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RESEARCH REPORT

DEVELOPMENT AND VALIDATION OF A MOBILE TABLE WITH ATTACHED SCANNER FOR TREE-RING STUDIES

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ABSTRACT

Large tropical tree samples are driving new research in dendrochronology. The development of imaging tools for these substantial samples represents a significant challenge. Specifically, tree-ring measurements are strongly associated with images acquired through scanning, with an A3 large-format scanner being the preferred choice for these sizable samples. However, the literature lacks information about image distortions resulting from this approach. To address this gap, we developed a system comprising a table, a mobile scanner lift, and a fixed sample-support unit. This system ensures the production of aligned composite images of wooden disc samples and safeguards the scanning equipment from damage. To test its efficiency, we evaluated distortions in the measurements of tree-ring widths across various digitized images at nine different heights, ranging from 2 to 10 mm. Remarkably, we observed no distortions in the growth ring measurements at any assessed height. Furthermore, the images of samples positioned 2 mm and 3 mm away from the scanner glass were clear, allowing precise measurements of small growth rings between 0.1 and 0.5 mm in size. Our equipment offers flexibility of use with other models and sizes, including A4 scanners. It can digitize wooden discs with diameters ranging from 60 to 200 cm.

Keywords: tree-ring analysis, image analysis, depth measurement, giant trees, tropical wood, South America.

INTRODUCTION

Discoveries of large-diameter trees in South America (Scipioni *et al.* 2019) and particularly in the Amazon (Gorgens *et al.* 2019) are driving new research in tropical dendrochronology. In turn, these discoveries are stimulating the development of tools to obtain samples of these giant trees (Caetano-Andrade *et al.* 2021). Researchers usually collect wood samples from living trees using non-destructive manual or motorized increment borers. However, these techniques involve limitations in large trees because of the size of the instruments. Moreover, these samples' relatively small analysis surface (between 0.5 and 1.5 cm) makes it challenging to recognize the presence of false rings, wedging rings, partially indistinct growth rings, missing rings, and other growth irregularities (Wils *et al.* 2009; Cattaneo *et al.* 2013; Carroll and Sillett 2023). The use of full wooden discs enables integral analysis of the cross-sectional surface and the growth rings, facilitating the identification of irregularities and helping to identify the annual growth rings with greater certainty. In tropical and

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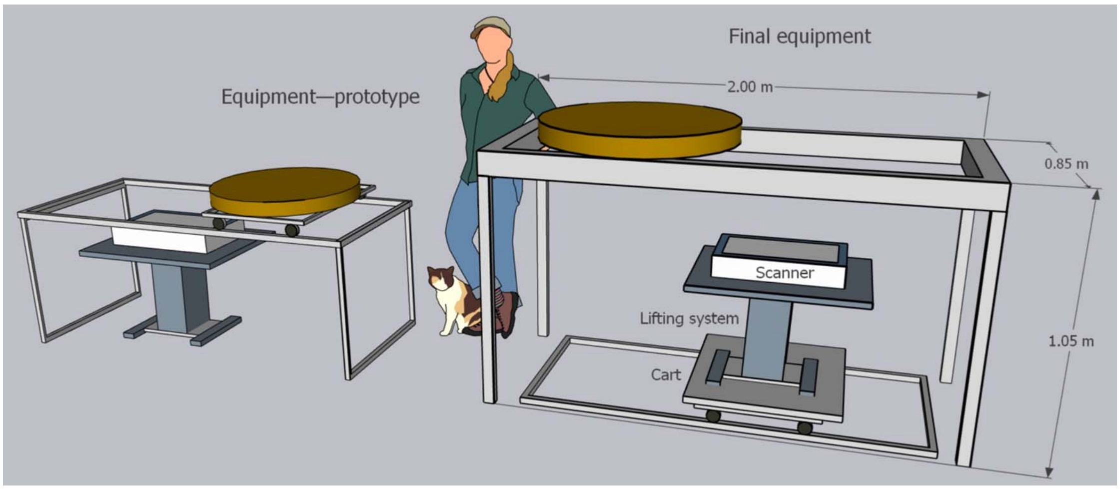

Figure 1. Views of the prototype (Scipioni *et al.* 2023) (left), and the final equipment with the A3 scanner (right).

subtropical trees, the ring boundary is often difficult to recognize (Oliveira *et al.* 2010; Worbes and Fichtler 2010; Albiero-Júnior *et al.* 2020), which increases the possibility of errors in the crossdating process (Black *et al.* 2016). Using wooden discs and their integral images permits researchers to avoid these drawbacks while constructing robust chronologies in tropical areas (Giraldo *et al.* 2023).

The use of wooden discs poses challenges when they come from large-diameter trees. Handling large samples in the laboratory requires strategies for their correct digitalization, including adaptations to the support tables and the use of small cranes (Scipioni *et al.* 2023). The most frequently used scanner in dendrochronological studies is the A3 size scanner (Griffin *et al.* 2021; Roquette *et al.* 2023). Scanners digitize images of physical objects and capture photons that are transferred into pixels. The analysis software then matches the pixel size to the physical measurement using a scale or considering the actual scanning resolution (Epson 2007; García-Hidalgo *et al.* 2022).

The images produced from samples of large trees positioned on the scanner typically come from narrow wood pieces obtained from sections of the pith-to-bark area of the wooden discs. Although these samples are lighter than wood discs, they must still be handled with care to avoid damaging the scanner glass. Discs with a radius of greater than 50 cm are typically heavy and require external lateral support for scanning. Lifting the specimen over the scanner is risky because any slip could damage the glass (Scipioni *et al.* 2023). However, large samples must be handled over the equipment to generate multiple images from pith to bark, increasing the likelihood of damaging the scanner. To solve this problem—and to enhance the scanning area of the A3 scanner and avoid cutting the large samples—we designed a scanner-lifting table with elevation control in conjunction with a sample-support table. This paper is an evolution of the prototype (see Scipioni (2023)) with significant changes to the design (Figure 1). With this setup, the scanner could capture A3 images of a greater surface area, allowing for the analysis of larger samples from centuries-old wooden discs. To enhance its application in dendrochronology research, we adjusted the protective systems and conducted calibration tests on the scanner to study depth of field with color CCD line sensor (Epson Corporation 2016). These tests aimed to assess whether the distance between the sample and the table affects the image resolution or the accuracy of growth ring measurements.

MATERIALS AND METHODS

Equipment Prototype

We modified a table with an OftPlus bivolt electric lifting system for use with the Epson

12000 XL scanner weighing ca. 14.3 kg (31.5 lb) (Epson Corporation 2016). The prototype table could support up to 50 kg (Figure 1), and the lifting height of the table was between 65 and 85 cm (Scipioni *et al.* 2023). We added a 27-mm piece of Medium-Density Fiberboard (MDF) to the tabletop to fit the A3 scanner on the original piece. We installed a potentiometer on the table column to adjust the lifting and lowering speed, thus avoiding damage from sudden contact between the equipment glass and the sample. For physical contact protection around the perimeter of the scanner, we installed four columns (25 cm) comprising threaded metal bars with washers and metal nuts to allow the height of contact protection between the wooden sample and the scanner to be adjusted. We installed another electrical component called a microswitch stroke in one of the columns, allowing the user to turn off the lifting table when the scanner level encounters the sample, thus avoiding damage to the scanner glass and overloading the lifting table's electric motor (Scipioni *et al.* 2023).

We also used rectangular carbon steel tubes (20 × 30 mm with 0.9-mm walls) to build a structural table independent of the lifting table to position the wood sample above the scanning table. Large-disc samples of *Araucaria angustifolia* (Bertol.) Kuntze and *Ocotea porosa* (Nees & Mart.) Barroso were used to develop the prototype (Figure 1). The polished sample face was positioned downward for scanning. We placed the sample on an iron cart with four pulleys arranged on a track. The lifting table holding the Epson XL 12000 scanner allowed for the successful digitization of large samples.

The iron structure allowed lateral displacement of the sample, with the aim of facilitating scanning from the pith toward the bark and without handling the sample in new scans. However, the prototype design of the sample-support table limited the cart's travel and scanning area because of the position of the sample-support crossbars on the cart. The goal of scanning large samples is to keep the scan radius constant so that images can be merged and layered into a single image, which was not feasible with the prototype. Additionally, the protection system prevented partial contact of the sample with the scanner glass. Scans of the samples presented clear images of growth ring distinction suitable for dendrochronology studies. However, changes to the prototype's operating structure and adaptations providing more protection towers were necessary to avoid damage to the scanner and the lifting table drive motor. The carbon steel structure also required reinforcement to support large samples (>1.5 m dbh, diameter at breast height).

Final Equipment

We modified the prototype by inverting the order of the movement system and the scanner table and placing the sample on a fixed hollow table with a stronger weight-bearing structure (ca. 350 kg) (Figure 1). We constructed the sample-support table using 30 × 50-mm (W × H) rectangular carbon steel tubes with 2-mm walls (Figure 2a). The sample table measured 85 × 200 × 105 cm (W × L × H). We placed the displacement cart—constructed from a 20 × 30-mm rectangular carbon steel tube with 0.9-mm walls—at the bottom, under the scanner table (Figure 2a). The scanner cart measured 60 cm × 80 cm (W × L) and was placed on a rail of the same width and a length of 150 cm.

We performed several simulations of the scanner table ascent with different sample sizes to determine the appropriate spacing of the protective tower installations on the perimeter of the scanner. In this final configuration, we installed four more protection towers with an equipment travel shutdown switch, increasing the protection points between the sample and the scanner. The finished equipment had eight scanner protection towers, with four contact sensors to protect the scanner (Figures 2b–c). We installed the sensors in the central towers. Wooden discs of different diameters (0.6–1.6 m) and cores (>42 cm) were used as test samples to make accessory adjustments: a) a glass support for cores measuring 850 × 1000 × 3 mm (Figure 2d) and b) an adjustable bar for smaller discs (Figure 2e). The final design allows the scanner to cover the entire diameter of the sample with greater scanner protection because of the presence of more sensors, as well as greater capacity to

Figure 2. Final equipment scanning table system: (a) scanner table system with sample >85 cm in diameter, (b) side view of the sample above the scanner, (c) protection tower with limit switch, (d) glass for increment cores > 42 cm (accessory 1), (e) transversal support bar for 60 to 80 cm discs (accessory 2), and (f) measurement of the distance between the wooden sample and the scanner glass.

support heavy samples, opposite to the prototype, whose scanning area was limited because of the structure of the cart, and the weak iron sample-support structure that sagged (>50 kg).

Analysis of Growth Rings

To analyze the growth rings, we used two samples of large-diameter trees: *Araucaria angustifolia* (Brazilian pine, conifer; dbh= 122 cm) and *Ocotea porosa* (imbuia, hardwood; dbh= 160 cm). We leveled the cross-section surfaces of the wooden discs and polished them to visualize the growth rings. The uneven transversal surface was leveled by mechanical wear using various cutting equipment (chainsaw, manual planer, column router, bench sander), and the polishing of the samples to visualize the growth rings was carried out with manual sanders (orbital or roto-orbital) with different sandpaper abrasive grain size (60 to 600 grains).

The images of the wood samples were obtained using the Epson 12000 XL-PH scanner at a resolution of 1200 dpi, in color and A3 size. We maintained a 2-mm gap between the scanner glass and the plastic edge of the equipment to prevent entire large samples from encountering the glass. Therefore, the scans were made with a minimum scanning height of 2 mm. The images were digitized at 1-mm intervals, totaling nine images. We assessed image quality through side-by-side comparisons to check the sharpness and distortion of the growth rings. Using a caliper, we measured the spacing between the sample and the scanner (Figure 2f).

The widths of the first 60 growth rings in the bark-to-pith position were inspected under a stereoscopic microscope, and the growth-ring boundaries

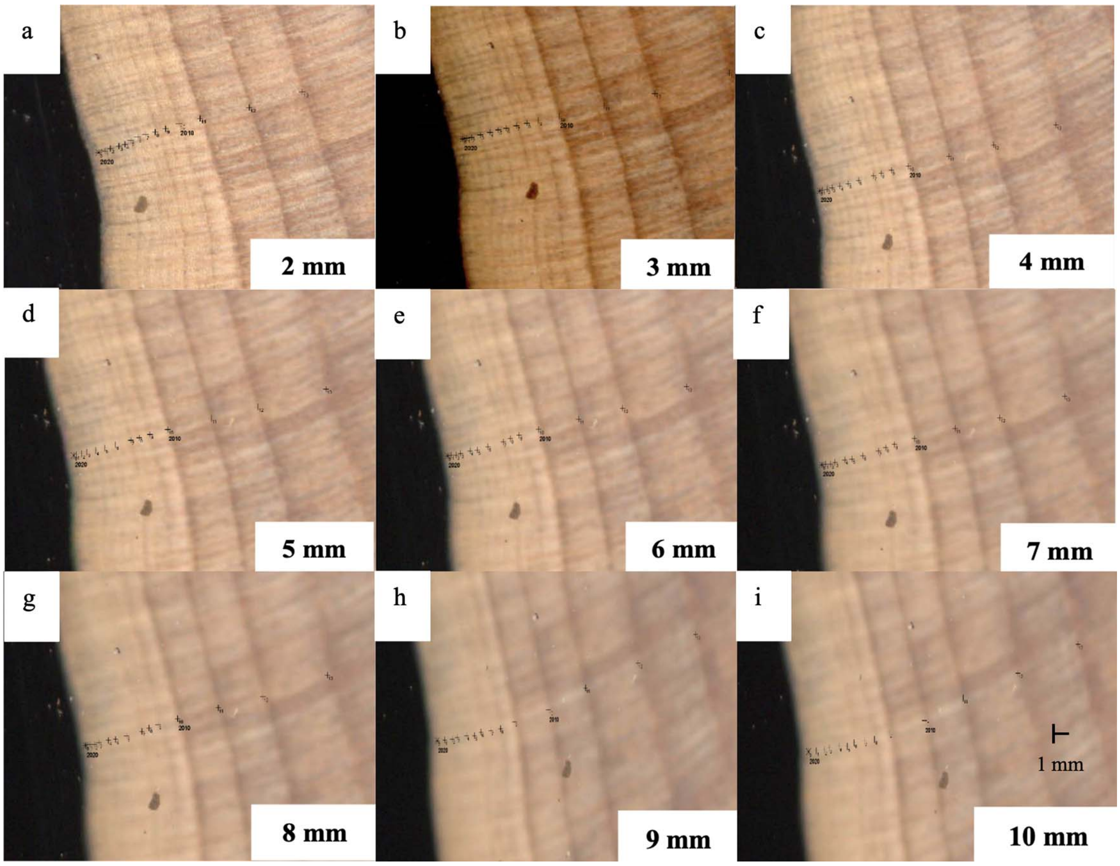

Figure 3. Scanned images at different contact heights between wood samples and the scanner on the lift table. Species: *Araucaria angustifolia* (a–i).

marked with a pencil and scanned. We considered growth ring measurements as paired data; that is, each ring was represented at different scanning times by scanning height (2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm) and measured at the same positions in all images. We measured the growth rings in the images to 0.001 mm using CooRecorder 9.8.1 (Larsson, 2023a), checking the measurement values, crossdating, and correlation coefficient between samples using CDdendro 9.8.1 (Larsson 2023a). Subsequently, we extracted the data into a specific *.rwl format and exported it to an Excel spreadsheet (OpenRWL 1.0 2005).

We performed separate statistical analyses for *Ocotea porosa* and *Araucaria angustifolia*, hypothesizing that no difference would exist between the measurements of growth rings at different scanning heights (H0: $\mu = \mu_0$ versus HA: $\mu \neq \mu_0$). We performed accuracy tests for the growth ring measurements by comparing the width of tree rings in images digitized at different heights. The statistical analyses included a descriptive analysis of the data and a data normality test, which found that none of the data groups were normally distributed. Therefore, the repeated measures ANOVA (non-parametric) and Friedman test with pairwise post hoc Durbin–Conover comparisons (Pohlert 2018) were performed to test the hypothesis. The analyses used Jamovi software (Jamovi 2022).

RESULTS

The scanning table can image wood samples between 60 and 200 cm in diameter and increment cores up to 100 cm long. The images of samples

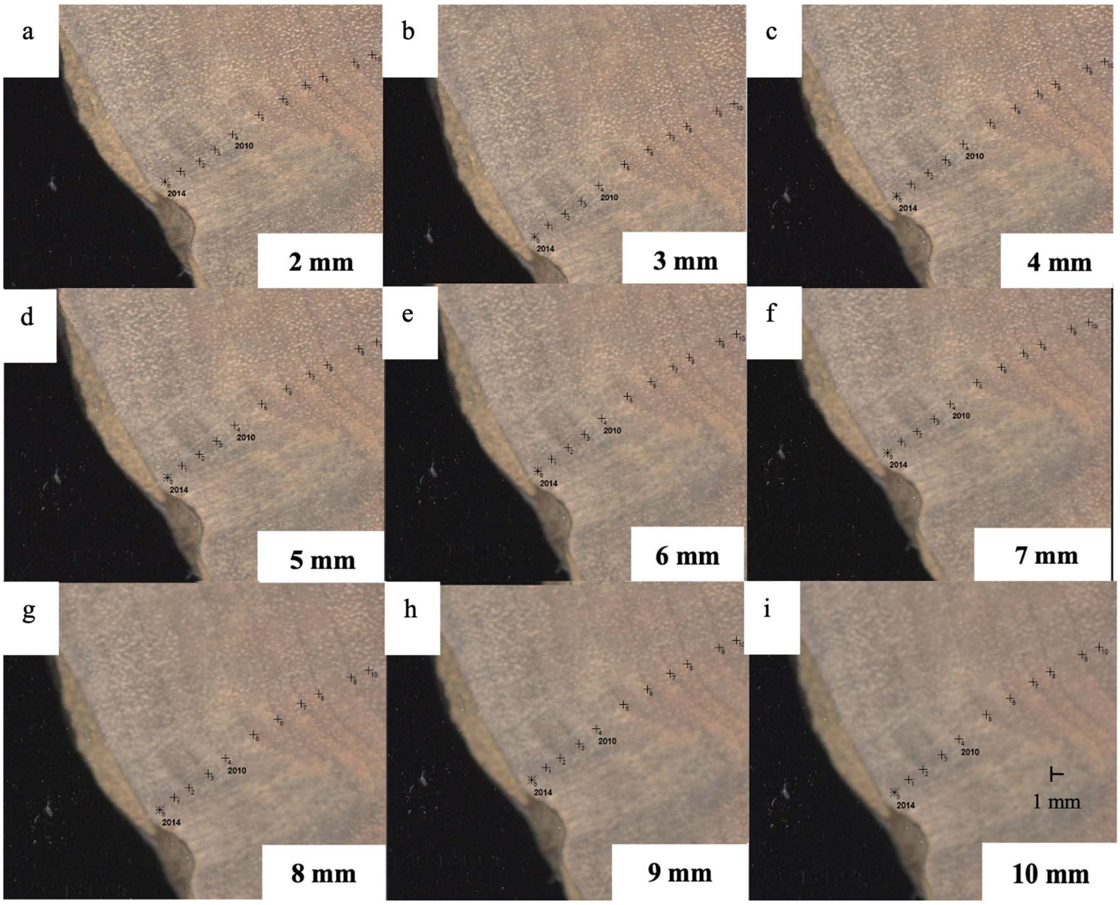

Figure 4. Scanned images at different contact heights between wood samples and the scanner on the lift table. Species: *Ocotea porosa* (a–i).

2 mm and 3 mm away from the scanner glass were satisfactory for measuring growth rings (Figures 3 and 4). Distinguishing the limits of the small multi-century *Araucaria* rings with sizes between 0.1 and 1 mm became difficult in images obtained at distances greater than 3 mm from the scanner glass, as can be observed in the last ten growth rings of the *Araucaria angustifolia* sample (Figure 3).

Table 1 shows the median, minimum, and maximum values of the widths of the growth rings of the studied species (Figures 1 and 2 in Supplementary Material). *Araucaria angustifolia* presented higher median value of ring widths. The Shapiro-Wilk tests showed that the growth-ring data measured (N = 60) at all scanning heights for the two species analyzed were not normally distributed ($p < 0.05$; Table 1) (Ring-to-ring details: Tables 1 and 2 in Supplementary Material). We found no difference between the growth ring measurements at different scanning heights in the two species studied ($p > 0.05$; Table 2) or in the pairwise comparisons for each species ($p > 0.05$; Tables 3 and 4 in Supplementary Material).

Because of the adjustable protection columns, the scanner table system is flexible for use with other scanner models and sizes. The ability to shift the scanner table to accommodate large samples results in aligned images, facilitating the construction of a composite pith-to-bark image in image editing software. Digitizing images by raising and lowering the scanner to various heights at an adjustable speed provides agility in the image procurement process. The scanner's protective structures are efficient, preventing the equipment's sudden

Table 1. Descriptive analysis of tree-ring widths measured at different scanning heights.

A. angustifolia	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm	10 mm
Median (mm)	1.96	1.95	1.96	1.97	1.95	1.96	1.96	1.94	1.94
Minimum (mm)	0.15	0.11	0.11	0.09	0.13	0.13	0.13	0.15	0.13
Maximum (mm)	6.01	6.02	5.97	5.99	5.98	5.98	5.98	6.03	6.03
Shapiro-Wilk W	0.926	0.932	0.930	0.929	0.927	0.927	0.928	0.931	0.932
Shapiro-Wilk p	0.001	0.002	0.002	0.002	0.002	0.001	0.002	0.002	0.002
25th percentile	0.897	0.880	0.863	0.863	0.840	0.887	0.828	0.875	0.875
50th percentile	1.70	1.66	1.69	1.69	1.59	1.60	1.60	1.64	1.64
75th percentile	2.92	2.84	2.98	3.08	3.09	3.07	3.07	2.94	2.89
Ocotea porosa	2 mm	3 mm	4 mm	5 mm	6 mm	7 mm	8 mm	9 mm	10 mm
Median (mm)	1.77	1.80	1.80	1.80	1.80	1.81	1.90	1.90	1.85
Minimum (mm)	0.36	0.34	0.34	0.34	0.34	0.34	0.38	0.38	0.38
Maximum (mm)	5.34	5.34	5.34	5.34	5.21	5.21	5.10	5.10	5.10
Shapiro-Wilk W	0.925	0.932	0.932	0.931	0.930	0.930	0.924	0.923	0.923
Shapiro-Wilk p	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.001	<.001
25th percentile	1.07	1.05	1.05	1.05	1.05	1.05	1.07	1.05	1.05
50th percentile	1.77	1.80	1.80	1.80	1.80	1.81	1.90	1.90	1.85
75th percentile	2.90	2.98	2.98	2.98	3.01	3.01	2.97	2.97	2.97

contact with the wood sample. The reduced need for handling during the scanning process minimizes physical damage to the polished wood sample and keeps it intact without the need for cuts to generate images of increment cores.

DISCUSSION

Many researchers produce images from sanded increment cores using a desktop scanner. In choosing the image resolution, the researcher must balance the amount of detail required and the size of the image files. An image with a 1200–2400-dpi resolution is almost always sufficient in dendrochronology studies for samples with clear ring boundaries (Hietz 2011). Digital photography has emerged as an alternative to scanning tree rings (Nutto *et al.* 2005). However, the use of scanner equipment remains the predominant, customary, and most accessible method in dendrochronology laboratories (Scipioni *et al.* 2021; Roquette *et al.* 2023). The Scanning and Cybis dendrochronology system has become popular compared to more expensive traditional microscope-based or similar tree-ring measurement systems (Larsson 2023a, 2023b).

The potential for using images obtained by scanning samples of large tropical and subtropical trees represents a yet unexplored frontier with many potential species: *Araucaria angustifolia*, *Cedrela fissilis*, *Dinisia excelsa*, *Goupia glabra*, *Schizolobium parahyba*, and *Ocotea porosa* (Reis-Avila and Oliveira 2017; Scipioni *et al.* 2019; Scipioni and Fontana 2021; de Lima *et al.* 2022; Olmedo *et al.* 2022). The support and elevation tables described here facilitate obtaining images of these large samples, allowing the digitization of the entire surface of the wooden discs through composite images. The complete digitization of a whole disc sample assists in dating and evaluating the spatial arrangement of various growth anomalies on the surface of the specimen (*e.g.* scars, resin stains, false rings, wedging rings), mainly in difficult-to-date tropical and subtropical species, particularly old trees with many narrow rings. Thus, the image that covers the perimeter of the wooden disc rings with resolutions equal to or greater than 1200 dpi helps in dating large samples.

To obtain greater detail on the wood sample, Griffin *et al.* (2021) developed Gigapixel equipment, which achieves impressive image quality with a very high resolution (19,812 dpi, 1.28 μm per pixel) and

Table 2. Repeated measures ANOVA (non-parametric), Friedman test.

Species	χ^2	df	p
Araucaria angustifolia	1.92	8	0.983
Ocotea porosa	3.93	8	0.864

can nearly analyze the cellular structure of the xylem. Although Gigapixel uses free and open software, the final hosting of the image entails cloud computing service and hardware costs (US$70,000) beyond the funding budget of research funding agencies, especially in developing countries (García-Hidalgo *et al.* 2022), because this equipment is considered complementary to classical dendrochronology. The total cost of purchasing and adapting the lifting table and sample-support table was R$3812.60 (US$743.20, quoted on 29 February 2023, A4 or A3 scanner price not included).

Another proposal argues that the open-source tool CaptuRING (García-Hidalgo *et al.* 2022) is less susceptible to hardware limitations and failures in leveling flatbed scanner scans. The equipment speeds up the automatic storage process for each digital sample and associated metadata in optimized time, making it more than 50% faster than a flatbed scanner (García-Hidalgo *et al.* 2022). Additionally, CaptuRING increases resolution acquisition from 4200 dpi at full resolution with scanning to 5931 dpi with a 24 MP non-professional DSLR camera by controlling sample lighting without sample size limitations. However, the authors demonstrated its use only for increment core samples, not large wood samples (wooden discs). As an alternative for laboratories with a scanner, attaching a lifting table is more affordable, and the support table, which has a lower cost than CaptuRING, meets traditional dendrochronology analysis needs. The results of this study indicate that even at scanning heights ranging from 0.2 to 1 cm, no deformation of ring measurements occurs. The apparatus captures digitized images of large samples without touching the scanner glass, challenging a common misconception. The test of the measurement accuracy of growth rings at different scanning heights and the quality of the images when delimiting them resulted in the best operating positioning of the equipment without causing physical damage to the scanner. This allowed our system to obtain clear, high-resolution images for the delimitation of narrow tree rings.

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