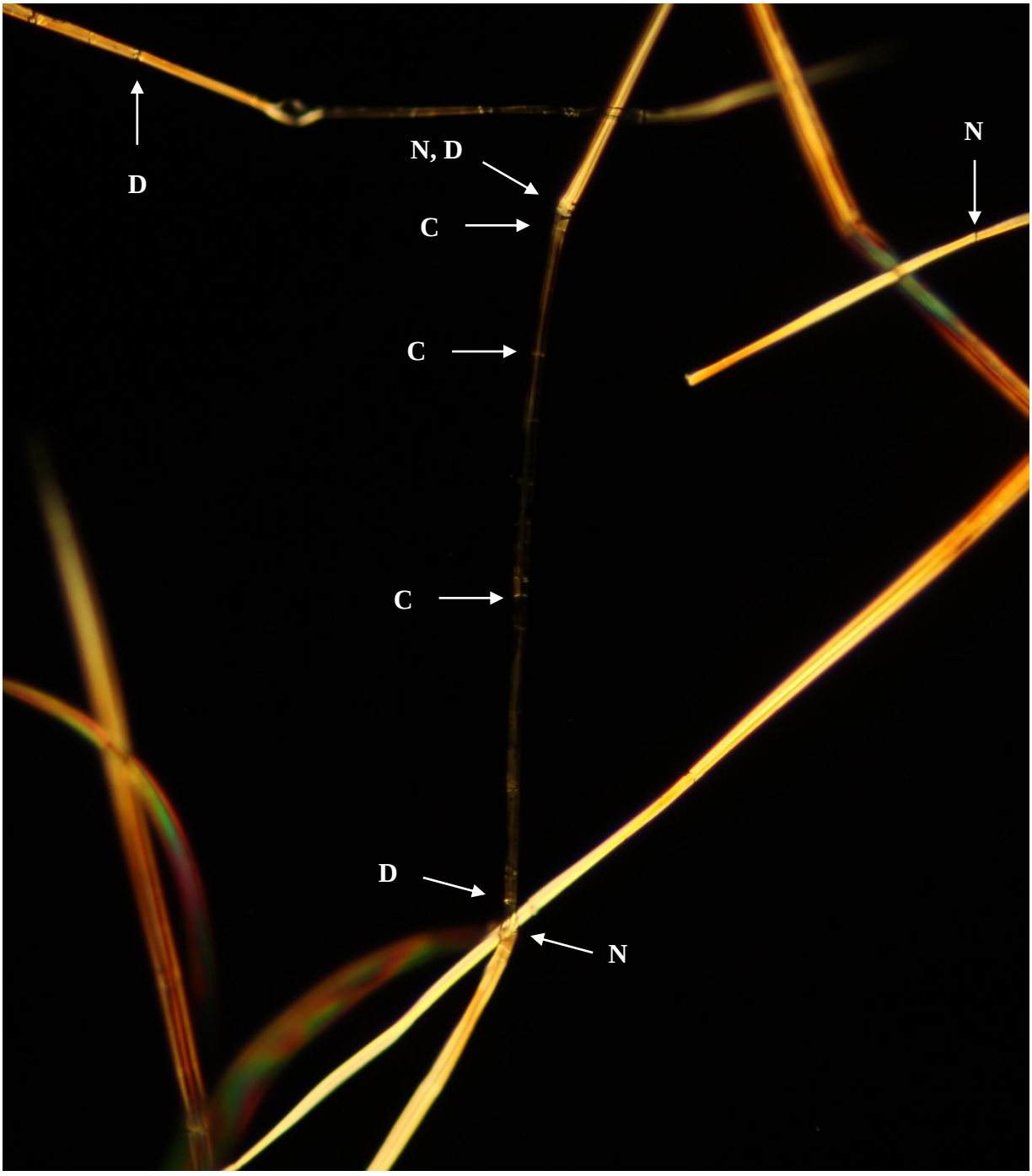

Figure 7. Enlarged photomicrograph of representative ultimates from *C. olitorius* (Sample B-30007) to demonstrate the appearance of nodes, dislocations, and cross markings. The ultimate in focus in the center of the image is the same as in Figure 4 but has been rotated to a position of extinction to highlight nodes, dislocations, and cross markings. Letters indicate the following features: N = nodes, D = dislocations, and C = cross markings. Ultimates were mounted in glycerin jelly and photographed under PPL at 100X total magnification.

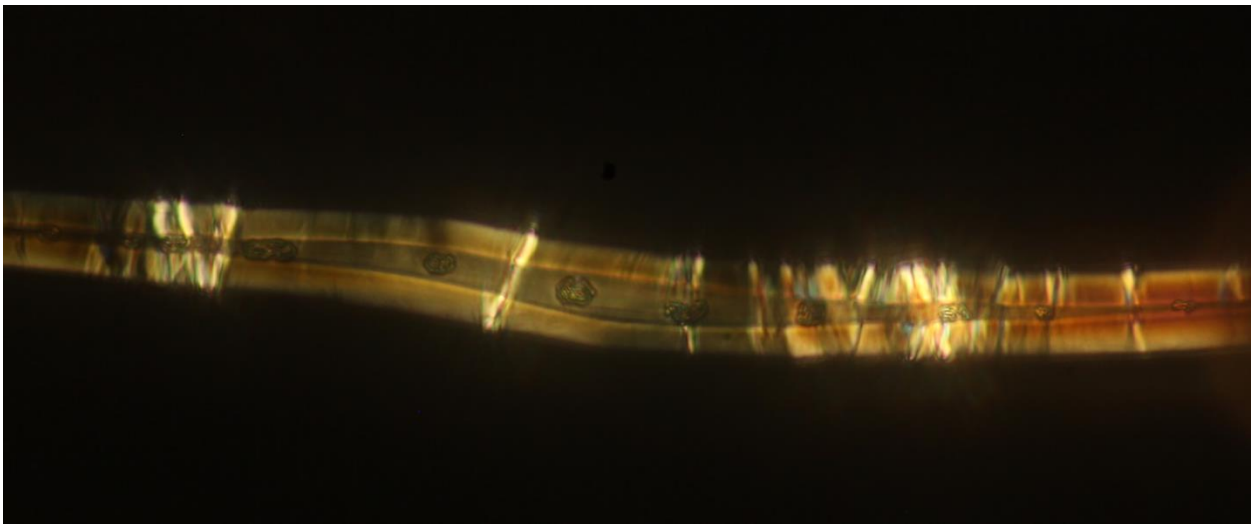

Figure 8. Enlarged photomicrograph of crystals in an ultimate from a jute coffee bean sack (Sample BF-009). Single crystals appeared in the middle section while a short chain was found to the left side of the photomicrograph. Notice also the abundance of dislocations and cross markings. The macerated sample was mounted in glycerin jelly and photographed under XP at 400X total magnification.

interpreting features can make comparing observations of different authors difficult. Alternatively, since cross-markings are thought to be the remains or impressions from where walls of adjacent cells attached to the fiber cells (27), perhaps differing methods of extracting fiber from the plant stems resulted in more or less frequent cross markings.

One feature of jute ultimates observed in this study but not discussed in any of the reviewed literature was the presence of non-birefringent crystal-like inclusions (**Figure 8**). These formations occurred in all samples of jute but were present in less than half the ultimates of any given sample. They seemed to occur inside the ultimates themselves as single crystals and chains of such (**Figure 8**). While they bear some resemblance to many-pointed cluster crystals, they might be more accurately described as clustered irregular polygons. However, they appeared slightly smaller than crystals reported by Catling and Grayson (27) and were not birefringent. Further, Catling and Grayson state that cluster crystals occur in jute far more rarely than cubic and rhomboid crystals, although these latter crystals were not observed in intact or macerated

specimens (27). It is possible that different crystal morphologies may only become apparent upon ashing a sample (27). However, this procedure, which heats the carbon-based vegetable fiber until it turns to ash and leaves behind crystals, was not undertaken in this work for two reasons. First, many forensic laboratories attempt to analyze and identify fibers without destructive methods. Although the type of crystals present can aid in identification (27, 53), this method is indeed destructive and may consume more sample than can be spared for the analysis. Second, the laboratory in which these inclusions were first noticed did not contain the apparatus to perform such ashing. While larger samples were available for this study, whether or not these inclusions were indeed the cluster crystals described in Catling and Grayson (27) was not determined.

3.4 The Herzog test for the cellulose twist direction of *C. capsularis* and *C. olitorius* ultimates

As discussed in **Section 1.2**, vegetable fibers have a thick S2 secondary cell wall made of cellulose that spirals at an angle to the fiber axis (29, 31-40). The Herzog test is a quick and reliable method to determine whether the cellulose spirals in an S or Z direction and is the same for all ultimates of a species (20, 53, 63, 64). The test involves aligning the fiber under cross polars to the two perpendicular positions at which it appears to be nearest extinction, inserting the compensator, and observing whether the fiber appears blue or orange in the perpendicular and vertical orientations. The blue color at the vertical extinction position and orange color at the horizontal extinction indicate the Z orientation while the opposite pattern of colors (blue when horizontal and orange when vertical) would indicate an S orientation. Consistent with other reports (16, 21, 50), all jute fibers examined were determined by the Herzog test to have a Z twist orientation of cellulose cell wall spiraling (**Figure 9**).

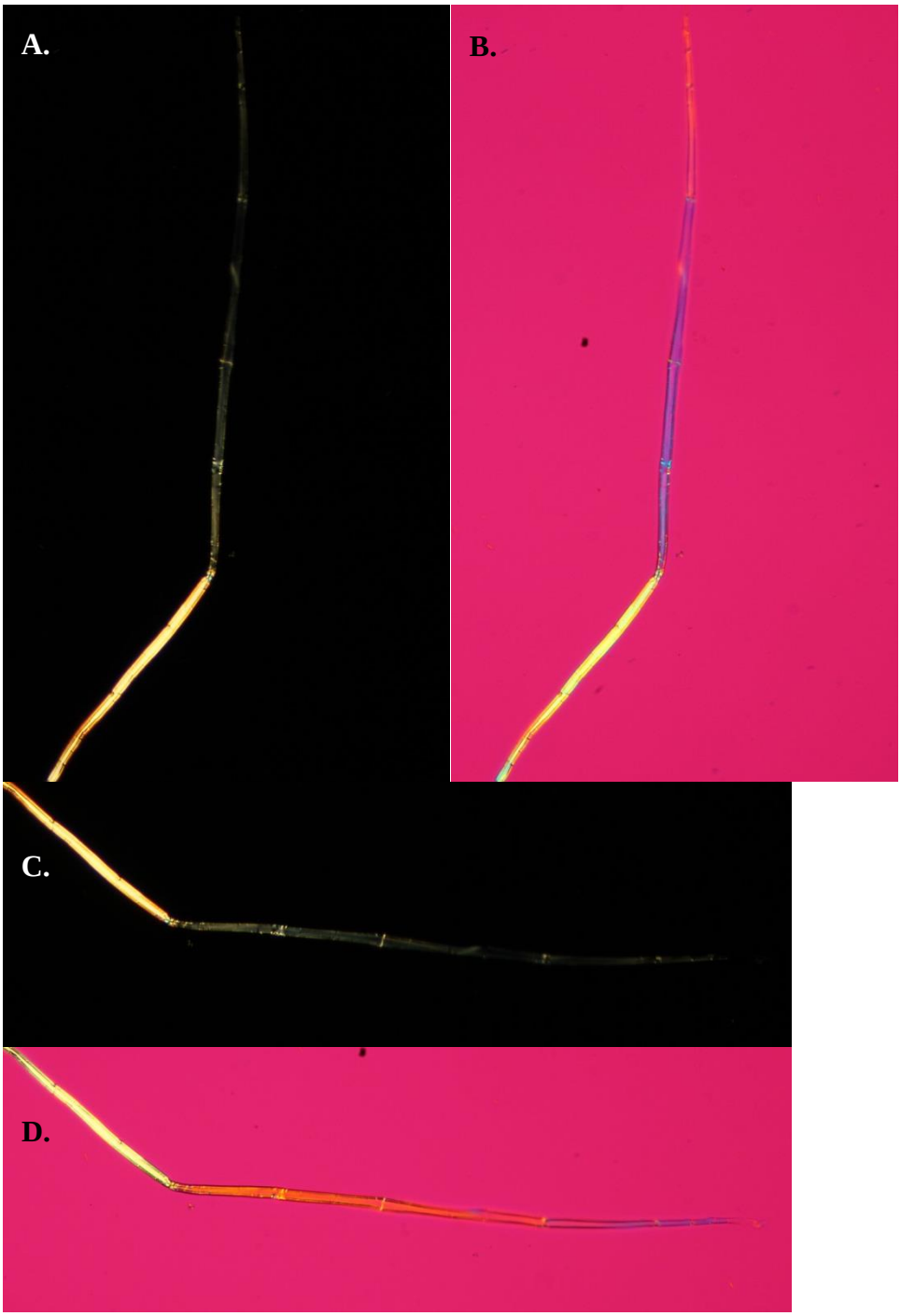

Figure 9. Photomicrographs of a representative ultimate of *C. capsularis* (Sample B-30026) to demonstrate the Herzog test for a Z twist fiber. A, **C.** The ultimate was oriented at the positions of minimal brightness under XP in the vertical and horizontal positions, respectively. **B.** When the compensator is inserted, the fiber appears blue in the vertical position. **D.** The fiber appears orange in the vertical position. The ultimate here is the same ultimate depicted in **Figure 5**. The macerated sample was mounted in glycerin jelly and photographed at 100X total magnification.

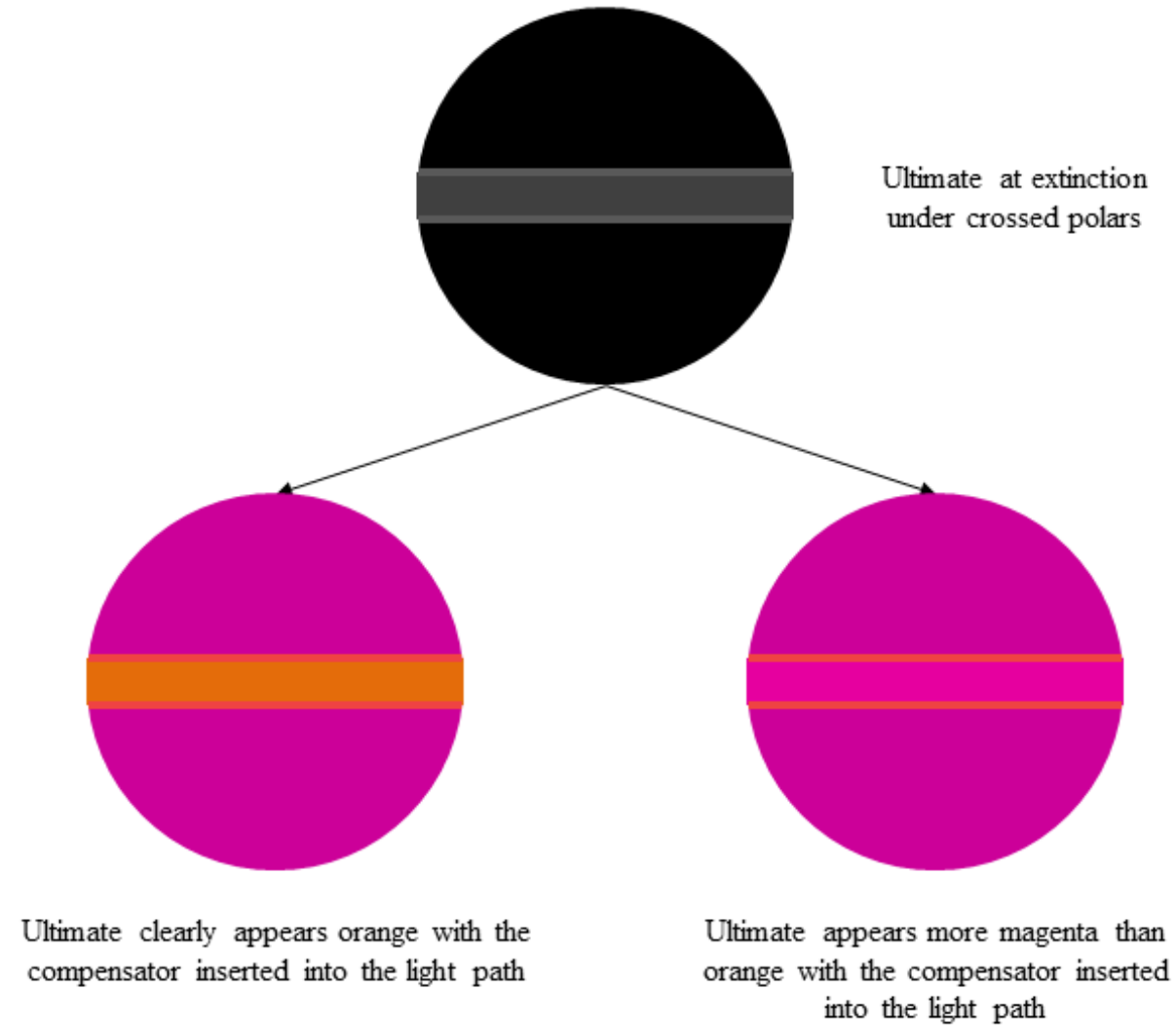

Figure 10. Schematic illustration of how the Herzog test for a Z twist fiber can result in either a definitive or uncertain determination of the twist direction. First, the ultimate is oriented to the horizontal position of minimum brightness under XP (top). When the first order red compensator is inserted into the light path (bottom), a Z twist fiber is expected to appear orange. In some instances, this was clearly observed (bottom left). Other ultimates appeared mostly magenta with a very faint orange hue that could turn to magenta with a faint very blue upon the slightly rotation of the fiber (bottom right). The circle represents the field of view.

During the course of observing many reference jute specimens, it became apparent that sometimes the blue and orange colors were very easy to distinguish while in other cases the colors were ambiguous (**Figure 10**). For example, first the jute ultimate would be oriented into the horizontal extinction position. Upon inserting the first order red compensator, some fibers

would clearly appear orange while others appeared mostly magenta with only a faint hint of orange, which could change to the opposite color, blue, upon the slightest rotation of the fiber. It is important to remember that vegetable fibers can never go to true, fully black extinction under XP due to inherent, randomness in the structure of the cell. Consequently two examiners with slightly different interpretations of the position of minimum brightness could in theory insert the compensator to perform the Herzog test and see mostly magenta with a hint of either orange or blue, making it difficult to conclude in which direction the cellulose twists. Fortunately, this potential difficulty can usually be overcome in practice by rotating the stage to observe the ultimate at other positions to make the colors more apparent and/or by observing multiple ultimates from the same sample to determine if the fiber has an S or Z twist.

However, in the initial observations, this phenomenon was thought to be linked to the species being examined. As the overall color of the Herzog test is determined by the S or Z direction of spiraling, it was proposed that the angle of the cellulose spiraling might be responsible for the observed differences in the Herzog test, namely that one species resulted in distinct blue and orange colors while the other resulted indistinguishable shades of magenta.

3.5 Raman spectroscopy of *C. capsularis* and *C. olitorius* ultimate cell walls

Several methods, including two dimensional X-ray diffraction (38-40), scanning electron microscopy (SEM) (32), and Raman spectroscopy (33-35), are available to assess the angle of cellulose spiraling. However, both of these approaches have limitations which make them unamenable to adoption by forensic laboratories. First, two dimensional X-ray diffractometers are not widely available and the current financial environment in many laboratories would prohibit the purchase of such powerful yet expensive instruments for such a narrow purpose. The

second method which held promise was utilizing SEM to directly observe the cellulose microfibrils and use trigonometry to calculate a spiraling angle (32). This would have involved removing the outer layers of the cell wall to selectively expose the S2 layer of the secondary cell wall (32). However, the publication presenting the SEM photomicrographs of wood fibers prepared in this manner did not include information about how to prepare the samples for such analysis (32) and attempts to reach the author were not successful. It remains to be seen whether this method for sample preparation could be reproduced. Thus, X-ray diffraction and SEM were not pursued in this work for the precise determination of the cellulose spiraling angle.

Consequently, analysis by Raman spectroscopy was selected to investigate the spiraling angle as it would entail the least expensive and simplest sample preparation. Raman spectroscopy is becoming more widely available in forensic laboratories, meaning its application to vegetable fibers could be adopted on a large scale. Sample preparation and analysis were available in the literature (34) and described in **Section 1.7**. In that study by Gierlinger *et al.*, the authors used ratios of specific peak heights and partial least squares regression modeling of entire spectra in order to predict a spiraling angle (34). The predicted angles were then verified for accuracy by comparison to angles determined by X-ray diffraction (34). By modifying the author's published procedure to undertake a simplified comparison of peak height ratios, the work herein sought to determine if there could be a simpler method to indicate differences in the spiraling angle.

The peaks chosen for analysis were 1096 cm^{-1} and 2983 cm^{-1}. The former corresponds to the symmetric stretches of C-C, C-O, and C-O-C bonds oriented parallel to the direction of the cellulose while the later corresponds to the symmetric C-H stretch perpendicular to the cellulose fibrils. The atoms involved in these critical bonds, highlighting how they align parallel and

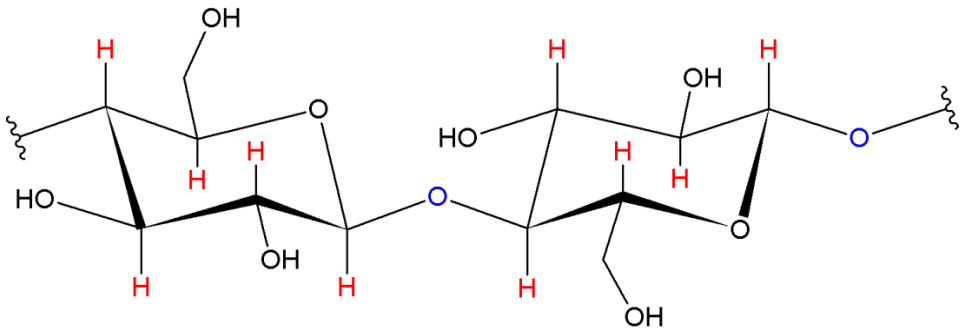

Figure 11. Structure of cellulose. The 1096 cm-1 Raman band corresponds to the symmetric stretches of C-C, C-O, and C-O-C bonds oriented parallel to the cellulose microfibril; the oxygen atoms involved are colored blue for emphasis. The 2983 cm^{-1} Raman band corresponds to the symmetric C-H bond oriented perpendicular to the cellulose microfibril; the involved hydrogen atoms are colored red for emphasis.

perpendicular to the cellulose chain, are emphasized in the structure of cellulose appearing in **Figure 11**.

For this exploratory analysis, four Raman spectra were collected from the middle of the cell wall of a single cell from one reference specimen each of species. The ratio of the 1096 cm^{-1} and 2983 cm^{-1} peak heights was 1.81 for *C. capsularis* (**Figure 12A**) and 1.76 for *C. olitorius* (**Figure 12B**). Given the similarity of these ratios, the error introduced by manual baseline corrections, and the small sample size, this simplified peak height ratio method provided insufficient information to determine whether the cellulose spiraling angles could be similar or different between the samples. This method had been attempted due to the ease of calculating peak height ratios as opposed to using more complex statistical modeling of spectra to predict a precise angle. Taking advantage of such a shortcut could have made it more likely for such a technique to be adopted by forensic laboratories owing to it being easier to understand the method, thereby reducing the time and effort needed to train analysts on the new method. However, it seems apparent that the full procedure described by Gierlinger *et al*. (34) would

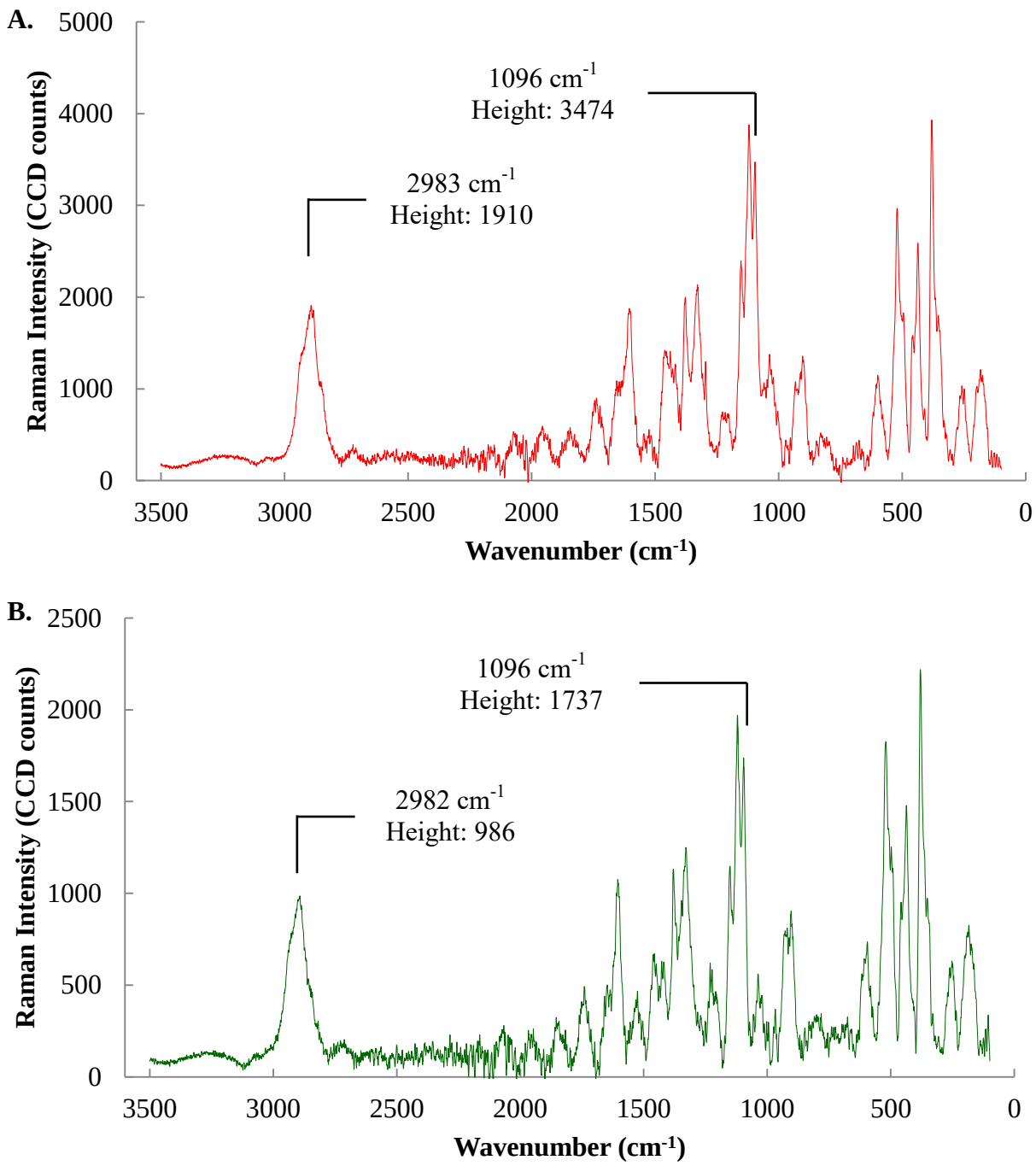

Figure 12. Average Raman spectra of *C. capsularis* and *C. olitorius*. Spectra were collected from 100—3,500 cm^{-1} at four randomly chosen locations in the cell wall interior from a single ultimate from technical fiber cross sections. Spectra were baseline corrected and zeroed before being averaged. **A**. One ultimate of *C. capsularis* (Sample B-30058) had a 1096 cm^{-1} : 2983 cm^{-1} height ratio of 1.81. **B**. One ultimate of *C. olitorious* (Sample B-30059) had a ratio of 1.76.

indeed be necessary for predicting a cellulose spiraling angle that could be used to differentiate whether there are small differences in the cellulose spiraling angle between the two jute species. Thus, it remains undetermined whether there may be a difference in the angle that has not yet been discovered or whether there is no difference in the angle.

3.6 New considerations for the Herzog test

The initial observations of the clarity or ambiguity of the colors observed during the Herzog test of *Corchorus* ultimates was initially thought to be tied to each species. This hypothesis, that the two species have a slightly different angle at which cellulose spiraled in the S2 secondary cell wall layer, drove the project early on to attempt to characterize this angle using Raman spectroscopy. After several more months of microscopically examining ultimates, however, a new hypothesis was developed, the theory of which is discussed below and visually summarized in **Figure 13**.

In isotropic fibers where $n_{\parallel}$ equals $n_{\perp}$, the material is not birefringent and thus is not visible (appears black) under XP (61, 65, 66). This occurs for fibers with no regular internal arrangement of molecules; an example is fiberglass, as glass is a well-known amorphous solid (22). Upon inserting the compensator, usually only an outline of the material is visible while its interior is the same magenta color as the field of view. In fibers such as polyester, the regular, semi-crystalline arrangement of polymer chains means the fiber is anisotropic (49). In such fibers, $n_{\parallel}$ does not equal $n_{\perp}$ and complete extinction occurs at the horizontal and vertical positions when viewed under XP.

However jute fibers, which are anisotropic, do not go to complete extinction when oriented in the vertical and horizontal positions due to random variation in the orientation of the

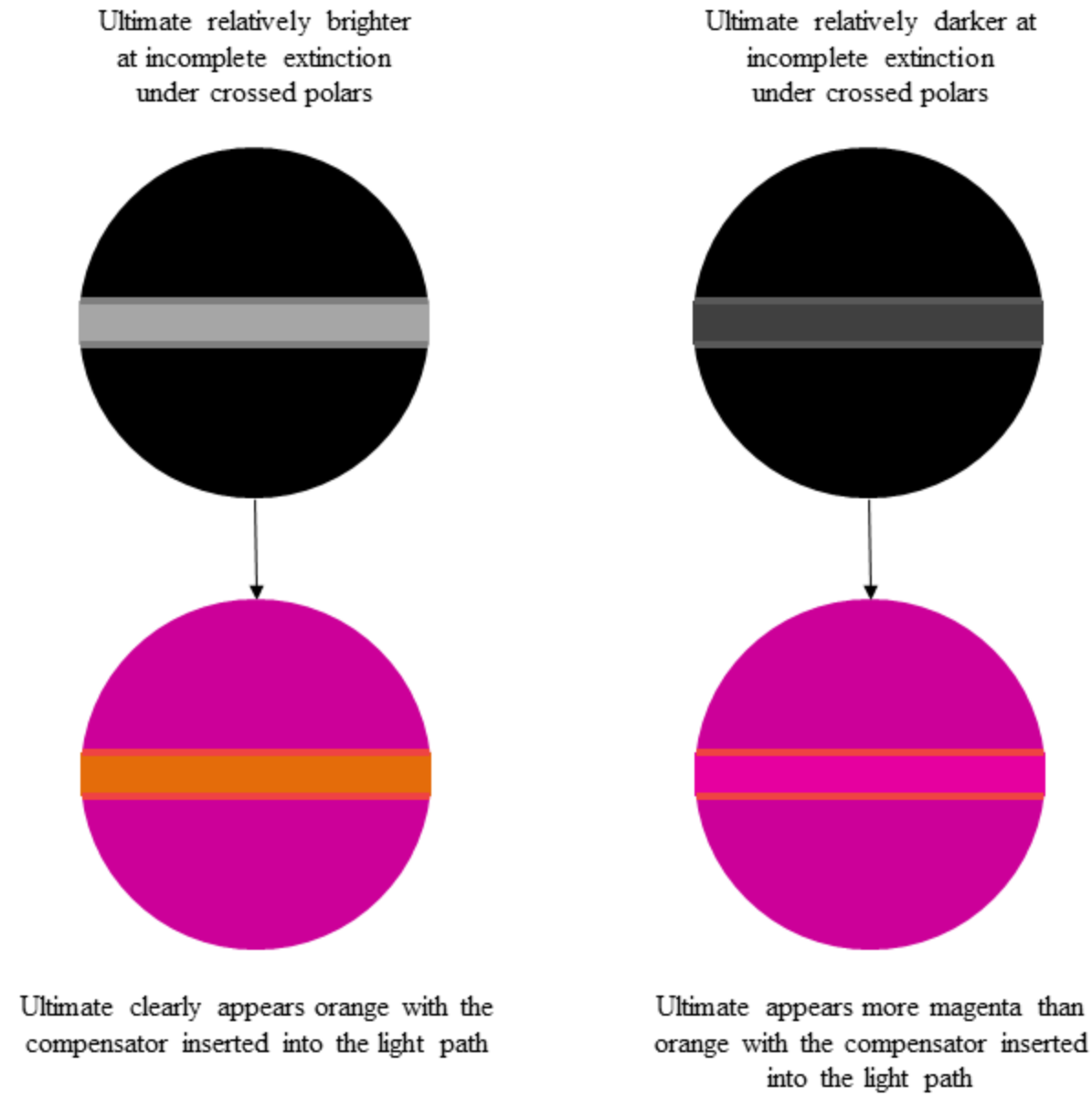

Figure 13. A new hypothesis to explain why some ultimates produce clear colors and others produce ambiguous colors during the Herzog test. At left, ultimates which appear brighter at extinction between XP produce clear orange or blue colors during the Herzog test. This is predicted to be due to a more regular ordering or cellulose microfibrils in the cell wall. At right, ultimates which go to more complete extinction between XP result in the more ambiguous magenta color during the Herzog test. This is hypothesized to be due to more disorder in the orientation of cellulose microfibrils in the cell wall.

cellulose chains. In general, the darker the interference colors observed under XP, the lower the birefringence and the more similar the refractive indices of the fiber parallel ($n_{\parallel}$) and

perpendicular ($n_{\perp}$) to the long axis of the fiber. These fibers that appear darker at extinction were observed to be the same ones that appear more magenta when viewed under XP with the compensator, producing an ambiguous result for the Herzog test (**Figure 13**). In contrast, the jute ultimates that remain brighter and go to a less complete extinction are the same ones that appear more clearly orange in the horizontal position and blue in the vertical position (**Figure 13**). Thus, it is hypothesized that ultimates displaying the more ambiguous, magenta color in the Herzog test which also appeared darker at extinction have more disorder in the orientation of their cellulose chains. Conversely the ultimates displaying clear oranges and blues in the Herzog test which were brighter at extinction are predicted to have a more ordered arrangement of cellulose microfibrils in the cell wall. SEM, X-ray diffraction, or Raman spectroscopy could be used to support these hypotheses if undertaken on a large scale for both species of *Corchorus* as well as other vegetable fibers. As much of the reviewed literature looked at small sample sizes for each species studied (33-35, 38, 40), a larger investigation could provide a new understanding of whether the colors observed in the Herzog test relate to the cellulose spiraling angle and, if so, how much the colors and angle varies in different plant species.

CHAPTER 4: Results and Discussion Part 2: Microscopic analysis of commercial jute goods

4.1 Rationale for the analysis of commercial goods analysis

Regardless of the persistent difficulties in distinguishing between fibers from each of the jute species, the ability to differentiate jute from other fiber types is necessary for more than just routine fiber identification in casework. Experienced examiners have noted that natural fiber products can contain fiber blends even if the products were advertised as a single fiber (53). To illustrate, a poorly executed proficiency test from the 1990s required fiber analysts to correctly identify manila hemp (also known as abaca, scientific name *Musa textilis*) in a sample of unlabeled cordage. However, the cordage purchased and furnished by the testing company was in fact was composed of a mixture of manila and sisal (scientific name *Agave sisalana*), even though the label indicated it was only manila. Analysts who correctly identified both were penalized while those who incorrectly only identified manila received full marks (53). Such proficiency tests impact the ability of analysts to maintain certification (67) and laboratories to maintain accreditation (68). Not only does this blunder illustrated why it is necessary to verify that product labels are accurate, it also demonstrates how vegetable fiber analysis is not as cut-and-dry as some may think.

4.2 Acquisition and summary of commercial goods

One hundred and thirteen commercial goods containing or made from jute, or samples of such, were collected. A subset of local brick-and-mortar and online retailers provided the goods either by sale or donation. The criterion to acquire a sample for the commercial goods collection was whether or not it was marketed as containing “jute” or “burlap”. Some samples advertised as

Table 2. Summary of commercial goods analysis by product type.

Product type	Total	Number containing jute fibers	Number containing other materials
Textile	85	69	15 polyester 1 unverified polyester
Geotextile	7	7	-
Cordage	7	7	-
Flooring	6	5	1 without fibrous material
Sacking	6	3	1 plastic weave 2 undetermined vegetable fibers
Miscellaneous	2	2	-
Total	**113**	**93**	**20**

"faux burlap" were also collected to investigate what types of fibers are currently being used in products designed as substitutes for true jute burlap. The items included in the commercial goods collection are summarized in **Table A.1** of **Appendix A**, which includes the unique sample identifier, the sample category, a description of the item, the source of the item, and the results of the analysis. All samples belonged to one of six categories: textiles, geotextiles, cordage, flooring, sacking, or miscellaneous. Of the 113 commercial goods analyzed, 93 contained jute and 20 contained non-jute fibers (**Table 2**). These results will be reviewed in more detail in **Sections 4.4—4.9** after a discussion of what characteristics were used to identify the fibers present in the commercial goods collection.

4.3 Features used to identify jute and non-jute fibers

Representative fibers from each item were microscopically analyzed to determine if they contained jute or substitute fibers based primarily on the presence of characteristic features of jute as described in **Sections 3.1—3.4**. This approach was chosen over others presented here

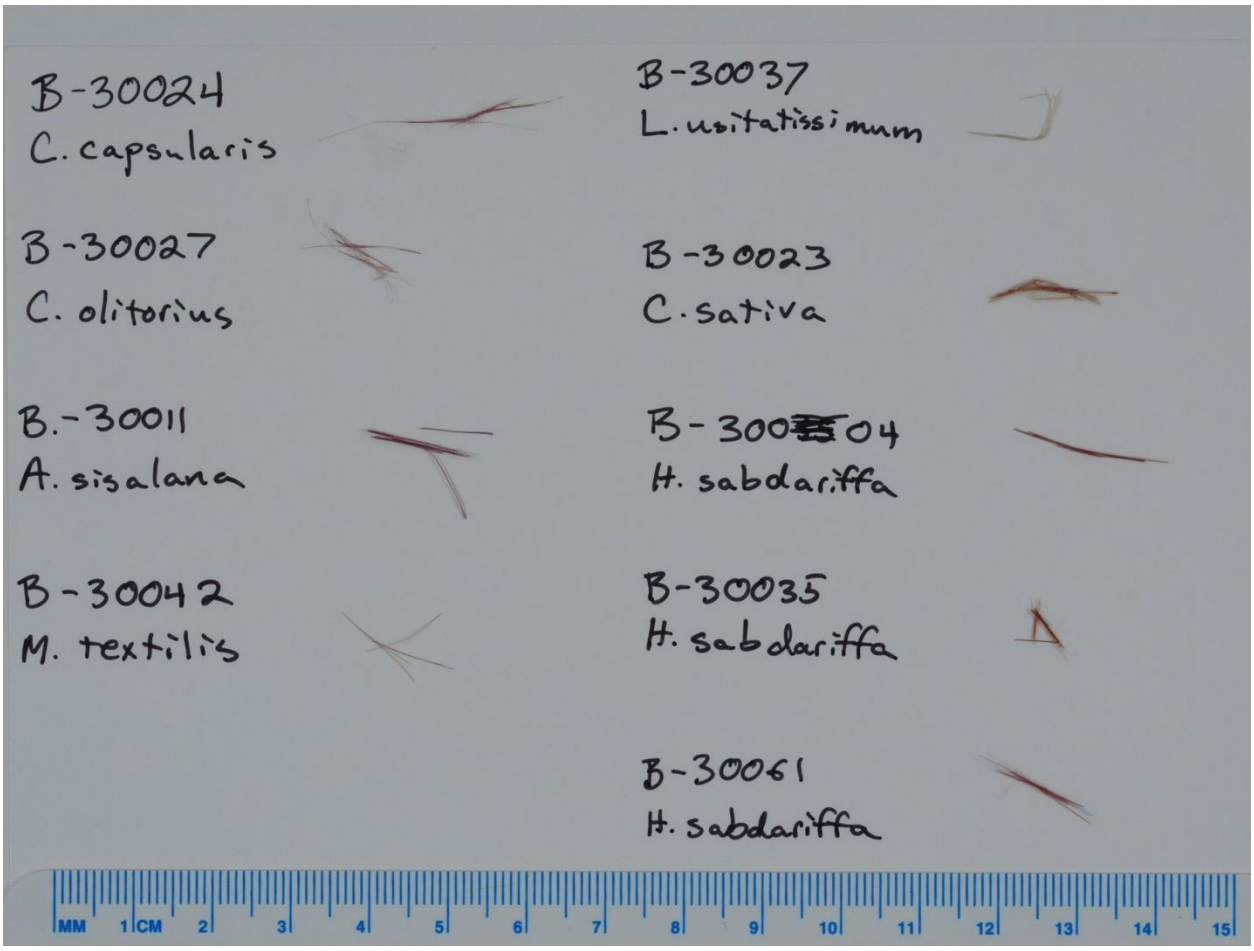

Figure 14. Photograph of the results of the phloroglucinol test for relative degree of lignification for reference samples of jute, some jute substitutes, and some common vegetable fibers. Darker pink staining indicated a higher degree of lignification. Scale as indicated in the photograph.

because it is recommended by the Scientific Working Group for Materials Analysis (SWGMAT) (44) and is well-aligned with current methods implemented by trace evidence analysts.

Several other features not previously discussed were used to verify whether or not a fiber was jute. First, a drop or two of phloroglucinol reagent was applied to sample cuttings to assess the relative amount of lignin in the vegetable fibers. Highly lignified fibers are stained a bright or dark magenta hue and partially lignified fibers a light to medium pink, while fibers with little to no lignin do not change color (20, 21). The results of the phloroglucinol test for selected reference vegetable fibers including jute, some jute substitutes, and other common vegetable

Table 3. Summary of the results of the phloroglucinol test for relative degree of lignification for reference samples depicted in Figure 14.

Sample number	Species	Expected color	Observed color
B-30024	*Corchorus capsularis*	Red to red-violet	Magenta
B-30027	*Corchorus olitorius*	Red to red-violet	Magenta
B-30011	*Agave sisalana*	Intermediate pink	Magenta
B-30042	*Musa textilis*	Intermediate pink	Pale pink
B-30027	*Linum usitatissimum*	No change to pale pink	No change
B-30023	*Cannabis sativa*	No change to pale pink	Pale pink to magenta
B-30004 B-30035 B-30061	*Hibiscus sabdariffa*	Lighter than jute	Magenta (all)

fibers were photographed, as shown in **Figure 14** and summarized in **Table 3**. *C. capsularis* and *C. olitorius* stained a vibrant magenta, as expected. *Agave sisalana* and *Cannabis sativa* both stained more darkly than predicted. The thickness of the *A. sisalana* fibers may explain why the stain appeared darker than expected. Most commercial *C. sativa* products are softer than the reference sample used for this experiment; it is possible that this particular sample contained more lignin than is typical due to incomplete extraction of the fiber from the plant or less processing than is typical for *C. sativa* commercial goods. In contrast, *Musa textilis* stained lighter than expected, although the very fine fibers of this sample may distort the perception of the color, making it appear paler. *Linum usitatissimum* had no visible color change as was expected. Finally, *Hibiscus sabdariffa* was expected to stain darker than intermediate pink but not quite as deeply magenta as jute. However, all three samples stained a bright magenta. The color by eye may have appeared slightly lighter than the deep magenta of the *Corchorus* samples, but not to an extent that this method could reliably distinguished these fibers.

It is important to note that the phloroglucinol test is not specific for jute, as many fibers can exhibit a high degree of lignification. However, these results can support an identification of a fiber when observed in in conjunction with other features. To this end, phloroglucinol was

added to all natural fibers in the commercial goods collection and the degree of staining was compared relative to the staining of the reference fibers noted above. The results are included in **Table B.1** of **Appendix B**. Most goods reacted strongly and stained a deep magenta to indicate heavy lignification, which supported the conclusion of most goods as containing jute fibers. Exceptions included textiles that were artificially dyed such dark colors (e.g. black or deep purple) that it was not possible to observe a color change. A few also displayed an intermediate pink color, although this happened most commonly on very lightly colored fibers. These samples may have been bleached to achieve such light coloring. Because these fibers contained all other features of jute, this single observation was not deemed to be inconsistent with identifying these few samples as jute.

Other macroscopics feature used to assist in the identification of jute from among other vegetable fibers is its characteristic heavy odor, texture when handled manually, and often earthy brown color. In general, bast fibers are typically softer than leaf fibers, and this holds true for jute when it is compared to fibers such as sisal. The nature of most jute goods obtained for this study is such that they are often more loosely woven, softer, and shed more fibers than other similarly available products. For example, sisal cordage from a hardware store may shed just as much as jute, but sisal has a more yellow color, is stiffer, and is less pungent. While hemp cordage might be of similar color and texture, it appears to shed slightly less and also has a characteristic odor that is easily distinguishable from that of jute. Such properties of gross samples can either facilitate an initial identification to later be confirmed or corroborate identification of a fiber based on microscopic characteristics. Because the amount of fiber evidence from a crime scene may be limited to only a single technical fiber, these properties are not always apparent for comparison. Nonetheless, experience with properties of bulk samples of

different vegetable fibers can provide an analyst with a valuable reference for comparison should larger samples be encountered in their casework, ensuring that no helpful information is overlooked.

Finally, one of the most helpful features in the identification of jute is its characteristically variable lumen (17, 27). For the most part, reference samples from the Microtrace Vegetable Collection had lumen which varied from slightly more than half the overall diameter at the widest points to tightly pinched as the narrowest points (refer to the thin and bolded arrows in **Figures 5 and 6**). Further, this feature was observed in the vast majority of the commercial jute samples (**Figure 15**). However, some samples, especially many of the commercial samples, also had ultimates with less variable lumens. In these ultimates, the lumen occupied roughly one-third of the overall diameter at the maximum, therefore being slightly narrower than the typical jute ultimate lumen (**Figure 15**). These lumens were less frequently pinched at their narrowest points and overall demonstrated more uniformity in diameter than the traditionally telltale ultimates with widely varying lumens. Interestingly, these more uniform lumens occurred fairly frequently in commercial goods but were less frequently observed in reference samples. This initially caused some doubt in considering whether the commercial goods could be true jute, given the mismatch in how frequently the different lumen types were observed. However, other reputable sources suggest that the wider variability in lumen morphology in the commercial goods compared to the reference samples does not necessarily indicate that the commercial goods were not true jute. Despite finding the thinner, more uniform lumens infrequently in reference samples observed in this work, Catling and Greyson include photomicrographs of the lumens of reference *C. capsularis* and *C. olitorius* specimens (27). These clearly depict not only a wide variety in relative lumen diameter within a single ultimate

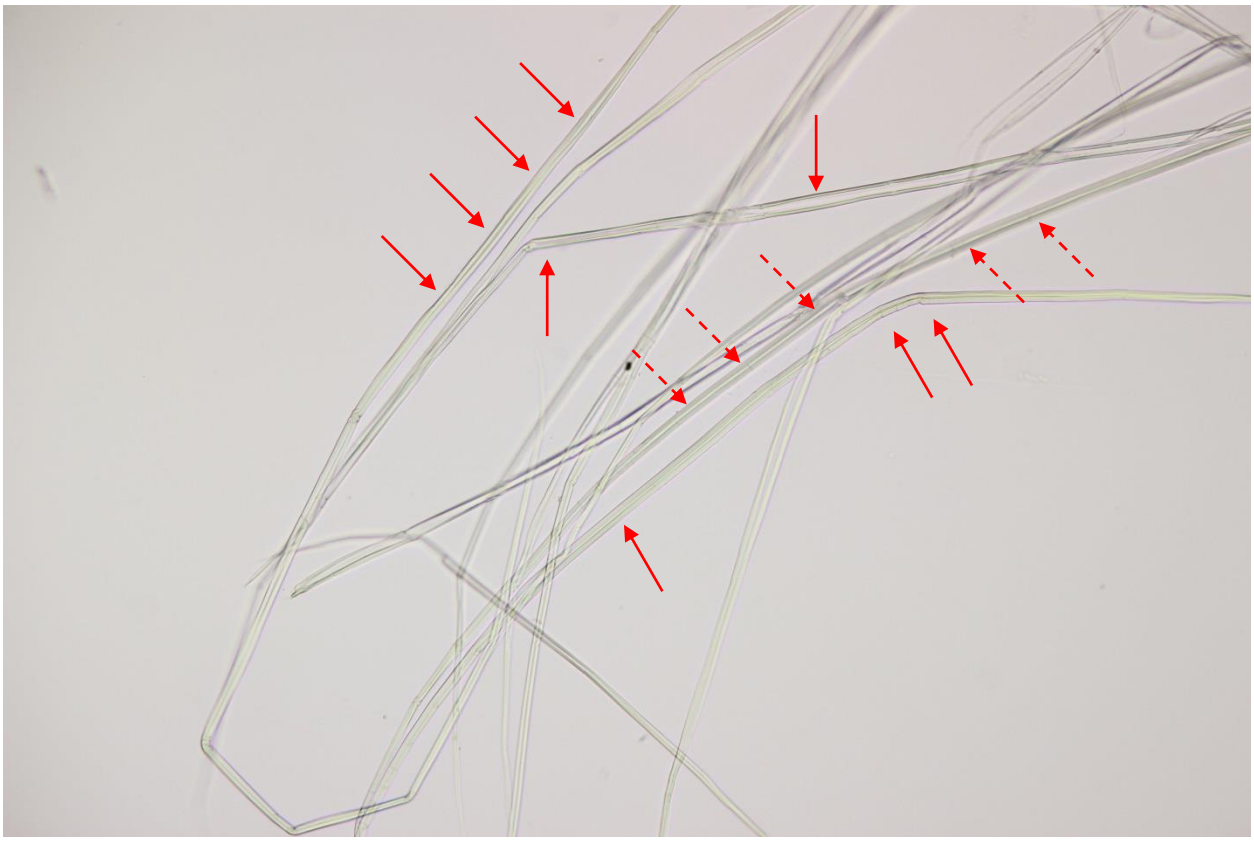

Figure 15. Ultimates from a sample of jute flooring (Sample BF-012) to demonstrate the variability in lumen morphology observed in many of the commercial goods. Solid arrows point of areas of ultimates demonstrating widely varying lumen diameter. Dashed arrows point to an ultimate demonstrating the more uniform and slightly narrower lumen morphology. Ultimates were mounted in glycerin jelly and photographed under plane polarized light (PPL) at 100X total magnification.

but also provide proof that the thinner lumen does indeed occur in both species. Thus, the variation in lumen diameter observed in the commercial samples was concluded to fall within the range of expected variation for both *Corchorus* species. This assisted in preventing false exclusions due to the lack of thinner lumen in the reference samples observed for this project.

4.4 Analysis of textile samples

Of the 85 textile samples, 78 swatches were obtained from two home decorating retailers and one specialty retailer, explaining why this product class is disproportionately represented in

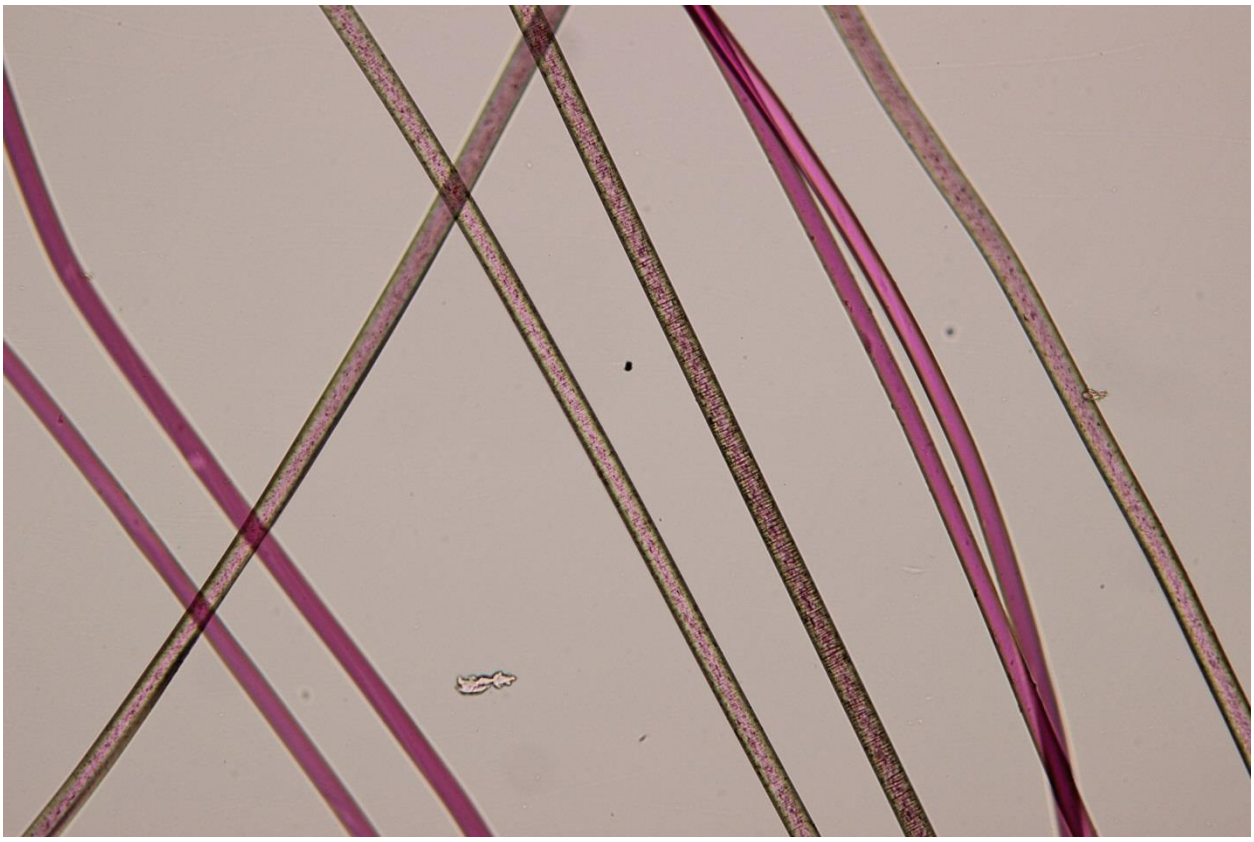

Figure 16. Blend of polyester fibers from a swatch of fuchsia textile advertised as "Vintage Burlap" (Sample BF-023). Only the more lightly colored fibers contained light-scattering delusterant particles. The relatively uniform diameter was indicative of a circular cross section. Fibers were mounted in Cargille oil of refractive index 1.70 and photographed under plane polarized light (PPL) at 200X total magnification.

the overall collection of goods. Sixty-nine samples were verified to contain jute, 15 contained polyester, and one was not analyzed because it was advertised as polyester "faux burlap".

One of the aforementioned home decorating retailers provided 10 samples, five composed of jute (BF-016 through BF-020) and five composed of man-made fibers which were smooth to the touch (BF-021 through BF-025). These latter five samples were identified as polyester on the basis of microscopically observed morphological and optical properties. **Figures 16 and 17** illustrate these features in Samples BF-023 and BF-024 respectively, which were representative of this group of samples. All five swatches contained a blend of polyester fibers with and without delusterant particles that were in all other aspects similar (**Figure 16**). All

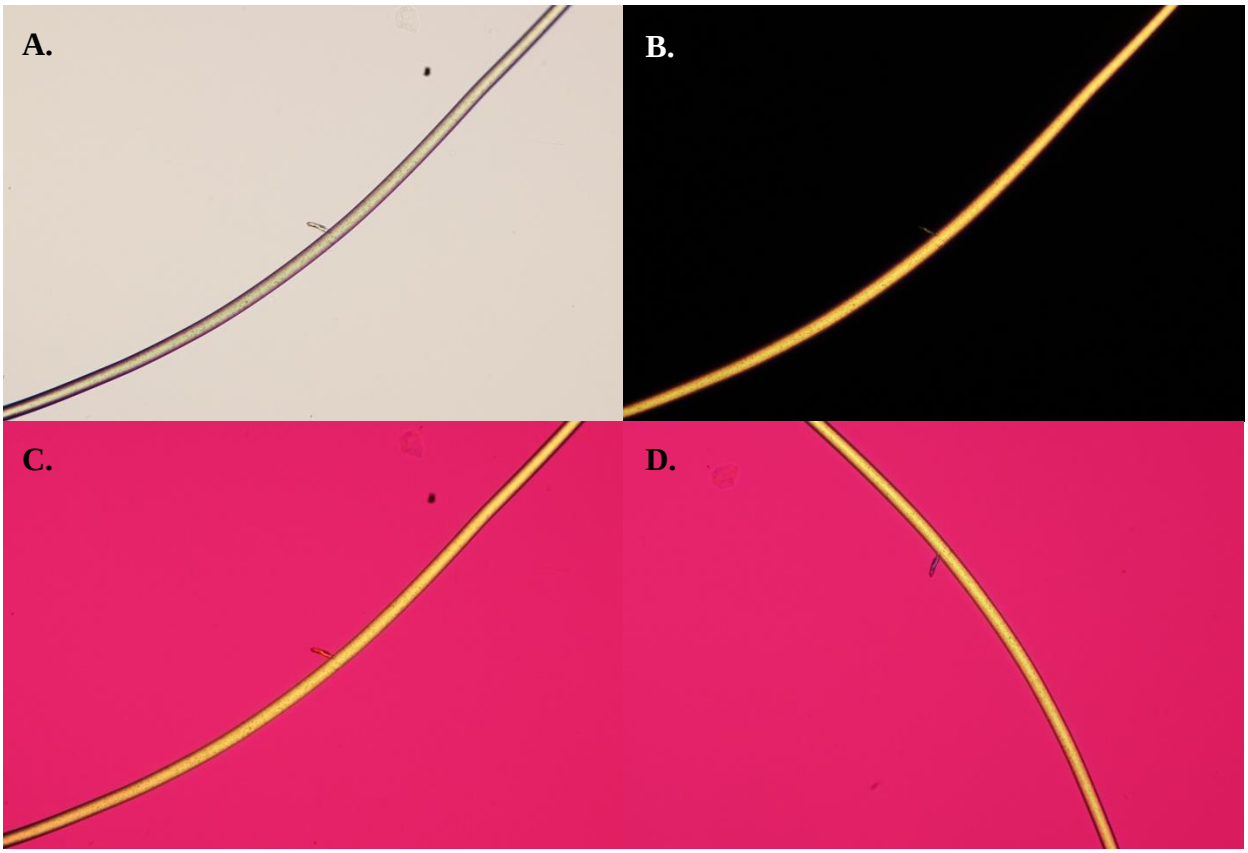

Figure 17. Photomicrograph series of a polyester fiber from a textile swatch advertised as "Vintage Burlap" (Sample BF-024). A. Reference photomicrograph in PPL in the NE-SW position. **B.** High (possibly fourth) order interference colors were observed between XP. **C.** In the NE-SW position the ultimate exhibits addition of wavelengths into higher order pastel colors, approaching white, between XP with the compensator in place. **D.** In the NW-SE position the ultimate exhibits subtraction of wavelengths to lower order pinks. Together **C** and **D** illustrate that this fiber had a positive sign of elongation. The fiber was mounted in glycerin jelly and photographed at 100X total magnification.

fibers had a reasonably consistent diameter between 14.8 and 19.8 μm and had an apparently circular cross-section as determined by the uniform diameter and symmetric pattern of birefringence colors under XP (**Figure 17B**). Refractive indices for these five samples determined an $n_{\parallel}$ of approximately 1.70 and an $n_{\perp}$ of approximately 1.53 to 1.55. From these refractive indices the calculated value for birefringence is approximately 0.15 to 0.17, indicating a positive sign of elongation which is corroborated by the presence of addition colors in the northeast-southwest (NE-SW) position and subtractive colors in the northwest-southeast (NW-

SE) position when the fibers are viewed under XP with the first order red compensator (**Figures 17C and 17D**). All of these characteristics are consistent with polyester.

These five samples were advertised as five different colors of a product named “Vintage Burlap”. The webpage listing all product samples, from which swatches were typically ordered, included the fiber composition for all other products except these (69). Interestingly, this main webpage did not elaborate on the fiber composition for these five “Vintage Burlap” products. A customer could click to request more information, at which point individual pop-up boxes for these five products did disclose that they were composed of polyester. Because these five samples were less clearly labeled than as all other products, such fabrics could be ordered under the incorrect assumption that the product is dyed burlap made from true jute. Curiously, the five samples from the same company that contained jute but were not advertised in the product name as such. This information was again only found by again searching the detailed product description. This perhaps suggest that the visual appearance and texture of burlap is more desirable for interior decorating purposes, which is reasonable as true jute products shed substantially and may therefore not be ideal for many customers.

The burlap specialty retailer furnished every sample in its collection for this study, a total of 62 samples. Fifty-eight were confirmed to be true jute while the remaining four (BF-026 through BF-028 and BF-032) were determined to be polyester on the basis of properties similar to those described earlier in this section. Upon review of the seller’s website (70), the specifications for the jute burlap mentioned slight imperfections in the fabric, its biodegradability, and a warning that machine washing and drying can unravel and damage the fabric. In contrast, the four polyester “burlap” products were clearly labeled as faux burlap and advertised as “creating the same rustic atmosphere as burlap” (71). Another online retailer

marketed their products (primarily table linens for events) as superior to true jute. The website noted shedding of fibers, the distinctive earthy odor, the inability to be machine washed, and the coarse texture as disadvantages when compared to the polyester material from which all their products were manufactured (72). Similarly, another interior decorating company provided seven samples, six of which were polyester but only one of these was expressly advertised as faux burlap (73). These advertisements from sellers may provide insight as to why polyester is being used by multiple companies to replace jute burlap; namely, that polyester is more easily cared for, less easily damaged, and longer lasting. These advantages likely explain the use of polyester as a man-made substitute fiber for jute, particularly for interior decorating purposes.

4.5 Analysis of geotextile samples

Seven geotextile samples, all consistent with true jute, were obtained from two individuals associated with Michigan State University (MSU) Department of Horticulture. Thus they not retailers but were end users of the burlap geotextiles. None of the samples (samples BF-001 through BF-003 and BF-106 through BF-109) could be attributed to a specific manufacturer but all were leftovers from the usual course of their work for the Department of Horticulture. One provider stated that the burlap was purchased for wrapping tree roots while the other added that the burlap could also be used to prevent the erosion of ecological features such as river banks. All were verified as true jute on the basis of macroscopic observation of the color, texture and odor of the bulk item; deep magenta staining in the phloroglucinol test indicating high lignin content; and microscopic observation of ultimates.

4.6 Analysis of cordage samples

Six samples of cordage were obtained from a popular home improvement store, a dollar store, a Midwestern big-box store, and an online Ebay seller (samples BF-010, BF-089, BF-098 through BF-101, and BF-113). All were verified as consistent with true jute as described above.

4.7 Analysis of flooring samples

Five samples (BF-011 through BF-015) of different jute floor coverings were obtained from an online store specializing in vegetable fiber rugs. These five samples represented all of the retailer's jute offerings and came with a rubbery backing to prevent skidding. All were found to contain jute fibers on the basis of the same macroscopic characteristics, reaction in the phloroglucinol test for lignin, and microscopic characteristics as described above.

A single sample of carpeting was obtained from a popular home improvement store upon asking if the store sold any carpet with jute backing. The employee was unsure if there was jute in the sample provided for this study, and indeed a visual examination determined that the backing was composed of a plastic mesh and no fibrous material was apparent. This agreed with reports from carpet manufacturers and the International Jute Study Group (IJSG) that the popularity of jute carpet backings has been steadily declining in favor of more durable synthetic materials (41, 74).

4.8 Analysis of sacking material samples

Five samples of sacking materials were obtained for analysis. One (BF-004) was excluded as it was provided by the MSU Department of Horticulture as an example of the synthetic materials replacing burlap sacking for sandbags. It was woven from strips of a plastic

polymer material but was otherwise not fibrous in nature. The other five sacks were obtained from a local coffee retailer. As an end recipient rather than original merchant of the sacks, the shop was therefore not responsible for the advertising of the sack as jute or any other material. However, the staff was knowledgeable enough to provide three samples of sacks they believed to be burlap and two sacks of a lighter-hued fiber which they could not identify. On the preliminary inspection, the three samples (BF-007 through BF-009) had the characteristic brown color, scratchy but soft texture, and odor of true jute. These three sacks were used for the transportation of coffee beans from India, Indonesia, and Ethiopia. One sack (BF-007) contained a tag indicating that the bag itself, as opposed to the coffee beans, originated from a jute mill in India. All criteria for the determination of the bags as jute were met for these three samples.

The other two sacks (BF-005 and BF-006) were used for the transportation of decaffeinated green coffee beans from Colombia. These were a pale straw color, much scratchier than jute, less pliable than jute, and not as soft as jute. These features are all consistent with sisal (*Agave sisalana*). Microscopic analysis revealed the presence of two fibers types (**Figure 18**).

The first had a very wide lumen, a diamond-shaped pattern along the entire ultimate, and lacked nodes, dislocations, and cross markings. The diamond pattern appears or original from dark markings that look like four-pointed stars. In general, these ultimates were somewhat shorter and plumper than jute ultimates. The star shapes and diamond pattern are similar to features of coir (*Cocus nucifera*) fiber ultimates, which most resembled the unknown fiber. However, a sample of coir fiber was not available for analysis and thus a definitive comparison of all features could not be made.

The second, more common fiber in the sample had a more uniform lumen roughly one-third to one-half of the overall fiber diameter, few nodes and dislocations, and rare cross

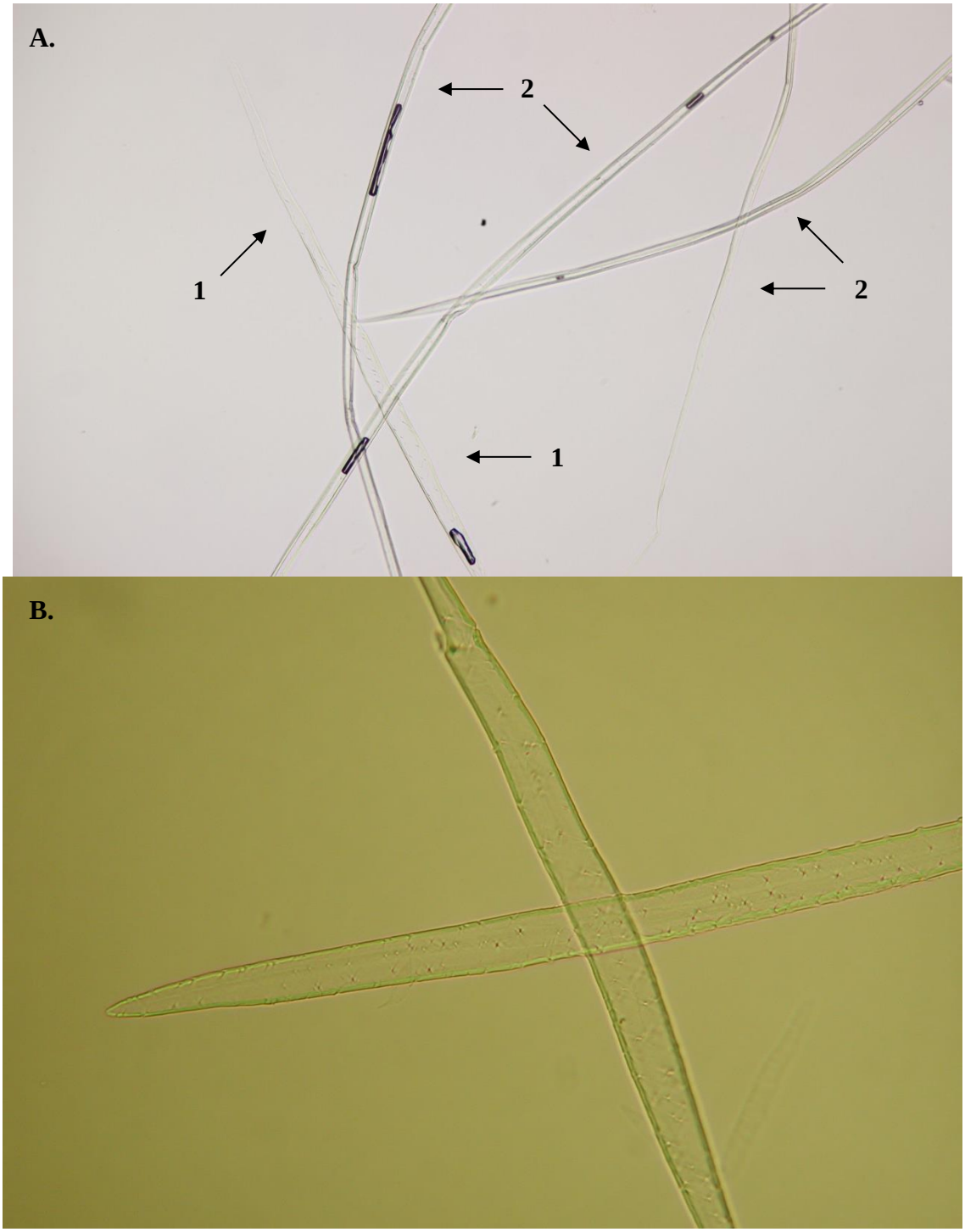

Figure 18. Blend of macerated fibers from coffee bean sacking (Sample BF-005) and comparison to macerated coir fibers (Sample B-30002). A. Numbered arrows point to the two types of fibers found in the macerated sample from the coffee sack. Fibers were mounted in glycerin jelly and photographed under PPL at 100X total magnification. **B.** Reference image of coir fibers to demonstrate similarity to the first unknown fiber in the coffee sack. Fibers were mounted in water and photographed under PPL at 200X total magnification.

markings. This fiber demonstrated first order pale gray interference colors, had a positive sign of elongation, and twisted in the Z direction. Due to the similarity of the bulk sample with other macroscopic properties of sisal, this fiber was tentatively identified as sisal. When ashed, *A. sisalana* samples typically reveal a large number of acicular (needle-shaped) crystals occurring singly, in pairs, or in small groups (27). Sometimes the crystals also appear curved like small black bananas if any leaf material remained attached to the crystals at the time of ashing (27). While ashing samples was not possible with the equipment available in the laboratory, this method could have been used to confirm that *A. sisalana* was the primary fiber present in the two coffee sacks.

4.9 Analysis of miscellaneous samples

Two items in this category were obtained. The first (BF-103) was a sample of fibers tweezed from a multi-level cat scratching post and climbing tower. The tag on the item indicated that the fabric covering each layer of the climbing toward was jute. The second (BF-112) was burlap twine trim around the edges of a decorative holiday ornament. Both were confirmed to be consistent with jute by the same methods as described for other samples.

4.10 Trends in jute fiber substitution in commercial goods

That the geotextile, cordage, and miscellaneous jute products were verified as true jute was unsurprising. The goods were marketed as such, and in general, a consumer expects a product label to be accurate.

While 20 out of 113 examined jute or burlap products, or 18%, were found to contain non-jute materials, none of these 20 samples seemed to represent deliberate inaccuracies in

product labeling. All 16 of the non-jute textile samples were obtained from online retailers and were concluded to contain polyester. As was mentioned directly on the retailer's websites, the durability, ease of maintenance, and burlap-like appearance of polyester likely explains why this synthetic fiber was found to be widely advertised as a substitute for true jute burlap, particularly for indoor applications. Additionally, the fact that a home improvement store employee advised that the store might no longer carry carpet with jute backing concurred with the IJSG statistics that few carpets are currently being manufactured with jute backings when more durable synthetic options are available.

In contrast, it may initially be surprising that as sacking rose from 39% to 58% of jute exports from India and Bangladesh in the last two decades, only half of the sacks analyzed in this study did not contain jute (41). Certainly the small number of sacks analyzed limits any widely generalizable conclusions. However, sacking traditionally used for animal feed has largely been replaced with more durable synthetic materials (75). The international transportation of coffee beans evidently still utilizes jute sacks, as three were obtained for this project from a local coffee shop. Although two of the five coffee sacks were composed of non-jute fibers, it would be hasty to draw conclusions about how commonly each sack may be in this market. It is interesting to note that the non-jute vegetable fiber sacks were used solely for the transportation of decaffeinated coffee beans, perhaps as a way to provide packaging which prevents confusion between caffeinated and non-caffeinated varieties. Without knowing how much of the coffee bean market is occupied by caffeinated versus decaffeinated beans that adhere to such a packing scheme, it is not realistic to assume only half of jute sacks are actually jute. It must be remembered that these sacks were obtained from end-users rather than the entities that

manufacture, advertise, and sell them, and thus it may be that the two non-jute sacks would never have been mistaken for jute in the first place.

4.11 Difficulties encountered in the analysis of commercial goods

Commercial goods typically showed slightly more variability in features than the reference samples. This may be possible due to the larger number of jute commercial samples (nearly 100) compared to the number of reference samples (nine). With regards to the lumen diameter, one possible reason why the reference sample lumens don't show as much variability may be due to the age of the plants when the fibers were harvested. The age of the samples affects how much of the secondary cell wall is deposited, with more of the wall being laid down over time. Plants that were older at the time of harvest have more time to lay down secondary cell wall than plants harvested earlier. It may be possible that the reference samples were collected from less mature jute plants than those used for the commercial goods. Further, it is unknown whether the manufacturers of jute goods typically use jute harvested from a single source or whether bales of jute from multiple sources are mixed together before using them to manufacture retail goods. Hence it is possible that the ultimates observed from commercial goods more accurately represent lumen morphology of the entire jute population. While a country of origin and year of collection is available for all reference jute samples, it is impossible to definitively show if plant age at harvest might explain the wider variety in lumen morphologies among the commercial samples versus the reference samples.

Another limitation of this work was the use of characteristic fiber odors and textures to aid in identification. These are both inherently subjective criteria, which imply that the analyst must have sufficient experience with handling fiber samples to accurate interpret the significance

of these two properties. If such mastery can be achieved, these properties may be helpful in ruling out jute from other fibers. For example, hemp (*C. sativa*) and flax (*L. usitatissitmum*), and sisal (*A. sisalana*) can be quickly eliminated from consideration in this way. This can be particularly true if the ultimates of the two species are very similar to each other, as in the case of several jute substitutes, including roselle (*Hibiscus sabdariffa*), kenaf (*H. cannabins*), and aramina (*Urena lobata*). To extend the utility of this approach, unsuccessful efforts were made to obtain any size reference sample of textiles made from these latter three fibers. The difficulty in obtaining swatches or any product made from these fibers may be interpreted as an indication of how rarely they are available in the United States. Thus, it was considered unlikely that any of these jute substitute fibers might have been used in any of the commercial goods. While odor and texture aided the identification of samples as jute, such interpretations should be made cautiously and not be used as a sole criterion by which to exclude the presence of other fibers in a sample.

A final limitation of this work arises from bias introduced in which stores were selected in order to request or purchase samples. On a broad scale this study is limited to retailers willing to provide samples at low or no cost. Ideally, multiple stores of the same type (e.g. multiple home improvement stores) in multiple locations would have been visited. Further, more than one unit of each product would have been obtained in the same visit and by visiting the store over the course of several months or years. These measures would help identify if products may only occasionally contain non-jute fibers as a result of occasional changes in suppliers or represent more consistent substitutions. Such a rigorous sampling procedure would permit more general conclusions to be drawn about fraud trends in jute and burlap product mislabeling.

4.12 Photography of commercial goods samples for the future development of a jute fiber database

All commercial goods were photographed macroscopically to record the physical state of the products at the time of purchase, sampling, or analysis. Additionally, a series of photomicrographs has been nearly completed for every sample. In this context, a complete set of photographs for a sample includes the macroscopic image of the sample and nine photomicrographs of one or more representatives ultimates oriented in four positions: the NE-SW position (one in PPL, one between XP, and one between XP with the compensator inserted), the NW-SE position, vertical, and horizontal (the latter all being collected both between XP and between XP with the compensator). This full range of images provides an invaluable, comprehensive repository of reference images which can be used to impartially confirm observations traditionally recorded in writing. Many highly-regarded reference texts suffer from a finite space in which to publish images, resulting in inclusion of only one or two photomicrographs which cannot fully depict all microscopic features of a fiber (22, 27, 47-50, 61, 63). This visual reference library intends to improve the uniformity of vegetable fiber analysis among fiber analysts across the country. New analysts can consult this compendium and evaluate for themselves morphological and optical phenomena unique to different samples. Misinterpretation of the written observations and inappropriate applications of such information by novice analysts can become something of the past.

The short-term goal is to electronically publish these images, along with the corresponding written descriptions and interpretations, to serve as a freely available reference to forensic or other scientists interested in the natural variation in jute fibers and current trends in jute fiber substitutions. In addition, a summary of the frequency with which substitute fibers are

used in different classes of jute products will also be included with the database. The long-term goal is develop the database so that it can be updated with submissions by users of jute goods that they encounter in casework. This will serve the purpose of improving the scope of the goods included in the database to be more representative of the occurrence of jute goods available on the market. To date, no studies have examined how frequently different types of jute goods are subject to misleading labeling or outright substitution of fibers. In laboratories with limited time and resources, this complication aims to be a useful commentary on current trends to assist examiners in a more thorough examination of particular product types.

CHAPTER 5: Conclusions and Future Work

5.1 Efforts to identify a method to discriminate jute fibers from *C. capsularis* and *C. olitorius*

Microscopic observations of morphology and optical properties, measurement of ultimate dimensions, and simplified Raman analysis of the cell wall cellulose orientation were unable to differentiate ultimates from *C. capsularis* and *C. olitorius*. Without a rapid, inexpensive, and simple method to determine which species of jute is present in a sample it is in turn not possible to determine whether commercial jute goods contained one or both jute species. Such a method could therefore provide an additional level of discriminatory information about possible sources of questioned samples from crime scenes after initial identifying a sample as jute. Specifically, such information could aid an investigation if an item of jute evidence originated from only one species and known samples for comparison contained jute from the same, the other, or both jute species. The experiments detailed herein describe one of the first dedicated attempts to distinguish ultimates of the jute species in an effort to provide this additional information to forensic laboratories and investigators.

A limitation of this approach is that it is currently unknown whether commercial goods often contain jute fibers from just one or both *Corchorus* species. Given that they have slightly different preferred habitats (13, 14), it may be that jute plants are harvested on site and only sent to nearby distributors with the result that manufacturing companies buying locally may, knowingly or unknowingly, be only using fibers from a single species of jute in their goods. Conversely, it is also possible that jute plants and fiber are sourced from such wide geographical regions that some or even all manufacturers produce goods which are a blend of fibers from both species. In the absence of a simple, rapid, and inexpensive technique for differentiating fibers of

the two species or a consistently traceable system of marking the origin of plants used in manufactured goods, most modern laboratories remain unable to determine which species are present in commercial available jute products.

However, this need not be the end of the story. The Raman spectroscopy analysis performed in this work was a vastly simplified version of the analysis undertaken by the original authors of the method (33-35). Full statistical modeling of Raman spectra from many samples of the two species may indeed reveal differences in the cellulose spiraling angle that the simplified analysis was unable to detect. Moreover, as Raman spectroscopy becomes more widely used for forensic cases (76, 77), increasing the number of applications of this technique improves the affordability of the instrument and serves to make it more a more widely accepted technique both in the laboratory and in the courts. As a result, it is suggested that any future efforts toward characterizing the cellulose spiraling angle of the jute fibers be focused on more closely reproducing the technique as it was applied by the original authors (33-35).

5.2 Evaluating the frequency with which goods advertised to contain jute are composed of other fibers

Slightly fewer than 18% of commercial textile, geotextile, cordage, flooring, sacking, and miscellaneous jute goods were determined to contain fibers other than jute. The overall lack of non-jute vegetable fibers was somewhat surprising, given the proficiency test mishap from the 1990s (which partially inspired this project) and published literature on the frequency of natural fibers products being swapped or mislabeled (12, 78). However, some of the referring literature was published several decades ago, likely before the widespread adoption of synthetic materials for such applications as livestock feed and carpet backing (41, 74, 75). Such a decline in the use

of jute for these applications may have resulted in lesser demand, reducing former instances of substituting it out for less expensive or more readily available fibers. Furthermore, many of the jute textile samples analyzed here were obtained from craft or specialty retailers catering to a developed world market with disposable income. Therefore it may not be surprising that polyester, a more durable fiber that can create fabrics with appearance of jute without the inconveniences (shedding fibers, pungent earthy odors, and an inability to machine wash the fabric), is currently the most common fiber substituted in goods marketed as jute.

In general, the small number of samples analyzed for all product categories except textiles raises concerns about whether this analysis can be representative of all jute goods currently available in the United States and in the world. A limitation of this pilot study was that the collection of commercial goods was limited to what was inexpensively available in a limited geographical area over a short period of time and what was available inexpensively from online retailers. It follows that future studies could improve upon this work by including a more representative sample of jute products available on the market by obtaining multiple units of products from all stores selling these goods. This would help determine if some stores are more likely to carry mislabeled products. Additionally, repeatedly obtaining these goods from the same retailers would allow analysis of whether the frequency of mislabeling at a given store is relatively constant or if it changes over time, perhaps due to switches in suppliers. Detecting or reducing instances of fraud may be avoided by requiring shipments or batches of jute and vegetable fiber goods sold in the United States to provide certificates of verification clearly stating where the jute used in the item came from. Such protections may be difficult to enact and enforce, as much of the manufacturing takes place overseas, even if it does ensure that the customer receives the product they are paying for.

By continuing to pursue the development of an online database of jute goods, the ability to accommodate user submissions of jute items encountered in casework strives to improve its representation of jute products in circulation with time. Prior to this work, no studies examined how frequently jute mislabeling occurred in different types of products claiming to contain jute. Without this systematic study of how often and in which product types such substitutions are likely to occur, the forensic fiber examiner is ill-equipped to know how likely it is that he or she is dealing with a jute substitute rather than true jute. Familiarity with the products in which substitutes commonly replace jute can thus guide an examiner toward a more thorough examination of particular products, thereby ensuring an efficient use of time and resources.

APPENDIX

Table A.1. Description of items in commercial goods collection and results of microscopic analysis.

Sample identifier	Sample class	Physical Condition	Item description	Source	Analysis results
BF-001	Geo-textile	Cutting	Large, loosely woven burlap geotextile used for erosion control.	Dan Bulkowski (MSU Horticulture)	Jute
BF-002	Geo-textile	Large piece	Medium weave burlap for wrapping tree roots (horticulture). Medium-sized piece. May be from same source as BF-003.	Dan Bulkowski (MSU Horticulture)	Jute
BF-003	Geo-textile	Large piece	Medium weave burlap for wrapping tree roots (horticulture). Large piece. May be from same source as BF-002.	Dan Bulkowski (MSU Horticulture)	Jute
BF-004	Sacking	Large piece	Synthetic burlap. Often used for sandbags.	Dan Bulkowski (MSU Horticulture)	Woven plastic polymer
BF-005	Sacking	Whole	Sacking used for transporting decaf green coffee beans from Colombia, South America. Some red and green threads used. Bag printed with information. Front: A. LAUMAYER, GREEN COFFEE BEANS, 70 kg Net, 3 02 0458. A red number "20" is written and circled. Reverse: ARMENIA EXCELSO, PRODUCT OF COLOMBIA, 3 02 0458.	The Coffee Barrel 2237 Aurelius Rd. Holt, MI http://www.thecoffeebarrel.com/index.phtml	Unidenti-fied vegetable fiber

Table A.1 (cont'd).

BF-006	Sacking	Whole	Sacking used for transporting decaf green coffee beans from Colombia, South America. Some red and green threads used. Bag printed with information. Front: A. LAUMAYER, GREEN COFFEE BEANS, 70 kg Net, 3 02 0458. Reverse: ARMENIA EXCELSO, PRODUCT OF COLOMBIA, 3 02 0458.	The Coffee Barrel 2237 Aurelius Rd. Holt, MI http://www.thecoffeebarrel.com/index.phtml	Unidenti-fied vegetable fiber
BF-007	Sacking	Whole	Sacking used for transporting coffee beans from India. Bag printed with information. Front: INDIAN COFFEE, MONSOONED MALABARAA, ALLANA Reverse: C:111400000633, 14/53/2012/38/C.No.26738, OAKLAND, UNITED STATES, NETT 50 KILOS, 233 There is also a tag on the bag itself. The tag reads: FOOD GRADE JUTE BAG, MADE IN INDIA, HOWRAH JUTE MILL, H5JM(illegible letter)NC3QL	The Coffee Barrel 2237 Aurelius Rd. Holt, MI http://www.thecoffeebarrel.com/index.phtml	Jute

Table A.1 (cont'd).

BF-008	Sacking	Whole	Sacking used for transporting coffee beans from Ethiopia. One strand of hot pink fiber used. Bag printed with information. Front: BAGERSH, PRODUCE OF ETHIOPIA, 010/0006/0028, CERT.NO.0028. Handwritten: 20210. Reverse: WASHED, YIRGACHEFFE, GRADE 2, ORGANIC, BCS OKO GARANTIE	The Coffee Barrel 2237 Aurelius Rd. Holt, MI http://www.thecoffeebarrel.com/index.phtml	Jute
BF-009	Sacking	Whole	Sacking used for transporting coffee beans from Indonesia. Several trans of teal fibers used. Bag printed with information. Front: 015/8828 (illegible), JAVA EST (illegible), WASHED ARABICA GRADE 1, WONOSOBO, PROD. OF INDONESIA.	The Coffee Barrel 2237 Aurelius Rd. Holt, MI http://www.thecoffeebarrel.com/index.phtml	Jute
BF-010	Cord-age	Whole	Three pack of 36 m jute twine. Two spools are natural color, one speel is green. Label states the brand is Tool Bench Hardware. Made in China, imported into the US by Greenbrier International, Inc. at 500 Volvo Parkway, Chesapeake, VA 23320.	Dollar Tree, 5823 West Saginaw Highway, Lansing, MI 48917	Jute

Table A.1 (cont'd).

BF-011	Floor-ing	Swatch	8cm x 8.5cm swatch. Rug swatch with rubber-like backing to improve adhesion to floor to reduce slippage. Sample name: Jute Mahal, White. Color is ivory. Some dark spots.	Sisal Rug Direct online store Order #100033338 Contact: sales@sisalrugs.com Website: http://www.sisalrugs.com/	Jute
BF-012	Floor-ing	Swatch	8cm x 8.5cm swatch. Rug swatch with rubber-like backing to improve adhesion to floor to reduce slippage. Sample name: Jute Mahal, Birch. Color is uniform, cool, light brown.	Sisal Rug Direct online store Order #100033338 Contact: sales@sisalrugs.com Website: http://www.sisalrugs.com/	Jute
BF-013	Floor-ing	Swatch	8cm x 8.5cm swatch. Rug swatch with rubber-like backing to improve adhesion to floor to reduce slippage. Sample name: Jute Mahal, Artic Gold. Multi-colored from ivory to a warm, honey reddish-brown.	Sisal Rug Direct online store Order #100033338 Contact: sales@sisalrugs.com Website: http://www.sisalrugs.com/	Jute
BF-014	Floor-ing	Swatch	8cm x 8.5cm swatch. Rug swatch with rubber-like backing to improve adhesion to floor to reduce slippage. Sample name: Jute Mahal, Wheat. Color is light, warm brown.	Sisal Rug Direct online store Order #100033338 Contact: sales@sisalrugs.com Website: http://www.sisalrugs.com/	Jute
BF-015	Floor-ing	Swatch	8cm x 8.5cm swatch. Rug swatch with rubber-like backing to improve adhesion to floor to reduce slippage. Sample name: Jute Mahal, Clay. Color is light, warm brown.	Sisal Rug Direct online store Order #100033338 Contact: sales@sisalrugs.com Website: http://www.sisalrugs.com/	Jute

Table A.1 (cont'd).

BF-016	Textile	Swatch	13cm x 14cm swatch. Sample name: Meridian Woodsmoke (SID: 592) Natural color with print.	Regal Drapes online store Website: www.regaldrapes.com	Jute
BF-017	Textile	Swatch	13cm x 14cm swatch. Sample name: Meridian White (SID: 591) Ivory color with print.	Regal Drapes online store Website: www.regaldrapes.com	Jute
BF-018	Textile	Swatch	13cm x 14cm swatch. Sample name: Meridian Natural (SID: 590) Gray with print.	Regal Drapes online store Website: www.regaldrapes.com	Jute
BF-019	Textile	Swatch	13cm x 14cm swatch. Sample name: Lumine White (SID: 545) Ivory with blue (silky, non-jute) embroidery.	Regal Drapes online store Website: www.regaldrapes.com	Jute
BF-020	Textile	Swatch	13cm x 14cm swatch. Sample name: Lumine Fall Leaf (SID: 544) Gray with black (silky, non-jute) embroidery.	Regal Drapes online store Website: www.regaldrapes.com	Jute
BF-021	Textile	Swatch	13cm x 14cm swatch. Sample name: Vintage Burlap Khaki (SID: 867)	Regal Drapes online store Website: www.regaldrapes.com	Polyester
BF-022	Textile	Swatch	13cm x 14cm swatch. Sample name: Vintage Burlap Orange (SID: 869)	Regal Drapes online store Website: www.regaldrapes.com	Polyester
BF-023	Textile	Swatch	13cm x 14cm swatch. Sample name: Vintage Burlap Fuchsia (SID: 865)	Regal Drapes online store Website: www.regaldrapes.com	Polyester
BF-024	Textile	Swatch	13cm x 14cm swatch. Sample name: Vintage Burlap Ivory (SID: 866)	Regal Drapes online store Website: www.regaldrapes.com	Polyester

Table A.1 (cont'd).

BF-025	Textile	Swatch	13cm x 14cm swatch. Sample name: Vintage Burlap Avocado (SID: 862)	Regal Drapes online store Website: www.regaldrapes.com	Polyester
BF-026	Textile	Swatch	Faux Burlap Collection 60" roll 100% polyester Color: Vintage Jute (cool, light variegated brown)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807	Polyester
BF-027	Textile	Swatch	Faux Burlap Collection 60" roll 100% polyester Color: Cinnamon (warm, medium brown)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Polyester
BF-028	Textile	Swatch	Faux Burlap Collection 60" roll 100% polyester Color: Winter Wheat (light, neutral wheat brown)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Polyester
BF-029	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Bridal Rose	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-030	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Ceremony White	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-031	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Espresso	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-032	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Winter Wheat (Faux)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Polyester

Table A.1 (cont'd).

BF-033	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Perfect Pink	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-034	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Rainforest	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-035	Textile	Swatch	The Bridal & Event Collection 11 oz/48" roll Color: Sea Glass Green	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-036	Textile	Swatch	11 oz/60" burlap Color: Natural	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-037	Textile	Swatch	11 oz/60" burlap Color: Barrel Brown	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-038	Textile	Swatch	11 oz/60" burlap Color: Antique Lace	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-039	Textile	Swatch	11 oz/60" burlap Color: Espresso Bean	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-040	Textile	Swatch	11 oz/60" burlap Color: Desert Sand	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-041	Textile	Swatch	11 oz/60" burlap Color: Terra Cotta	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-042	Textile	Swatch	11 oz/60" burlap Color: Antique Brass	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-043	Textile	Swatch	11 oz/60" burlap Color: Hazel	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-044	Textile	Swatch	11 oz/60" burlap Color: Rust	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-045	Textile	Swatch	11 oz/60" burlap Color: Pumpkin	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-046	Textile	Swatch	11 oz/60" burlap Color: Golden	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-047	Textile	Swatch	11 oz/60" burlap Color: Wheat	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-048	Textile	Swatch	11 oz/60" burlap Color: Raspberry	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-049	Textile	Swatch	11 oz/60" burlap Color: Craftsman Green	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-050	Textile	Swatch	11 oz/60" burlap Color: Hampton Blue	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-051	Textile	Swatch	11 oz/60" burlap Color: Midnight	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-052	Textile	Swatch	11 oz/60" burlap Color: Camo (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-053	Textile	Swatch	11 oz/60" burlap Color: Chevron (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-054	Textile	Swatch	Holiday Collection Color: Vintage Plaid (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-055	Textile	Swatch	Holiday Collection Color: Shimmer Ivory & Gold (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-056	Textile	Swatch	Holiday Collection Color: Shimmer Natural & Gold (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-057	Textile	Swatch	Holiday Collection Color: Shimmer Red & Gold (10 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-058	Textile	Swatch	Holiday Collection Color: Pure Red (11 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-059	Textile	Swatch	Holiday Collection Color: Eucaliptus (11 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-060	Textile	Swatch	Holiday Collection Color: Evergreen (11 oz)	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-061	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Crisp White	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-062	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Corn Silk	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-063	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Natural	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-064	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Farm Table	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-065	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Willow	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-066	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Storm	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-067	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Granit Grey	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-068	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Jet Black	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-069	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: True Red	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-070	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Ribbon Pink	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-071	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Apricot	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-072	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Copper	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-073	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Amethyst	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-074	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Spirt Orange	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-075	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Sour Apple	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-076	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Avocado	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-077	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Evergreen	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-078	Textile	Swatch	11 oz/48" roll Shalimar Burlap Color: Eucalyptus	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-079	Textile	Swatch	22 oz/48" Color: Natural	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-080	Textile	Swatch	10 oz Color: Peacock Blue	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-081	Textile	Swatch	10 oz Color: Hunt Club Green	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute

Table A.1 (cont'd).

BF-082	Textile	Swatch	10 oz Color: Primrose Pink	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-083	Textile	Swatch	Color: Black	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-084	Textile	Swatch	10 oz/60" Color: Wheat	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-085	Textile	Swatch	10 oz Color: French Vanilla	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-086	Textile	Swatch	10 oz Color: Light Olive	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-087	Textile	Swatch	10 oz Color: Deep Red	The Burlap Factory/Big Duck Canvas 741 West Winder Industrial Parkway Winder, GA 30680-7807 Website: http://www.theburlapfactory.com/	Jute
BF-088	Textile	Swatch	Faux Burlap	The Burlap Shop online store 1050 Northfield Ct. Suite 300 Roswell, GA 30076 Website: www.theburlapshop.com Phone: 770-442-8777 E-mail: Sales@TheBurlapShop.com	Polyester

Table A.1 (cont'd).

BF-089	Cord-age	Large piece	Welt Cord Jute #10 5/32" Sold by the yard/meter	Ebay seller: northwesttarpandcanvas Northwest Tarp & Canvas, LLC Jim Watt (Owner) Onsite manufacturing, boat canvas repair, heavy duty tarps, custom covers 703 West Holly Street Bellingham, WA 98225	Jute
BF-090	Textile	Swatch	Upholstery supplies fabric Jute webbing No strip for crafts, wedding 3 3/4"	Ebay seller wholesale_upholstery_supplies Shipped from Stephen Sickles PO Box 142 Beecher Falls VT 05902 Shipped with a leather sample stamped with the image of a steer head and the words "Dave Robertson, morethanleader.com, Steve Stickles"	Jute
BF-091	Textile	Swatch	Burlap	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Jute
BF-092	Textile	Swatch	Faux burlap	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester (unverified)

Table A.1 (cont'd).

BF-093	Textile	Swatch	Jute 100% polyester Black	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester
BF-094	Textile	Swatch	Jute 100% polyester Gray	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester
BF-095	Textile	Swatch	Jute 100% polyester Natural	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester
BF-096	Textile	Swatch	Jute 100% polyester Slate Blue	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester
BF-097	Textile	Swatch	Jute 100% polyester White	www.brightsettings.com P.O. Box 374 701 East Spring Street Titusville, PA 16354 Phone: 866-827-4177 Fax: 866-827-7747	Polyester

Table A.1 (cont'd).

BF-098	Cord-age	Whole	Mibro KingCord Heavy Duty Jute, 190 feet, twisted Natural color Manufactured to MIBRO's exacting specifications in China The MIBRO Group, Buffalo, NY 14225; Toronto, Ontario M1L 4S6 www.mibro.com 302071 0 66366 30207 3 LA302071FR-D	Meijer retail store #25 2055 W. Grand River Ave Okemos, MI 48864	Jute
BF-099	Cord-age	Whole	Mibro KingCord Fine Jute, 190 feet, twisted Green color Manufactured to MIBRO's exacting specifications in China The MIBRO Group, Buffalo, NY 14225; Toronto, Ontario M1L 4S6 www.mibro.com 301511 0 66366 30151 9 3 LA301511FR-D	Meijer retail store #25 2055 W. Grand River Ave Okemos, MI 48864	Jute
BF-100	Cord-age	Whole	100% Jute twine, #30 x 190 ft Natural color 7 lb working load limit Distributed by Crown Bolt, Aliso Viejo, CA 92656 Made in China 0 30699 65325 6 172540	The Home Depot 1749 Newman Rd Okemos, MI 48864	Jute

Table A.1 (cont'd).

BF-101	Cord-age	Whole	100% Garden Jute Twine, #30 x 200 ft Green color 7 lb working load limit Made in China Distributed by Home Depot, 2455 Paces Ferrt Rd NW, Atlanta, GA 30339 0 30699 12795 5 172540 SKU 494 250 12795	The Home Depot 1749 Newman Rd Okemos, MI 48864	Jute
BF-102	Floor-ing	Swatch	Shaw Style/Color: Viking Buckwheat-THS Construction: 100% BCF Olefin Product Part: 0701649725 Order SKU: 326-686 Sample SKU: 629-742 Note: Store worker said he had heard the middle layer (between the olefin fibers and plastic backing) is made of jute, but couldn't find any documentation to corroborate that.	The Home Depot 1749 Newman Rd Okemos, MI 48864	No fibrous material present

Table A.1 (cont'd).

BF-103	Miscel-laneous	Loose fibers	Loose fibers tweezed from a jute and paper multi-level condo cat furniture. Fibers tweezed only from jute level coverings, not paper rope around the posts. Tag front reads: "51 in. after assembly, paper rope & jute construction, 5 scratching post & perch, 4 levels of fun" Tag reverse reads: "51 in x 22 in x 15 in, KEY 062, 3394964, 7 08820 39834 4, Dist. by Meijer Distribution, Inc. Grand Rapids, MI 49544, Made in China, www.meijer.com"	Meijer retail store #25 2055 W. Grand River Ave Okemos, MI 48864	Jute
BF-104	Textile	Loose fibers	Loose fibers tweezed from the burlap lining of a decorate basket. Tag front reads: "The Rococo Collection, Burlap Lined wire Basket, 12.6 in x 8.7 in x 4.3 in, whitmor" Tag reverse reads "6708-5630, 0 38861 63182 8, Made in China, (C)2014 Whitmor, Inc., 8680 Swinnea Road Suit 105, Southaven, MS 38671, 1-888-WHITMOR, help@whitmor.com, www.whitmor.com"	Meijer retail store #25 2055 W. Grand River Ave Okemos, MI 48864	Jute

Table A.1 (cont'd).

BF-105	Textile	Loose fibers	Loose fibers tweezed from a burlap canvas type soft crate. Tag front reads: "Home store" Tag reverse reads: "Natural Burlap Crate, 15 in L x 10 in W x 11.5 in H, 3281253, 838, 8 86926 45627 1, Dist. By Wholesale Merchandisers LLC, 2929 Walker, NW, Grand Rapids, MI 49544, Made in China, Nuerrh, DNS1002" Tag inside product reads: "Shell: 100% burlap exclusive of decoration, spot clean only, made in China"	Meijer retail store #25 2055 W. Grand River Ave Okemos, MI 48864	Jute
BF-106	Geo-textile	Large piece	36" x 36" untreated burlap sheet Product 3636UR	Professor Tom Fernandez, MSU Horticulture Burlap from A.M. Leonard (www.amleo.com)	Jute
BF-107	Geo-textile	Large piece	48" x 48" untreated burlap sheets Product 4848UR	Professor Tom Fernandez, MSU Horticulture Burlap from A.M. Leonard (www.amleo.com)	Jute
BF-108	Geo-textile	Whole	Burlap sock, old, with holes, source uncertain	Professor Tom Fernandez, MSU Horticulture Burlap from A.M. Leonard (www.amleo.com)	Jute
BF-109	Geo-textile	Cutting	Burlap sock cutting, medium golden colored	Professor Tom Fernandez, MSU Horticulture Burlap from A.M. Leonard (www.amleo.com)	Jute

Table A.1 (cont'd).

BF-112	Miscel-laneous	Whole	Wooden fox-shaped Christmas ornament lined with burlap	ModCloth online retailer	Jute
BF-113	Cord-age	Cutting	FD107 10M 3-ply twisted burlap string natural ribbon fiber jute twine rope toy L	Ebay seller: leisure-z	Jute
BF-115	Textile	Swatch	Bengal Burlap Natural #BLAP. 100% jute, 6.4 oz per square yard, 46/47" wide. Thread count is 11 threads per inch x 10 threads per inch.	Dharma Trading Company	Jute
BF-116	Textile	Swatch	Bengal Burlap Bleached #BLAPB. 100% jute, 6.4 oz per square yard, 46/47" wide. Thread count is 11 threads per inch x 10 threads per inch.	Dharma Trading Company	Jute

Table A.2. Observations of fibers from the commercial goods collection.

Sample identifier	Analysis results	Physical properties	Optical properties
Aggregate observations of all jute reference samples	Not applicable	Lumen: Diameter typically varied within a single ultimate from approximately half of overall diameter to tightly pinched. Some ultimates had a lumen diameter up to three-fourths of the overall diameter. Some ultimates had lumen diameters that were slightly thinner and more uniform, ranging from approximately one-fifth to one-third of the overall diameter; these cells had at least one section of lumen diameter varying widely over a short distance. Texture: Irregular and occasionally rough. Some ultimates with wider lumen appeared to have a texture similar to wood grain. Lignification: Stained bright or deep magenta upon application of phloroglucinol reagent, indicating a high degree of lignification Other cell types: Not necessarily present. Pitting: Not always observed. Odor: Characteristic, pungently earthy odor detectable in large samples	Dislocations and nodes: Common and not evenly spaced. Cross markings: Occasional to extremely frequent and not evenly spaced. Interference colors: Pale, first order yellows to second order bright blues. Sign of elongation: Positive. Direction of cellulose twist determined by the Herzog test: Z. Non-birefringent crystal-like inclusions: Present in the sample but not necessarily in all ultimates.
BF-001	Jute	Consistent with jute	Consistent with jute
BF-002	Jute	Consistent with jute	Consistent with jute
BF-003	Jute	Consistent with jute	Consistent with jute
BF-004	Woven plastic polymer	Not analyzed	Not analyzed

Table A.2 (cont'd).

BF-005	Unconfirmed vegetable fibers. Fiber 1 was not able to be identified. Fiber 2 is similar to sisal (*Agave sisalana*).	Two fibers were present in a blend Bulk sample observations Texture: Bulk sample much stiffer than jute. Lignification: Bright magenta indicative of highly lignified fibers Other cell types: Not noted Pitting: Not noted Odor: Characteristic, sharp odor of sisal was detectable in large samples. Color: Sacking was a pale, straw yellow color. Fiber 1 Lumen: Very wide. Texture: Diamond-shaped pattern along the entire ultimate. General: Most ultimates of this type are broken. In general the ultimates are shorter and plumper than jute or sisal ultimates. Fiber 2 Lumen: Roughly one-third to one-half the overall diameter. Lumen could become pinched but in general was less variable than is typically observed in jute ultimates.	Common to both fiber types Interference colors: First order grays Sign of elongation: Positive Non-birefringent crystal-like inclusions: Not noted Fiber 1 Dislocations and nodes: Absent Cross markings: Absent Direction of cellulose twist determined by the Herzog test: Not recorded Other features: The diamond pattern visible in plane polarized light is accentuated. The pattern appears to originate from four-pointed stars. The star shapes are superficially similar to but more prominent than those that appear in coir (*Cocos nucifera*) ultimates. Fiber 2 Dislocations and nodes: Few Cross markings: Rare Direction of cellulose twist determined by the Herzog test: Z

Table A.2 (cont'd).

BF-006	Unconfirmed vegetable fibers. Fiber 1 was not able to be identified. Fiber 2 is similar to sisal (*Agave sisalana*).	Two fibers were present in a blend Bulk sample observations Texture: Bulk sample much stiffer than jute. Lignification: Bright magenta indicative of highly lignified fibers Other cell types: Not noted Pitting: Not noted Odor: Characteristic, sharp odor of sisal was detectable in large samples. Color: Sacking was a pale, straw yellow color. Fiber 1 Lumen: Very wide. Texture: Diamond-shaped pattern along the entire ultimate. General: Most ultimates of this type are broken. In general the ultimates are shorter and plumper than jute or sisal ultimates. Fiber 2 Lumen: Roughly one-third to one-half the overall diameter. Lumen could become pinched but in general was less variable than is typically observed in jute ultimates.	Common to both fiber types Interference colors: First order grays Sign of elongation: Positive Non-birefringent crystal-like inclusions: Not noted Fiber 1 Dislocations and nodes: Absent Cross markings: Absent Direction of cellulose twist determined by the Herzog test: Not recorded Other features: The diamond pattern visible in plane polarized light is accentuated. The pattern appears to originate from four-pointed stars. The star shapes are superficially similar to but more prominent than those that appear in coir (*Cocos nucifera*) ultimates. Fiber 2 Dislocations and nodes: Few Cross markings: Rare Direction of cellulose twist determined by the Herzog test: Z
BF-007	Jute	Consistent with jute	Consistent with jute
BF-008	Jute	Consistent with jute	Consistent with jute
BF-009	Jute	Consistent with jute	Consistent with jute
BF-010	Jute	Consistent with jute	Consistent with jute
BF-011	Jute	Consistent with jute	Consistent with jute

Table A.2 (cont'd).

BF-012	Jute	Consistent with jute	Consistent with jute
BF-013	Jute	Consistent with jute	Consistent with jute
BF-014	Jute	Consistent with jute	Consistent with jute
BF-015	Jute	Consistent with jute	Consistent with jute
BF-016	Jute	Consistent with jute	Consistent with jute
BF-017	Jute	Consistent with jute	Consistent with jute
BF-018	Jute	Consistent with jute	Consistent with jute
BF-019	Jute	Consistent with jute	Consistent with jute
BF-020	Jute	Consistent with jute	Consistent with jute
BF-021	Polyester	Apparent cross section shape: Circular Diameter: 17 μm Delusterant particles: Absent	n∥: close to or slightly above 1.70 n⊥: between 1.53 and 1.55 Birefringence: 0.15 to 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-022	Polyester	Apparent cross section shape: Circular Diameter: 17 μm Delusterant particles: Absent	n∥: close to or slightly above 1.70 n⊥: 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-023	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: close to or slightly above 1.53 Birefringence: 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive

Table A.2 (cont'd).

BF-024	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: close to or slightly above 1.53 Birefringence: 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-025	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-20 μm Delusterant particles: Present	n∥: 1.70 n⊥: between 1.53 and 1.55 Birefringence: 0.15 to 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-026	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly greater than 1.70 n⊥: between 1.53 and 1.55 Birefringence: 0.15 to 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-027	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 17 to 20 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: between 1.53 and 1.55 Birefringence: 0.15 to 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-028	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15 to 20 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-029	Jute	Consistent with jute	Consistent with jute

Table A.2 (cont'd).

BF-030	Jute	Consistent with jute	Consistent with jute
BF-031	Jute	Consistent with jute	Consistent with jute
BF-032	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15 to 20 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly less than 1.70 n⊥: close to or slightly greater than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-033	Jute	Consistent with jute	Consistent with jute
BF-034	Jute	Consistent with jute	Consistent with jute
BF-035	Jute	Consistent with jute	Consistent with jute
BF-036	Jute	Consistent with jute	Consistent with jute
BF-037	Jute	Consistent with jute	Consistent with jute
BF-038	Jute	Consistent with jute	Consistent with jute
BF-039	Jute	Consistent with jute	Consistent with jute
BF-040	Jute	Consistent with jute	Consistent with jute
BF-041	Jute	Consistent with jute	Consistent with jute
BF-042	Jute	Consistent with jute	Consistent with jute
BF-043	Jute	Consistent with jute	Consistent with jute
BF-044	Jute	Consistent with jute	Consistent with jute
BF-045	Jute	Consistent with jute	Consistent with jute
BF-046	Jute	Consistent with jute	Consistent with jute
BF-047	Jute	Consistent with jute	Consistent with jute
BF-048	Jute	Consistent with jute	Consistent with jute
BF-049	Jute	Consistent with jute	Consistent with jute
BF-050	Jute	Consistent with jute	Consistent with jute
BF-051	Jute	Consistent with jute	Consistent with jute

Table A.2 (cont'd).

BF-052	Jute	Consistent with jute	Consistent with jute
BF-053	Jute	Consistent with jute	Consistent with jute
BF-054	Jute	Consistent with jute	Consistent with jute
BF-055	Jute	Consistent with jute	Consistent with jute
BF-056	Jute	Consistent with jute	Consistent with jute
BF-057	Jute	Consistent with jute	Consistent with jute
BF-058	Jute	Consistent with jute	Consistent with jute
BF-059	Jute	Consistent with jute	Consistent with jute
BF-060	Jute	Consistent with jute	Consistent with jute
BF-061	Jute	Consistent with jute	Consistent with jute
BF-062	Jute	Consistent with jute	Consistent with jute
BF-063	Jute	Consistent with jute	Consistent with jute
BF-064	Jute	Consistent with jute	Consistent with jute
BF-065	Jute	Consistent with jute	Consistent with jute
BF-066	Jute	Consistent with jute	Consistent with jute
BF-067	Jute	Consistent with jute	Consistent with jute
BF-068	Jute	Consistent with jute	Consistent with jute
BF-069	Jute	Consistent with jute	Consistent with jute
BF-070	Jute	Consistent with jute	Consistent with jute
BF-071	Jute	Consistent with jute	Consistent with jute
BF-072	Jute	Consistent with jute	Consistent with jute
BF-073	Jute	Consistent with jute	Consistent with jute
BF-074	Jute	Consistent with jute	Consistent with jute
BF-075	Jute	Consistent with jute	Consistent with jute
BF-076	Jute	Consistent with jute	Consistent with jute
BF-077	Jute	Consistent with jute	Consistent with jute
BF-078	Jute	Consistent with jute	Consistent with jute

Table A.2 (cont'd).

BF-079	Jute	Consistent with jute	Consistent with jute
BF-080	Jute	Consistent with jute	Consistent with jute
BF-081	Jute	Consistent with jute	Consistent with jute
BF-082	Jute	Consistent with jute	Consistent with jute
BF-083	Jute	Consistent with jute	Consistent with jute
BF-084	Jute	Consistent with jute	Consistent with jute
BF-085	Jute	Consistent with jute	Consistent with jute
BF-086	Jute	Consistent with jute	Consistent with jute
BF-087	Jute	Consistent with jute	Consistent with jute
BF-088	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: Close to or slightly greater than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-089	Jute	Consistent with jute	Consistent with jute
BF-090	Jute	Consistent with jute	Consistent with jute
BF-091	Jute	Consistent with jute	Consistent with jute
BF-092	Polyester (unverified)	Not analyzed	Not analyzed
BF-093	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: 1.70 n⊥: Close to or slightly greater than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive

Table A.2 (cont'd).

BF-094	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 12-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly less than 1.70 n⊥: Close to or slightly less than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-095	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-20 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly greater than 1.70 n⊥: Close to or slightly less than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-096	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-20 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly less than 1.70 n⊥: Between1.53 and 1.55 Birefringence: 0.15 to 0.17 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-097	Polyester	Sample homogenous: No Apparent cross section shape: Circular Diameter: 15-17 μm Delusterant particles: Present in some fibers and absent in others.	n∥: close to or slightly greater than 1.70 n⊥: close to or slightly less than 1.55 Birefringence: 0.15 Interference colors: High (third-fourth) order Sign of elongation: Positive
BF-098	Jute	Consistent with jute	Consistent with jute
BF-099	Jute	Consistent with jute	Consistent with jute
BF-100	Jute	Consistent with jute	Consistent with jute
BF-101	Jute	Consistent with jute	Consistent with jute
BF-102	No fibrous material present	Not analyzed	Not analyzed

Table A.2 (cont'd).

BF-103	Jute	Consistent with jute	Consistent with jute
BF-104	Jute	Consistent with jute	Consistent with jute
BF-105	Jute	Consistent with jute	Consistent with jute
BF-106	Jute	Consistent with jute	Consistent with jute
BF-107	Jute	Consistent with jute	Consistent with jute
BF-108	Jute	Consistent with jute	Consistent with jute
BF-109	Jute	Consistent with jute	Consistent with jute
BF-112	Jute	Consistent with jute	Consistent with jute
BF-113	Jute	Consistent with jute	Consistent with jute
BF-115	Jute	Consistent with jute	Consistent with jute
BF-116	Jute	Consistent with jute	Consistent with jute

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