PL@NTWOOD: A COMPUTER-ASSISTED IDENTIFICATION TOOL FOR 110 SPECIES OF AMAZON TREES BASED ON WOOD ANATOMICAL FEATURES

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SUMMARY

Sustainable management and conservation of tropical trees and forests require accurate identification of tree species. Reliable, user-friendly identification tools based on macroscopic morphological features have already been developed for various tree floras. Wood anatomical features provide also a considerable amount of information that can be used for timber traceability, certification and trade control. Yet, this information is still poorly used, and only a handful of experts are able to use it for plant species identification. Here, we present an interactive, user-friendly tool based on vector graphics, illustrating 99 states of 27 wood characters from 110 Amazonian tree species belonging to 34 families. Pl@ntWood is a graphical identification tool based on the IDAO system, a multimedia approach to plant identification. Wood anatomical characters were selected from the IAWA list of microscopic features for hardwood identification, which will enable us to easily extend this work to a larger number of species. A stand-alone application has been developed and an on-line version will be delivered in the near future. Besides allowing non-specialists to identify plants in a user-friendly interface, this system can be used with different purposes such as teaching, conservation, management, and self-training in the wood anatomy of tropical species.

Key words: Wood identification, computer-assisted identification, tropical tree species, Amazonian woods.

INTRODUCTION

Neotropical forests are home to approximately 78,800 species of flowering plants, which is about a third of the known plant genera and species on earth (Smith *et al*. 2004).

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Furthermore, Amazonian forests comprise ~40% of the remaining world's tropical forest and exhibit not only the greatest tropical biodiversity, but also the highest absolute rate of deforestation (Hubbell *et al*. 2008; Hansen *et al*. 2008). Habitat destruction, mainly due to road construction, livestock, extensive agricultural practices, mining, and timber trade, among others, is perhaps the biggest threat that tropical tree species are facing (Peres *et al*. 2010). Thus, to develop appropriate conservation strategies, complete and accurate taxonomic identification of the plant species present in those threatened forests is urgently needed.

Wood is perhaps one of the world's most used materials, due to the large number of domains (construction, fuel wood for cooking, manufacturing, arts, pulp and paper, *etc*.) where its properties are best suited. It is because of this demand that timber has become by far the most marketable commodity that can easily be extracted from old-growth tropical forests (Kumar 1982; Peres *et al*. 2010). Thus, taxonomic wood identification remains an important but challenging task to adequately design conservation plans and to support ecologically responsible forest management strategies, including legal logging. Certainly, wood anatomical features provide a considerable amount of information that can be used for timber traceability, certification and trade control (Jayeola *et al*. 2009). Yet, this information is still poorly used, even if numerous identification approaches have been developed since the recent advances in informatics (LaPasha & Wheeler 1987; Kuroda 1987; Ilic 1993; Barker 2005; Richter *et al*. 2005; Koch *et al*. 2007, 2011; Heiss 2009; Safdari & Devall 2009). Some of the most well known applications were based on systems like GUESS (LaPasha & Wheeler 1987), LUCID (CBIT 2010; http://www.lucidcentral.com), DELTA (Dallwitz 1980; http://delta-intkey. com), or Linnaeus II (Schalk & Troost 1999; http://www.eti.uva.nl/products/linnaeus. php), but those are mostly written for experts with a good knowledge of the botanical and anatomical jargon required to use the identification systems.

Given the urgent need for accessible and accurate methodologies for taxonomic identification (Smith & Figueiredo 2009; Webb *et al*. 2010), the development of user-friendly tools is necessary to reach a broad spectrum of users. In this paper, we present an original approach to the identification of 110 Amazon tree species using microscopic anatomical features: Pl@ntWood. This approach is based on the IDAO software package (Grard 2002; http://idao.cirad.fr/home), which uses a graphic interface to build and update a composite image of an unknown specimen, also providing a percentage of matching (*i.e*., similarity in terms of anatomical characters) between the unknown and all the species included in the application.

MATERIALS AND METHODS

Included species

One hundred ten species of Amazonian trees belonging to 34 angiosperm families were selected for the first version of Pl@ntWood. The species were chosen according to the availability of wood samples in the CIRAD wood collection and the botanical and economic importance of those woods. We tried to include species of as many different angiosperm families as possible aiming to cover a wide range of anatomical features

to be illustrated in the application. The list of the species studied constitutes a preliminary taxon selection, that will be extended over time. It can be obtained from the first author on request.

Wood collection

Wood samples and slides were selected from one of the most important wood collections of tropical trees: the CIRAD wood collection, based in Montpellier (France). This collection contains more than 34,400 wood samples representing approximately 2,200 genera and 8,500 species, and is the result of well over 70 years of work. The collection (CTFw) belonged formerly to the CTFT (Centre Technique Forestier Tropical) located in Nogent-sur-Marne (France), which started the collection in 1937 having an important sampling restriction: wood of tropical and subtropical trees of more than 10 centimeters in diameter at breast height (DBH). This collection comprises wood sectioning blocks, small wood cubes of ca. 1 cm^3, and microscope slides each containing, in general, iodine green-stained transverse, radial, and tangential sections. CTFw is and has been throughout its history a reference center dedicated to the identification of woods from tropical regions of the world (Stern 1988).

Wood anatomical features

The selected characters were chosen from the IAWA list of microscopic features for hardwood identification (Wheeler *et al*. 1989). For the first version of Pl@ntWood, we restricted the characters to those with enough discriminant power for the chosen species and that were observable at magnifications lower than 200×. Thus, some anatomical features were excluded, even if they could provide important information for wood identification. Our intent was to avoid features needing much background knowledge to be correctly identified and also, to make the tool as simple as possible. Some important identification characters not used in this version of the software, such as pitting and tyloses, may be included in future versions.

Hence, a total of 99 character states relating to 27 anatomical features were retained for the 110 Amazon tree species included in the application (Table 1). With this information, a data matrix was constructed including the anatomical characters describing each species; for this, we followed existing descriptions for the chosen species published in Détienne & Jacquet (1983) and on the InsideWood (data downloaded in 2009) website.

Photo library

To illustrate the species referenced in the identification tool, photomicrographs were taken using a digital camera (Nikon DS-Fi1) adapted to a light microscope (Olympus BX60). The photomicrographs correspond to views in three different thin sections (*i.e.*, transverse, radial, and tangential) and at several magnifications (*i.e.*, 20×, 40×, 100×, and 200×). All photomicrographs were taken from slides previously stored in CTFw.

Database management

The photo library and the data matrix containing the species descriptions were managed using Pl@ntNote software (Birnbaum *et al*. 2009; http://umramap.cirad.fr/amap2/logiciels_amap/index.php?page=plantnote). This software is a free, easy-access, and flexible tool that allows the management of potentially any kind of botanical data.

Table 1. IAWA list of characters included in Pl@ntWood.

IAWA #	Feature
	Porosity
3	Wood ring-porous
4	Wood semi-ring-porous, type1
4	Wood semi-ring-porous, type2
5	Wood diffuse-porous
	Vessel arrangement
6	Vessels in tangential bands
7	Vessels in diagonal and/or radial pattern
8	Vessels in dendritic pattern
	Other vessel arangement
	Vessel groupings
9	Vessels exclusively solitary (90% or more)
10	Vessels in radial multiples of 4 or more common
11	Vessel clusters common
	Other vessel groupings
	Perforation plates
13	Simple perforation plates
14	Scalariform perforation plates
15	Scalariform perforation plates with ≤ 10 bars
16	Scalariform perforation plates with 10–20 bars
17	Scalariform perforation plates with 20–40 bars
18	Scalariform perforation plates with ≥ 40 bars
19	Reticulate, foraminate, and/or other types (of multiple perforation plates)
	Vessels per square millimetre
46	≤ 5 vessels per square millimetre
47	5–20 vessels per square millimetre
48	20–40 vessels per square millimetre
49	40–100 vessels per square millimetre
50	≥ 100 vessels per square millimetre
	Septate fibres and parenchyma-like fibre bands
65	Septate fibres present
66	Non-septate fibres present
67	Parenchyma-like fibre bands alternating with ordinary fibres
	Axial parenchyma
75	Axial parenchyma absent or extremely rare
	Apotracheal axial parenchyma
	Axial parenchyma present
76	Axial parenchyma diffuse
77	Axial parenchyma diffuse-in-aggregates
	Paratracheal axial parenchyma
	Paratracheal parenchyma present
78	Axial parenchyma scanty paratracheal
79	Axial parenchyma vasicentric
80	Axial parenchyma aliform
81	Axial parenchyma lozenge-aliform
82	Axial parenchyma winged-aliform
83	Axial parenchyma confluent
84	Axial parenchyma unilateral paratracheal

(Table 1 continued)

IAWA #	Feature
	Banded parenchyma
	Banded parenchyma present
85	Axial parenchyma bands more than three cells wide
86	Axial parenchyma in narrow bands or lines up to three cells wide
87	Axial parenchyma reticulate
88	Axial parenchyma scalariform
89	Axial parenchyma in marginal or in seemingly marginal bands
	Ray width
96	Rays exclusively uniseriate
97	Ray width 1 to 3 cells
98	Larger rays commonly 4- to 10-seriate
99	Larger rays commonly >10-seriate
100	Rays with multiseriate portion(s) as wide as uniseriate portions
	Ray height
102	Ray height >1 mm
	Ray height <1 mm
	Rays of two distinct sizes
103	Rays of two distinct sizes
	Rays of one size
	Rays: cellular composition
104	All ray cells procumbent
105	All ray cells upright and/or square
106	Body ray cells procumbent with one row of upright and/or square marginal cells
107	Body ray cells procumbent with mostly 2–4 rows of upright and/or square marginal cells
108	Body ray cells procumbent with over 4 rows of upright and/or square marginal cells
109	Rays with procumbent, square and upright cells mixed throughout the ray
	Sheath cells
110	Sheath cells present
	Sheath cells absent
	Tile cells
111	Tile cells present
	Tile cells absent
	Rays per millimetre
114	≤ 4/mm
115	4–12/mm
116	≥ 12/mm
	Storied structure
118	All rays storied
119	Low rays storied, high rays non-storied.
120	Axial parenchyma and/or vessel elements storied
121	Fibres storied
122	Rays and/or axial elements irregularly storied
	Secretory elements and cambial variants
	Oil and mucilage cells
124	Oil and/or mucilage cells associated with ray parenchyma
125	Oil and/or mucilage cells associated with axial parenchyma
126	Oil and/or mucilage cells present among fibres

(Table 1 continued)

IAWA #	Feature
	Intercellular canals
127	Axial canals in long tangential lines
128	Axial canals in short tangential lines
129	Axial canals diffuse
130	Radial canals
	Tubes / tubules
132	Laticifers or tanniniferous tubes
	Laticifers or tanniniferous tubes absent
	Cambial variants
	No cambial variants
133	Included phloem, concentric
134	Included phloem, diffuse
135	Other cambial variants
	Mineral inclusions
	Prismatic crystals
137	Prismatic crystals in upright and/or square ray cells
138	Prismatic crystals in procumbent ray cells
139	Prismatic crystals in radial alignment in procumbent ray cells
140	Prismatic crystals in chambered upright and/or square ray cells
141	Prismatic crystals in non-chambered axial parenchyma cells
142	Prismatic crystals in chambered axial parenchyma cells
143	Prismatic crystals in fibres
	Druses
145	Druses in ray parenchyma cells
146	Druses in axial parenchyma cells
147	Druses in fibres
148	Druses in chambered cells
	Silica
160	Silica bodies in ray cells
161	Silica bodies in axial parenchyma cells
162	Silica bodies in fibres

Analysis of the data matrix with Xper2 software

Once the species descriptions were compiled, the descriptive data matrix was exported from Pl@ntNote to Xper2 (Ung *et al*. 2010; http://lis-upmc.snv.jussieu.fr/lis/?q=en/resources/software/xper2), a free-access software dedicated to taxonomic descriptions and computer-aided identification, which allows one to edit standardized descriptions and to compare morphological dissimilarities. The Xper2 software was used to evaluate the suitability of the data matrix, by exploring the discriminating power of each character. Xper2 also allowed us to complete the species descriptions in English and French, based on the constructed data matrix.

Graphic interface

Pictures that best illustrated each character state were selected from the photo library to build the graphic interface of the application (Fig. 1). Line drawings for all
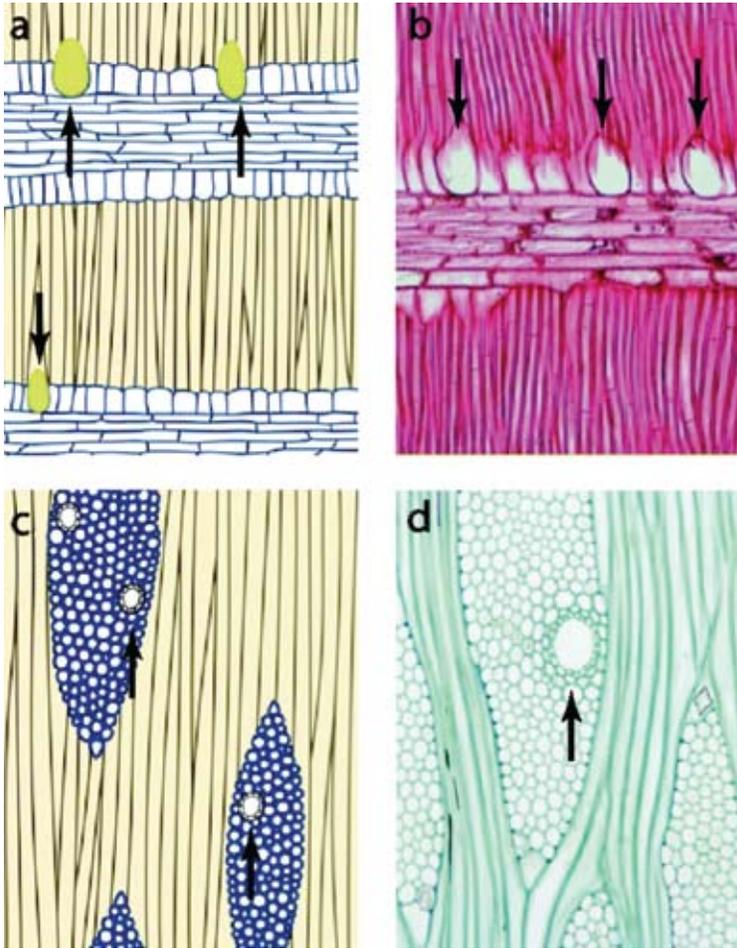
Figure 1. Two examples of vector drawings (left) illustrating anatomical features, compared to light microscopic views (right). – **a** and **b** show oil cells in *Ocotea schomburgkiana* (Lauraceae), **c** and **d** radial canals in *Spondias mombin* (Anacardiaceae).

99 character states were first made from these pictures, then digitized and transformed into vector drawings using Corel Draw® X4. This resulted in 27 anatomical plates, thus illustrating each character and its states. We used different colors to represent each anatomical tissue, to facilitate its perception by users. An example of an anatomical plate illustrating the perforation plates is provided in Figure 2.

The graphic interface (Fig. 3) of the application was then designed to provide an easy access to the 27 selected identification characters. This interface was assembled by superposition of layers, each layer representing one character state. The IDAO software uses a previously constructed Microsoft Access® database, which links the layers and character states, thus completing the application.
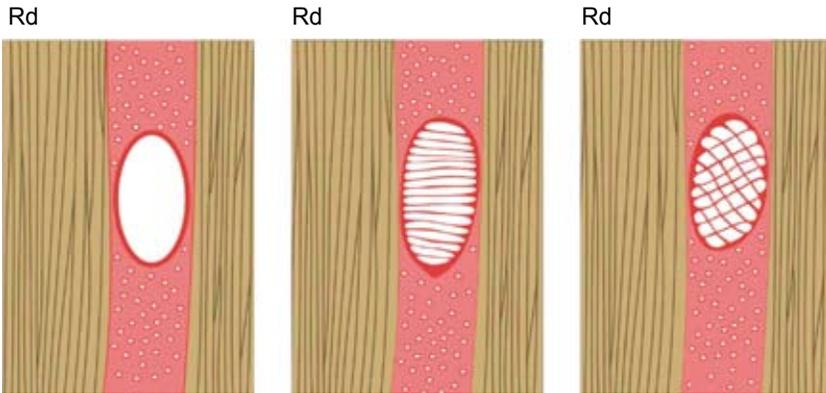
Figure 2. An example of the 27 plates illustrating wood anatomical characters used for identification. This plate illustrates, from left to right, the three character states of the perforation plates: 1) Simple perforation plate, 2) scalariform perforation plate, and 3) reticulate, foraminate, and/or other types of perforation plate. Rd indicates the radial nature of the thin slice.
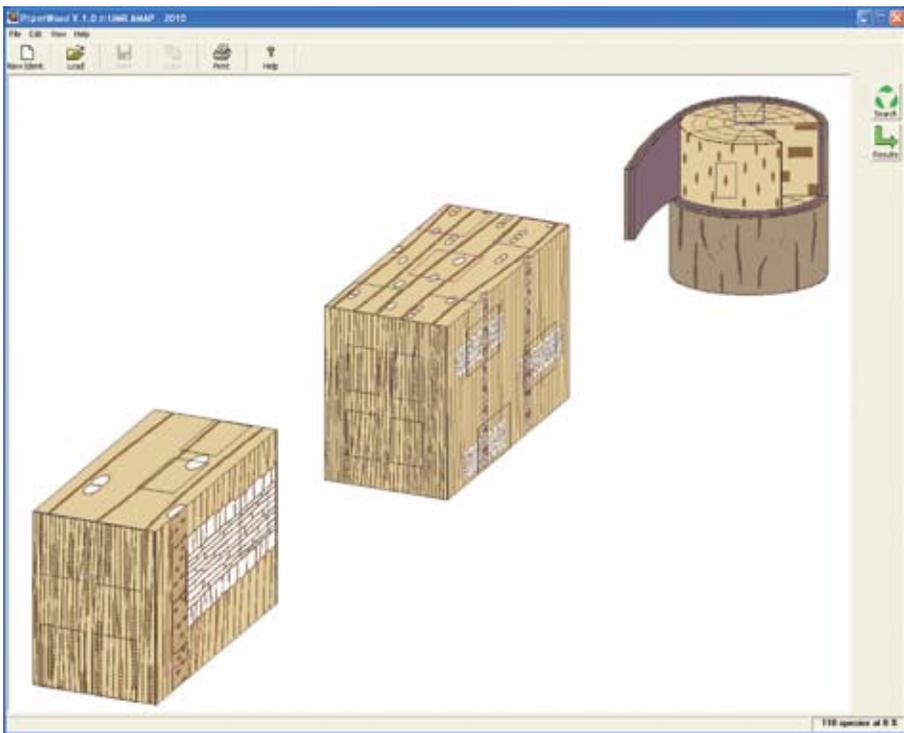

Figure 3. Pl@ntWood graphic interface showing three different wood sections at different magnifications. Reactive areas in the form of frames correspond to different anatomical features accessible to the users.
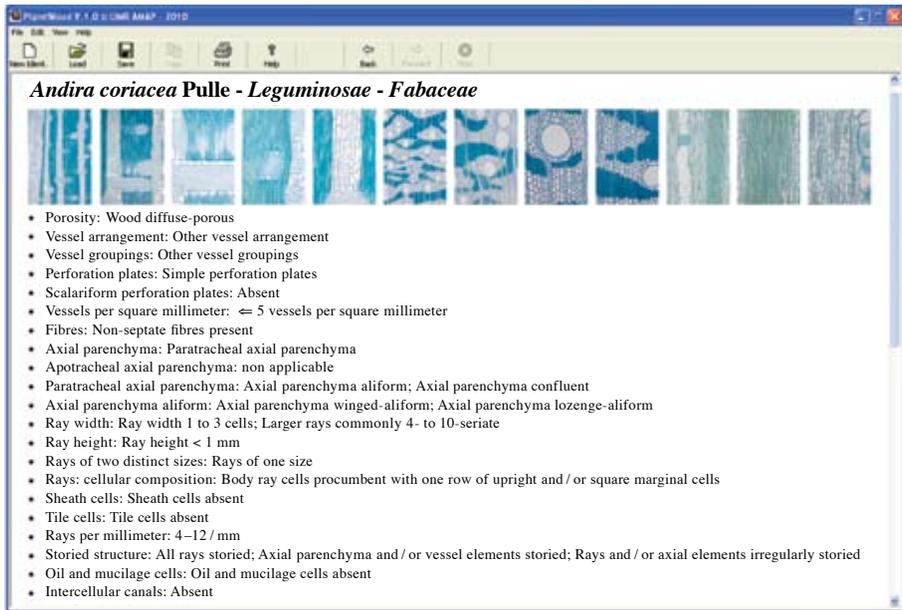
Figure 4. Example of the factsheet for *Andira coriacea* (Fabaceae). This sheet shows the species' illustrations and the anatomical description of the wood.

RESULTS AND DISCUSSION

A beta version of Pl@ntWood is downloadable at www.plantnet-project.org, in the Pl@ntwood case studies section (collaborative projects). This is a free stand-alone application running on a PC micro-computer, equipped with a Pentium processor and Windows system (98SE, 2000, XP or Vista for the MS-Windows Version), with a minimum of 512 MB Ram, a color display of 800×600 or more; and 40 MB of memory on the hard drive. An online version will be available in the future.

Pl@ntWood is a graphic identification tool based on microscopic wood anatomical features. It allows the user to choose an anatomical character by comparing the wood sample with the images representing each character (Fig. 1). The graphic interface shows three different wood sections, at different magnifications, each containing reactive areas that correspond to different anatomical features (Fig. 3). By clicking on one of those areas, the user accesses a screen showing the possible states of that particular feature. Then the user selects and validates the character state that most resembles the unknown wood sample, resulting in an updated image of the wood. The user may go back and forward as many times as necessary, and can stop at any point in the process. The number of species matching with the character states selected by the user is visible in a frame located at the bottom-right of the window (Fig. 3), and is continuously updated with the feature selections made. When the results button is clicked, the list of species is given with a percentage of characters matching between the unknown

sample (*i.e.*, the characters selected by the user) and the anatomical description of each species included in Pl@ntWood. At any moment in the identification process, the user can access the species list, in which hyperlinks of species names lead to the respective descriptive pages. A species' factsheet shows its anatomical description and photomicrographs, illustrating relevant anatomical features, as shown in Figure 4.

By including graphical information in the identification tool, the need for strong background knowledge is minimized, making the use of wood anatomy more accessible for identification purposes. Nevertheless, variation in wood anatomical features is present (Wheeler & Baas 1998; Carlquist 2001) and identification tools cannot take into account all this variation. However, the descriptive sheets included in Pl@ntWood, which contain detailed anatomical information, could also provide non-anatomical characters for the user. For example, geographic distribution, fluorescence, as well as illustrations of morphological and anatomical variability could be included, helping the user to verify the identification's accuracy.

Pl@ntWood does not pretend to replace the expertise and skills of wood specialists. We simply hope that it will provide a useful approach, complementary to those already available, to which it could helpfully be coupled in the future. Furthermore, Pl@ntWood is not intended for the full identification of all relevant woods, but is a new product that will be expanded and improved in the future: 1) by adding more information to each species' descriptive sheet, 2) by expanding its scope to other Amazonian species (especially the most endangered woods according to CITES listing), and later to other floras, and 3) by making the application available on other devices such as personal digital assistants (PDAs) or mobile phones. In addition, with this work we set a precedent for graphic-based identification, and given the fact that Pl@ntWood is a fully graphic identification system, it seems particularly suitable for education purposes. An adaptation of this work to temperate and Mediterranean species and other life forms such as lianas, which are essential components of tropical ecosystems (Caballé 1998; Schnitzer 2005) is one of our future goals. For this, it might be necessary to completely redefine the macro- and micro-anatomical characters included in the application.

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