Structural Characterization of Buri (*Corypha utan* Lam.) Petioles

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Anatomical analysis was conducted on Buri (*Corypha utan* Lam.) petioles in order to generate baseline data about the anatomy of buri petioles where buntal fibers are extracted and to determine the origin of these fibers. It is with hope that this baseline data can contribute in maximizing its yield in terms of quality and quantity, and suggesting other usage of wasted buntal fibers such as in pulp and papermaking industry. Vascular bundle and ground parenchyma area percentages were analyzed using advanced digital imagery. Variation both along the length (base (B), middle (M), top (T)) and across the radius (outer periphery (PO), core (C), inner periphery (PI)) of the petiole were considered in the evaluation. Fiber morphology was also conducted. Analysis showed that the petiole is made up of vascular bundles and ground parenchyma cells the proportion of which was highest at the middle and top portion, respectively. The bundle was actually the buntal fiber itself. Bundle diameter was highest at the basal portion while its element percentages were greatest in the middle portion. The structure of the bundle was unique because of the two fiber caps enveloping the other elements. This provided the vascular bundle enough strength and protection to withstand manual extraction including the weaving process. Considering both the quantity and quality of buntal, it is suggested that farmers can prioritize harvesting from the middle, basal and finally, the top portion. Fiber morphology values were highest in the outer periphery, but it varies along the height of the petiole. Furthermore, fiber characteristics showed acceptable values for pulp and paper manufacture; hence, the petiole itself together with the waste buntal could be best suited for this purpose to maximize its utility.

Key Words: buntal fibers, *Corypha utan*, fiber measurements, ground parenchyma, vascular bundle

INTRODUCTION

Buri (*Corypha utan* Lam.) of the family Arecaceae is one of the palms in the Philippines with multiple uses. It is considered to be the third most important palm in the country, after coconut and nipa palm (Brink & Escobin 2003). The fronds or the large fan-shaped leaves are the most important part of the plant. From it, three types of raw materials can be derived namely, *buri*, *raffia*, and *buntal* fibers. *Buri* is the matured leaf used in the manufacture of placemats, hats and braids. The leaflets are also used for house thatches and wall materials especially in the countryside. *Raffia* is the young shoot or leaf of the palm. It is commercially traded in bleached or unbleached form and is usually woven for conversion into various handicraft items like cloth, hats, mats, bags, folders, portfolios, shoes, slippers and other handicraft items. It is also used for tying, décor and wrapping materials (FIDA 2006a). Buntal fiber, which is the main concern of this study, is the long light colored strand extracted manually from the petioles of buri palms. They are woven
into a variety of products including bags, hats, slippers and baskets that are exported to the USA, Hong Kong, Japan, Italy and China (Fiber Industry Development Authority (FIDA) 2006b). This industry in addition to other basketwork and articles from plant material amount to about $53 million (Philippine Forestry Statistics 2000) making it a major dollar earner for the country.

Although the utilization of buntal fibers started way back before World War II, it is interesting to note that there are no studies on the basic characteristics of buri petioles where buntal fibers are being extracted. The only available report was on the basic properties of the trunk (Espiloy et al. 1989). In fact, no information is available indicating on which part of the petioles are buntal fibers located. In addition, we do not know if buntal fibers can only be extracted from buri petioles. The palm family is a big family of plants consisting of 2600 species which includes rattans, coconut (Cocos nucifera), kaong (Arenga pinnata) and many ornamental plants. If the baseline data about buri petioles are similar with the characteristics of the fibers from these palms, then there may be a possibility that these palms can be viable sources of alternative buntal fibers.

This study was conducted in order to provide the much needed baseline information on buri petioles where buntal fibers are being extracted and to determine the origin of these fibers. It is with hope that this baseline data can contribute in maximizing its yield in terms of quality and quantity, and suggesting other usage of wasted buntal fibers such as in pulp and papermaking industry.

**MATERIALS AND METHODS**

**Plant Material**

Petioles from the outer leaves of buri palms estimated to be 20-30 years old were collected from Sariaya, Quezon. Sariaya, Quezon was chosen as the collection site because most of the commercially available buntal fibers in the market come from this town.

**Vascular Bundle And Ground Parenchyma Structure Analysis**

Petioles were cut into portions after which the basal, middle and top sections were separated. Three sections; the outer periphery (OP), core (C) and inner periphery (IP) were delineated out from which 1cm x 1cm x 1cm sample blocks were prepared. With a sliding microtome, 100-120 μm thick cross sectional slices were dissected out. Sampling was replicated 3 times. The sections were stained with safranin and fast green then mounted on a glass slide. Using a Nikon microscope with a digital camera (Nikon Cool-pix), five digital pictures were taken. These images were analyzed using the ImageJ Analysis software (rsb.info.nih.gov/ij/download.html).

Vascular bundle and ground parenchyma area percentages were determined following the procedures of Abasolo et al. (1999). Average values coming from the five images for each replicate was used in the evaluation. In addition, vascular bundle diameter was also derived. After measuring all the vascular bundles in the five images, the values were averaged to get the average values of each replicate.

**Fiber Morphology**

1cm x 1cm x 2.54 cm sample blocks was prepared for fiber morphology. There were five replicates for each region totaling 15 samples for the top, middle and basal portions. Sample blocks were reduced to matchstick-sizes and then macerated in a 50:50 hydrogen peroxide and acetic acid solution. Macerated fibers were thoroughly shaken and mounted on a clean glass slide so as to have enough fibrous materials for measurements. Using an Olympus microscope with a built-in micrometer, the fiber length (FL), fiber diameter (FD), lumen diameter (LD), and cell wall thickness (CWT) were measured.

To avoid measurement of the same fibers, the movement of the mechanical stage was restricted to only one direction. Thirty (30) unbroken or undamaged fibers were measured from each test tube. Number of fibers measured for one portion is 450 fibers. Number of fibers measured for one portion is 450 , i.e. for the 3 regions (PO, C, PI) 30 fibers were measured and with 5 replications.

**Statistical Analysis**

A 3 x 3 factor-factorial experiment in a Completely Randomized Design (CRD) was used in the analysis of the data. Moreover, Tukey’s honest significance difference (HSD) test was used to compare the means gathered. The analyses were performed using the Statistica Base software.

**RESULTS AND DISCUSSION**

**Outer Periphery (Po), Core (C) and Inner Periphery (Pi) of Buri Petioles**

After sectioning the petiole into outer and inner peripheries, it was observed that the petiole consists of the epidermis and irregularly shaped fibrous strands and reduced or incomplete vascular bundles. These elements provide mechanical support to the periphery of the petiole, though in different levels. Outer periphery has
more reduced vascular bundles with larger diameter and intact fiber sheaths located near each other while inner periphery has smaller diameter fiber strands far from each other. This suggests that the outer periphery has higher mechanical support than the inner periphery (Figure 1a & 1c).

The core part is like a typical monocotyledon structure, with regularly shaped vascular bundles with relatively uniform density (Tomlinson et al. 2001) embedded in the ground tissue consisting of parenchyma cells (Figure 1b).

**Ground Parenchyma and Vascular Bundle Percentages**

The ground parenchyma or ground tissue consists of irregularly shaped, thin-walled parenchyma cells (as viewed in transverse section) enclosing the vascular bundles. The cells are large and thin-walled, with almost no intercellular spaces, arranged in an orderly opposite pattern with geometrically distributed interstices.

Table 1 and 2 shows the analysis of variance for the average vascular bundle and ground parenchyma measured, respectively. Avb percentage was highest at the middle portion of the petiole (Figure 2a). From the base, going to the top and down to the middle portions, vascular bundle area percentage tends to increase. Across the radius, the PO region always had the highest percentage of vascular bundle, followed by the C and last was the PI region. The amount of vascular bundles along the length, across the radius and their interaction were significantly different from one another. The basal portion was significantly different from the top and middle portions while all the three regions across the radius were significantly different from one another.

Agp percentage was highest at the basal portion of the petiole (Figure 2b). Across the radius, it was highest in the PI region while lowest in the PO region. Like in the vascular bundle area percentage, ground parenchyma area percentage was significantly different along the length, across the radius and their interaction. The top and middle portions were significantly different from

![Figure 1. Vascular bundles from the outer periphery (a), core (b) and inner periphery (c) regions.](image)

**Table 1. Analysis of variance (ANOVA) of vascular bundle area percentage of Buri petiole.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P-LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (H)</td>
<td>2</td>
<td>2.08E+02</td>
<td>104.1387</td>
<td>13.98231</td>
<td>0.000217**</td>
</tr>
<tr>
<td>Radius (R)</td>
<td>2</td>
<td>7.34E+02</td>
<td>366.7973</td>
<td>49.2485</td>
<td>5.02E-08**</td>
</tr>
<tr>
<td>H x R</td>
<td>4</td>
<td>1.77E+02</td>
<td>44.29908</td>
<td>5.947873</td>
<td>0.003124*</td>
</tr>
<tr>
<td>Error</td>
<td>36</td>
<td>2.68E+02</td>
<td>7.447887</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>1.39E+03</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** highly significant, * significant, ns not significant

**Table 2. Analysis of variance (ANOVA) of ground parenchyma area percentage of Buri petiole.**

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
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<tr>
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<td></td>
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</tr>
</tbody>
</table>

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the basal portion. From the middle going to the top and basal portions and from the PO going to PI, ground parenchyma was increasing. PO, C, and PI regions were all significantly different from one another.

Kuo-Huang et al. (2004) studied the anatomical characteristics of coconut palm trunk and observed that the density of vascular bundles increases from the core to the periphery and from the base to the top, while for buri petiole, it is increasing from the base, to the top and down to the middle portion. The percentages of vascular bundle areas and fiber areas are significantly higher in the outer parts than in the inner parts of the central cylinder of the trunk. The findings cited were similar with the results of this study. The PO regions have higher Avb percentage than the C and PI regions. For Agp percentage, its relationship with Avb percentage is inversely proportional, the higher the Agp, the lower is the Avb percentage and vice versa.

Furthermore, this extensive evaluation of the structure unmistakably showed that commercially important buntal fibers were actually the vascular bundles themselves. Vascular bundle composition would therefore play a crucial role in understanding the integrity of the buntal fibers during extraction and weaving.

Vascular Bundle Diameter and Composition
The diameter of the bundles along the length and across the radius was significantly different from one another, but not their interaction (Table 3). All the three portions along the length were significantly different from one another. Across the radius, the PI region was significantly different from the PO and C regions. The diameter of the bundle was widest at the basal portion of the petiole and narrowest at the top portion of the frond (Figure 3). This agreed with the statements of the farmers that the coarsest buntal can be harvested near the basal portion.

Table 3. Analysis of variance (ANOVA) of vascular bundle diameter of Buri petiole.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P-LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (H)</td>
<td>2</td>
<td>0.34493</td>
<td>0.172467</td>
<td>67.10412</td>
<td>4.52E-09**</td>
</tr>
<tr>
<td>Radius (R)</td>
<td>2</td>
<td>0.11108</td>
<td>0.055541</td>
<td>21.61014</td>
<td>1.64E-05**</td>
</tr>
<tr>
<td>H x R</td>
<td>4</td>
<td>0.01508</td>
<td>0.00377</td>
<td>1.466693</td>
<td>0.253588 ns</td>
</tr>
<tr>
<td>Error</td>
<td>18</td>
<td>0.00257</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>0.51739</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** highly significant, * significant, ns not significant

The vascular bundles have diverse functions as cited by Quiroz et al. in 2008: the xylem transports water and nutrients as well as providing mechanical support; the parenchyma stores food as well as mitigates external pressures; and the fiber cap provides resistance to twisting, pressure and stretching during processing.

Studies about petioles of palms are very limiting that the comparisons made here were those of trunks of buri and other palms. Liese and Weiner (1987) identified different types of vascular bundles for several species of rattan depending on the number of metaxylem and phloem islands found on the bundle. There are bundles with one metaxylem vessel and two tangentially located phloem islands, bundles with one metaxylem vessel and
one phloem island and bundles with two metaxylem vessels and one phloem island. These types possess only one fiber cap. For the palm trunks, Espiloy et al. (1989) studied the anatomical properties of five erect palms in the Philippines, including the trunk of buri, the characteristics of the bundles varies, from the number of metaxylem vessels to the number of fiber caps comprising the bundle. From all the types of bundles enumerated, the vascular bundle of buri petioles was uniquely different. Though the basic components of the bundle of these materials were also present in the buri petiole eg., one metaxylem vessel, a protoxylem field, phloem and parenchyma, unlike in rattan with one fiber cap (Abasolo et al. 1999), it was surrounded by two compact fiber caps (Figure 4). This design provided enough protection for the buntal fibers during the extraction as well as on the processing stage.

Figures 5 to 7 show the ratio between the vascular bundle elements in the different portions along the height and across the radius of the petiole. At any portion, along the length and across the radius, fiber cells dominate the bundle (around 53 to 67% of the vascular bundle). Fibers offer protection and strength to buntal. This can explain why buntal fibers can be extracted manually and can still withstand the weaving process. It was followed by the parenchyma cells (20 to 28%), metaxylem (6 to 10%) and phloem (5 to 9%). The protoxylem was present in very minimal amount (1 to 4%). This would imply that the tissue requirement of buri was similar in any part of the frond. Mechanical tissues such as fibers are always higher in amount than those of the storage and conducting tissues.

The PO region was always dominated by fiber caps. It can be observed at the three portions along the length of
the frond. Generally, it was observed that from the PO to the C to the PI region, metaxylem was decreasing. Its part was being consumed by the parenchyma and phloem.

**Fiber Morphology**

Table 4 shows the average FL, FD, LD and CWT respectively, of the fibers measured. FL affects tensile strength. Higher FL means higher tensile strength. FL values tend to increase from middle (1.4744 mm) going to basal (1.4749 mm) and top portions (1.5447 mm) and from C (1.4275 mm) going to the PI (1.4974 mm) and outer PO (1.5691 mm) regions. Looking at the effects of height and radius, FL at the top portion was significantly different from the basal and middle part while the PO, C, and PI regions were all significantly different from one another. FL was longest at the top portion of the petiole. This can be related to more active cells dividing at the top, rather than at the lower portions. For the three regions across the radius, FL was always longest at the PO region. The analysis of variance for FL showed that fibers at the different portions along the height, across the radius and their interaction were significantly different from each other, at p-level of 0.05. In pulp and papermaking, longer fiber generates paper with higher tear resistance but less uniform sheet formation because of larger area for bonding.

Table 4. Average fiber length, fiber diameter, lumen diameter and cell wall thickness of the measured fibers.

<table>
<thead>
<tr>
<th>Position</th>
<th>Fiber Length (mm)</th>
<th>Fiber Diameter (mm)</th>
<th>Lumen Diameter (mm)</th>
<th>Cell Wall Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base PO</td>
<td>1.48969</td>
<td>0.02103</td>
<td>0.00925</td>
<td>0.00542</td>
</tr>
<tr>
<td>Base C</td>
<td>1.48582</td>
<td>0.01920</td>
<td>0.01135</td>
<td>0.00377</td>
</tr>
<tr>
<td>Base PI</td>
<td>1.44914</td>
<td>0.01649</td>
<td>0.00909</td>
<td>0.00368</td>
</tr>
<tr>
<td>Mid Po</td>
<td>1.56830</td>
<td>0.01700</td>
<td>0.00819</td>
<td>0.00441</td>
</tr>
<tr>
<td>Mid C</td>
<td>1.39860</td>
<td>0.01683</td>
<td>0.00921</td>
<td>0.00386</td>
</tr>
<tr>
<td>Mid PI</td>
<td>1.45618</td>
<td>0.01615</td>
<td>0.00811</td>
<td>0.00407</td>
</tr>
<tr>
<td>Top PO</td>
<td>1.64918</td>
<td>0.01663</td>
<td>0.00651</td>
<td>0.00506</td>
</tr>
<tr>
<td>Top C</td>
<td>1.39797</td>
<td>0.01571</td>
<td>0.00864</td>
<td>0.00354</td>
</tr>
<tr>
<td>Top PI</td>
<td>1.58695</td>
<td>0.01688</td>
<td>0.00771</td>
<td>0.00459</td>
</tr>
</tbody>
</table>

FD along the length and across the radius and their interaction were also significantly different from one another at p-level of 0.05. From the top (0.0164 mm) to the base (0.0189 mm) and from PI (0.0165 mm) going to PO (0.0182 mm) region, FD increases. The basal portion was significantly different from the top and middle portions, while FD at the PO and PI regions were significantly different from one another. FD being widest at the basal portion is similar with the results obtained for rattan species by Bhat et al (1990). Wider diameter of fibers as observed in flax causes lower tensile strength.
Table 5. Comparison of fiber characteristics of buri petioles with different species suitable for pulp and papermaking.

<table>
<thead>
<tr>
<th>Species</th>
<th>FL (mm)</th>
<th>FD (mm)</th>
<th>CWT (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corypha utan petioles</td>
<td>1.4980</td>
<td>0.0173</td>
<td>0.0043</td>
</tr>
<tr>
<td>Calamus merrillii (Abasolo 2008)</td>
<td>1.3649</td>
<td>0.0191</td>
<td>0.0046</td>
</tr>
<tr>
<td>Gigantochloa levis (Abasolo et al. 2005)</td>
<td>3.3</td>
<td>0.025</td>
<td>0.008</td>
</tr>
<tr>
<td>Hardwoods (Borch et al. 2001)</td>
<td>0.7-1.7</td>
<td>0.015-0.040</td>
<td>0.0025-0.005</td>
</tr>
<tr>
<td>Softwoods (Borch et al. 2001)</td>
<td>3-6</td>
<td>0.030-0.060</td>
<td>0.004-0.008</td>
</tr>
</tbody>
</table>

because of larger empty space in the fiber. In pulp and paper, fibers with wider diameter are more flexible than those with narrower diameter.

LD along the length and across the radius of the buri petiole was significantly different from each other, but their interaction was not significantly different. Both the top and middle portions were significantly different from the basal portions, while the PO and PI regions were both significantly different from the C region. LD was always widest at the basal portion (0.0099 mm), while across the radius, the core (0.0097 mm) always had the widest LD. Wider LD also causes lower tensile strength because of its larger void spaces, while it is favorable in pulp and papermaking because of liquid penetration into the empty spaces of fibers.

CWT differences seemed to be significant only across the radius of the petiole but not along the height. However, their interaction also showed significant differences. CWT tends to increase from the middle (0.0041 mm) going to the top (0.0044 mm) and basal (0.0045 mm) portions and from the C (0.0038 mm) to the PI (0.0041 mm) and PO (0.0051 mm) regions. For the effect of radius, both the C and PO regions were significantly different from the PO region. Cell wall was thickest in the PO region at any portion along the length. This can be a reason why the outer regions of buri petioles are denser than the other regions. Fibers with thicker cell walls have higher tensile strength than those with thinner walls. Tensile strength is the force needed to make the fibers break. In pulp and paper, fibers thicker walls produce papers with lower quality because of its bulkiness and coarseness.

To further justify that buri petiole together with the waste buntal fibers can be utilized for pulp and papermaking, Table 5 shows the comparison of the average values of the fiber characteristics of buri petiole with species being used for this purpose. Values show that the characteristics of buri petiole are comparable with the fiber characteristics
of hardwoods being used for pulp and papermaking.

Comparing the results of this study with the fiber properties of buri trunk (Espiloy et al. 1989), those of the trunk has more superior characteristics than that of the frond. The average fiber length, fiber diameter, lumen diameter and cell wall thickness in the trunk are 1.758 mm, 0.029 mm, 0.018 mm and 0.0074 mm, respectively. This can be attributed to their function. The trunk carries the whole plant itself which would require more strength while the petiole only carries the leaves. This can justify the superiority of the fiber characteristics of trunk as compared with that of the petiole.

Further studies are needed to fully establish the differences of fiber characteristics of buri trunks and petioles.

In summarizing the data collected for the fiber morphology, Table 4 shows that on the average, FL ranged from 1.39-1.64 mm, FD ranged from 0.015-0.021 mm, LD ranged from 0.006 to 0.011 mm, and CWT ranged from 0.003 to 0.005 mm.

The measured FL was shorter than the 1.5 to 2.7 mm that FIDA (1984) reported. However, FD and LD of the measured fibers were slightly higher. CWT of the measured fibers was also smaller than what FIDA earlier reported. Differences in the values could be traced from the samples that were macerated. FIDA macerated pure buntal fibers while this study macerated samples from the frond itself. This is to further strengthen the goal of this study, that is, to generate detailed baseline data on the anatomy of buri petioles. With the other commercial fibers like, abaca, pineapple, maguey, jute, banana, kenaf, ramie and salago, FL of buri petiole was shorter than the abovementioned fibers. Its FL was only longer when compared to coir, which has a value of 0.99 mm. FD and LD, as well as CWT varied for all the fibers mentioned.

CONCLUSION

The study covered basically the anatomical characterization of buri petioles. This was done to determine the actual origin of commercially important buntal fibers including the structural features that makes it suitable for handicraft manufacture. The buntal “fiber” is an entire vascular bundle that includes many fibers and additional cell types. Detailed anatomical analysis was also done to determine that part of the petiole where the buntal fibers were abundant. Vascular bundle area was biggest at the middle portion, next was at the top and lastly, at the basal portion of the petiole. The structure of the bundle was unique because of the two fiber caps enveloping the other elements. This provided the vascular bundle enough strength and protection to withstand manual extraction including the weaving process. Bundle diameter appeared to be widest at the basal portion, then the middle and lastly, at the top portion. Diameter should also be considered because it is an important factor in determining the grade of buntal fibers.

RECOMMENDATIONS

Considering both the area and the diameter of the bundles, in extracting buntal fibers, the farmers should give priority on harvesting from the middle, then the basal portion and lastly, at the top portion. Farmers harvest buntal fibers in ways that they practice from the beginning. By the competence they gained through long experience of buntal fiber extraction, they can tell when and where the best buntal fibers can be extracted. But the information gathered in this study may help the farmers maximize the petiole. To have more yield and better quality fibers, they should extract from the middle and basal portions. Furthermore, this can facilitate the sorting of the buntal fibers according to thickness. Also, based on the fiber morphology, buri petioles can also be used as raw materials for pulp and papermaking. Wastes from the extraction of buntal fibers and the petiole itself can be utilized in this industry and this will surely maximize its utilization, especially with the process that farmers are using in extracting buntal fibers.

The study covers only the structural characterization of buri petioles where buntal fibers can be extracted. It aimed to generate baseline information which is still lacking until now. It is recommended to further study the differences of properties according to leaf age.

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