TECHNICAL NOTE

Longleaf Pine Inner Bark and Outer Bark Thicknesses: Measurement and Relevance

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ABSTRACT

Measurements of bark thickness generally ignore the fact that bark is comprised of both living inner bark (phloem) and essentially dead outer bark (rhytidome). Discerning between them has ramifications for the utility of bark as a byproduct of timber harvesting and its functionality on a living tree. Inner bark and outer bark thicknesses for longleaf pine (*Pinus palustris* Mill.) were investigated using disks collected from trees harvested on a 70-year-old plantation. Inner bark thickness was relatively constant up the bole of each tree whereas outer bark thickness rapidly declined from its thickest point at stump height; at relative heights above 20%, the decrease in outer bark thickness was more gradual. The proportion of inner bark, therefore, increased up the bole, from an average of 15% at stump height to above 40% toward the top of the tree. Since inner bark is a richer source of extractives than old outer bark, tree tops may be preferable in terms of bark abundance and quality as feedstock for extractive-based products. Reductions in the inner and outer bark thicknesses on disk drying, with averages of roughly 20 and 10%, respectively, differed when the data were pooled by cardinal direction. Thus, variability in bark thickness around the circumference of a standing tree may actually be a manifestation of differences in bark moisture content.

Keywords: biomass utilization, fire resistance, phloem, *Pinus palustris*, rhytidome

Bark serves essential biological and ecological functions on a living tree as a barrier, sealing moisture within, and offering protection against damaging agents (e.g., fungi, insects) and events (e.g., fire); these functions are served primarily by the essentially dead outer bark (rhytidome). Any barrier properties imparted by the living inner bark (phloem) are arguably superseded by the critical function of translocating the products of photosynthesis. Together, the outer bark and inner bark provide a complex and multifunctional system essential for secondary growth. As a tree grows from season to season, the oldest zones of inner bark are periodically sealed off by the formation of new periderms. Just outside the innermost periderm, the process of obliteration transforms the previously living inner bark into an ultimately dead layer within the outer bark. These outer bark layers are unlike the annual rings in the xylem in that they are not specifically formed annually, and they are not retained for the life of the tree, as old layers of outer bark are lost to weathering.

Studies on southern pine bark anatomy have requisitely differentiated between the inner and outer bark components (Martin and Crist 1970, Howard 1971). Physical and mechanical properties have largely focused on the outer bark (Martin and Crist 1968, Martin 1969, White et al. 1974). The bark from loblolly pine (*Pinus taeda* L.) has received the most attention among the southern pines for chemical characterization in either its whole form (McGinnis and Parikh 1975, Labosky 1979), or following the separation of the inner bark from the outer bark (Clark and Mills 1970, Pearl and Buchanan 1976). Similar literature for longleaf pine (*Pinus palustris* Mill.) bark, in any form, appears to be nonexistent. Given recent interest in the restoration of longleaf pine ecosystems, studies on key attributes of longleaf pine are becoming more prevalent. Among the few field studies focused on the functionality of longleaf pine bark for protecting against insects (Hanula et al. 2000) and fire (Martin 1963, Wang and Wangen 2011), only whole-bark thicknesses were measured.

Characterizations of bark from the southern pines have been mostly driven by utilization interests; bark yields are roughly 10% along the bole (Cole et al. 1966) and up to 60% for small branches (Phillips et al. 1976). Bark residues are still commonly burned as fuel despite recent reports suggesting that greater value can be gleaned from bark-derived nutraceuticals, adhesive additives, and liquid biofuels (Ingram et al. 2008, Şen et al. 2010, Ku et al. 2011). The proportions of outer bark and inner bark can impact product yields given differences in their chemical and cellular compositions (Eberhardt and So 2005, Eberhardt and Reed 2006). On comparing loblolly pine bark residues from two industrial sources, different outer:inner bark ratios were observed (5.8:1 versus 1.5:1), undoubtedly reflecting both the size of the harvested timber and subsequent processing operations (Eberhardt et al. 2009). Specific to longleaf pine restoration efforts, a renaissance in longleaf pine harvesting (Landers et al. 1995) will afford the corresponding bark residues for utilization. Taking into consideration the functionality of bark on the living tree, and its potential to be an actively managed forest biomass resource, the present study was undertaken to provide what appears to be the first report of inner bark and outer bark thicknesses along the bole for longleaf pine.

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; millimeters (mm): 1 mm = 0.039 in.; hectares (ha): 1 ha = 2.47 ac.

Table 1. General characteristics of 70-year-old longleaf pine trees used in study.

Tree number	Dbh (cm)	Total height (m)	Height to live crown (m)
1	35.0	29.1	21.8
2	14.7	17.6	14.0
3	42.7	26.6	14.8
4	42.2	26.3	18.4
5	35.6	24.4	14.9
6	26.2	27.5	20.0
7	34.8	22.9	13.1
8	34.3	25.4	15.5
9	17.3	19.8	12.7
10	33.0	23.8	13.4
11	29.5	23.3	14.2
12	29.0	26.2	19.8
13	41.4	25.8	11.5
14	45.5	28.0	16.5
15	27.9	29.0	18.2

Materials and Methods

Tree Disk Collection

Fifteen 70-year-old longleaf pine trees were harvested in the summer (July 6 through July 25, 2005) from the J.K. Johnson Tract (92° 41′W, 30° 10′N) of the Palustris Experimental Forest (Kisatchie National Forest, Louisiana); at least one tree was randomly selected from each of the different spacing (1.3 × 1.3, 1.6 × 1.6, and 1.9 × 1.9 m), thinning (residual basal areas of 18.365 and 22.957 m^2 ha^{-1}, age 20 years), and pruning (none or to one log, age 20 years) treatments. After taking measurements from the felled trees, disks (5 cm thick) were cut every 0.61 m from the stump cut (0.15 m above ground level). Cardinal directions were retained by marking the tree bole with paint.

Tree Disk Measurements

A ruler was used to take disk measurements for inside and outside bark diameters along the cardinal directions. Cognizant of time requirements, bark thicknesses in the green state were only measured for disks taken at *ca.* 0.15, 5, 10, 15, and 20 m. These disks were placed in a walk-in cooler the same day as harvesting. In the laboratory, inner and outer bark thickness measurements were taken using digital calipers with the aid of an illuminated magnifying lens. Four maximum inner and outer bark thickness measurements were taken from each disk; these were distributed among the four quadrants (northeast, northwest, southeast, and southwest) for each disk. Each data point on all plots represents the average of the four inner bark or outer bark measurements taken from each disk. Bark thickness measurements were repeated after air-drying the disks. Following all thickness measurements, the bark was peeled from each disk using a chisel to allow the mass of bark and wood to be determined. Excel 2010 was used to conduct two-sample paired *t*-tests to test for differences between opposing measurements in the four cardinal directions. It is acknowledged that handling of the tree disks may have unavoidably resulted in some losses of very loose outer bark layers.

Results and Discussion

Trees used in this study covered a wide range of growth rates. Values for dbh ranged from 14.7 cm to 45.5 cm (Table 1). Total heights ranged from 17.6 m for the most suppressed tree to *ca.* 29 m for dominant trees. Using the values for total tree height and the height of each of the five sampling points, values for relative height were calculated. Inner and outer bark thicknesses were then plotted against these relative heights (Figure 1). The relative height values became increasingly scattered, as would be expected, with the wide range of total heights for the trees included in this study. The widest ranges for outer bark thickness (8–29 mm) and inner bark thickness (2–6 mm) were at stump height (0.15 m). At relative heights of approximately 20% and above, the decrease in outer bark thickness was more gradual. Inner bark thickness was essentially constant along the length of the tree bole. Curve fitting, in both cases, gave the best fit with logarithmic models.

An observation made when comparing the average outer bark thicknesses among the four quadrants for each disk was that the average values for the northern quadrants, at each of the sampling heights, were generally higher (10.5% overall) than those for the southern quadrants; this trend (7.8% higher overall) was less pronounced with the inner bark thicknesses. Two-sample paired *t*-tests

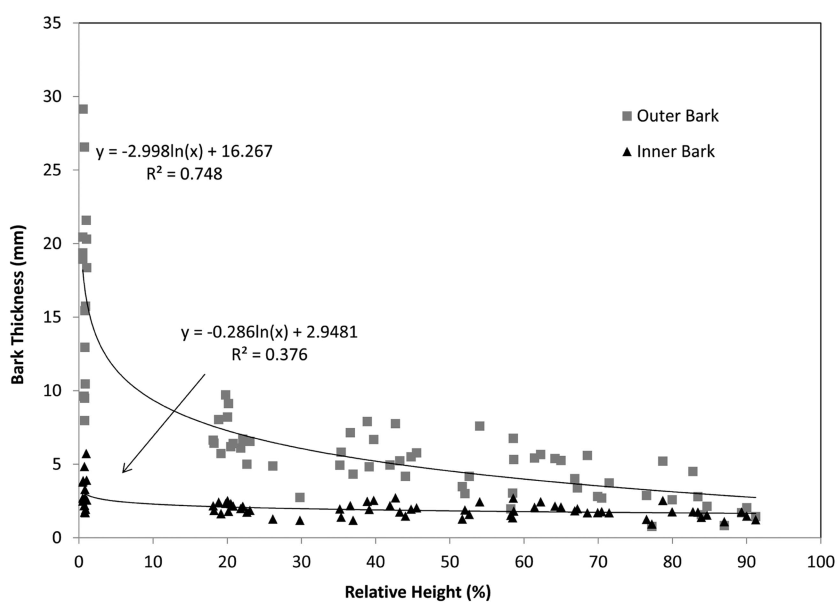

Figure 1. Average inner and outer bark thicknesses at relative heights up tree bole.

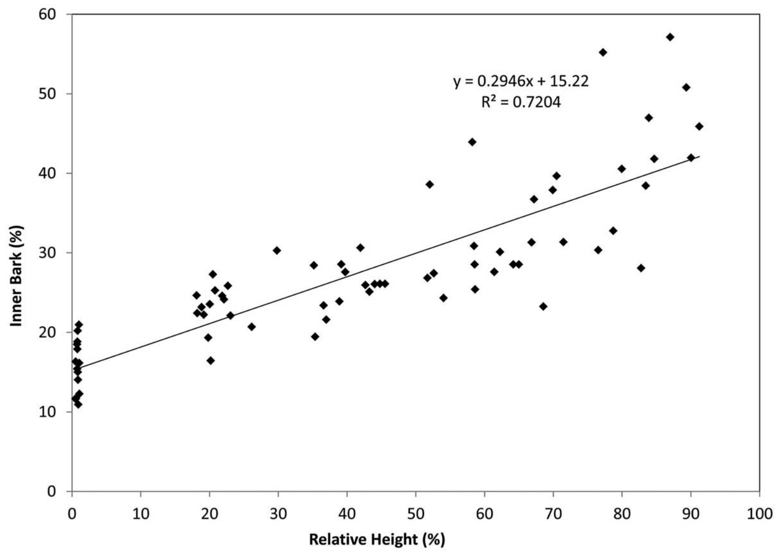

Figure 2. Increase in percent inner bark with increasing relative height up tree bole.

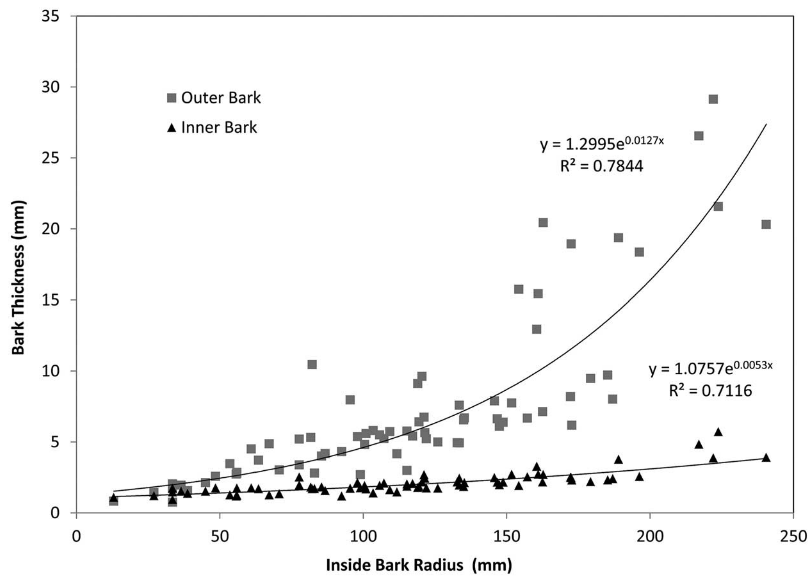

Figure 3. Average inner and outer bark thicknesses relative to inside bark radius.

were, therefore, conducted to assess whether there were indeed differences in bark thicknesses for opposing tree bole faces. Statistically significant differences were shown between the northern and southern faces for both the outer bark ($P = 0.0002$) and inner bark ($P = 0.0009$). The absence of a difference was expected when testing the eastern and western faces of the outer bark ($P = 0.5506$) and inner bark ($P = 0.5473$). Together, the above results validated the observation that outer and inner bark thicknesses do indeed vary around the tree bole and that the outer and inner barks thicknesses were greater on the northern face.

On a thickness basis, the proportion of inner bark increased from an average of 15% at stump height to above 40% toward the top of the tree (Figure 2). Peeling the whole bark from the wood disks gave 10% by weight of bark at stump height up to a relative height of 80%. Above this relative height, the proportion of whole bark approached 50% by weight; this value compares well to the 60% whole bark, by weight, reported for small longleaf pine branches (Phillips et al. 1976). Altogether, these results demonstrate that tree tops provide a rich source of inner bark for utilization. Since the extractives content of a southern pine inner bark was twice that in the outer bark (Eberhardt 2013), applications targeting extractives-based products may find the bark from logging residues (e.g., tree tops) to be preferable in terms of both whole-bark abundance and quality.

In the present study, inner and outer bark thicknesses were measured directly, as opposed to the common practice of calculating double-bark thickness by subtracting the inside bark diameter from the outside bark diameter of a disk. The average inner and outer bark thicknesses were plotted against the average radius of the wood (i.e., pith to cambium) for each disk (Figure 3). Both the inner bark and outer bark thicknesses increased exponentially with respect to the inside bark radius. Keeping the data separated by the different sampling heights allows one to break out weak linear relationships between whole-bark thickness and the inside bark radius (Figure 4). Thus, bark thickness at stump height can be distinguished from that further up the tree bole. Intuitively, trees with thicker bark, especially at stump height, would be better adapted to survive fire. Testing of bark thermal conductance for different tree species has

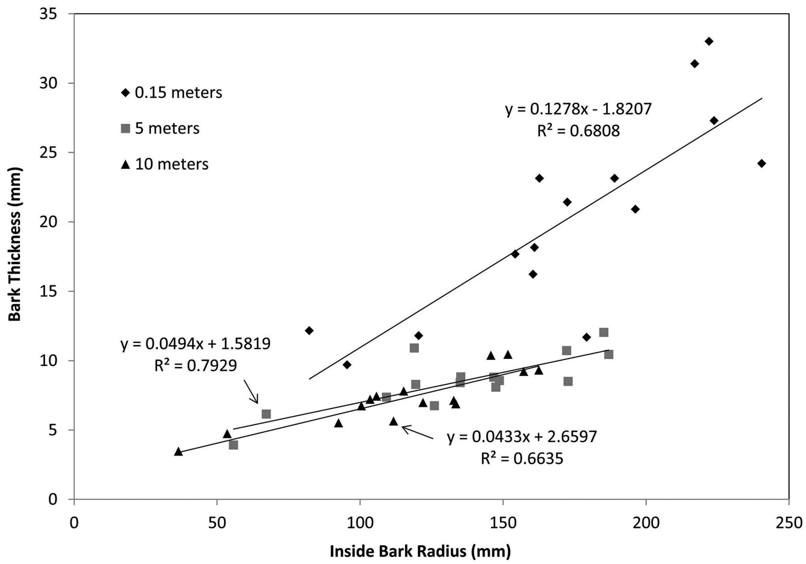

Figure 4. Average whole-bark thicknesses, for three sampling heights, relative to inside bark radius.

provided evidence for superior resistance for longleaf pine (Hare 1965, Martin 1963). While the environment may also play a role in fire resistance, frequent burning regimes do not appear to stimulate the formation of thicker bark in longleaf pine (Wang and Wangen 2011).

Sampling in the field with a bark-thickness gauge provides an immediate measurement of whole-bark thickness in the green state, albeit not a specific (e.g., maximum, minimum) value. Such gauges are based on the penetration of a probe that theoretically halts at the cambium; however, operator technique can easily result in biased data (Laasasenaho et al. 2005). A bark-thickness gauge could not be used in the current study since it would not afford the ability to differentiate between inner bark and outer bark. As for taking direct measurements for tree disks, the caveat is shrinkage from moisture losses during processing. Maximum bark thicknesses were determined for the fresh and air-dried disks to assess the magnitude of bark shrinkage. For the inner bark, the average percent thickness change for the northern (22.8%) and southern faces (18.7%) demonstrated the importance of timely specimen measurement. Less shrinkage was observed for the outer bark (northern face, 12.9%; southern face, 8.1%). A two-sample paired *t*-test was conducted and demonstrated that the differences between northern and southern faces of the outer bark ($P = 0.0002$) and inner bark ($P = 0.0124$) were statistically significant. Anecdotally, it is plausible that moisture content variability may be a factor in bark thickness variability for standing trees. The insulation capacity of bark has been shown to be a function of its thickness and moisture content (Bauer et al. 2010). The subtlety here is that the protection against fire afforded by bark is dynamic, with moisture affording bark swelling that imparts a transient increase in insulation capacity.

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