ISSN impresa 0717-3644
ISSN online 0718-221X

Maderas. Ciencia y tecnología 2023 (25): 24, 1-12

DOI: 10.4067/s0718-221x2023000100424

WOOD/WATER RELATIONS OF 15 SOUTH AMERICAN LESSER-USED WOOD SPECIES

Johannes Welling[1,2,♠]

https://orcid.org/0000-0001-6284-0759

John Albert Bartolo-Cuba[1]

https://orcid.org/0000-0001-5750-6721

José Carlos Sánchez-Blanco[1]

https://orcid.org/0000-0001-5257-600X

Javier Luis Ahrens-Castillo[1]

https://orcid.org/0000-0002-4239-5667

José Alfredo Ugarte-Oliva[1]

http://orcid.org/0000-0002-0847-4281

ABSTRACT

In the Amazonian forests of Perú a large variety of native wood species can be found, of which only a few are commercially exploited. Exploitation is focused on high density durable hardwoods for flooring applications. After selective logging of a few valuable trees the forests often are considered being "unproductive" because there is no market for most of the remaining trees. Having a long-term sustainable forest management and utilization plan in mind, a continuous extraction of more tree species is desirable. For opening out new markets for lesser-used species a concise knowledge of their physical and mechanical properties is essential. Fifteen lesser-used Peruvian wood species were investigated to characterize their wood/water relations. Density, shrinkage behavior, and sorption characteristics were determined. In addition, the functional relation between electrical resistance and moisture content was determined to provide a sound basis for non-destructive moisture content measurements.

Keywords: Electrical resistance/moisture relation, electrical wood properties, lesser-used Peruvian species, physical wood properties, sorption isotherm.

[1]Instituto Tecnológico de la Producción (ITP). Centro de Innovación Productiva y Transferencia Tecnológica de la Madera. (CITEmadera Lima). Lima, Perú.
[2]Holz-Expertise. Reinbek, Germany.
♠Corresponding author: welling@holz-expertise.de
Received: 30.06.2022 Accepted: 13.03.2023

INTRODUCTION

World-wide there are more than 60000 known wood species. In the Amazonian forests approximately 40 % of the world's wood species can be found (Cazzolla Gatti *et al.* 2022), a large part of which can be found in Perú. There are approximately 237 wood species which could be commercially exploited (SERFOR 2016). Currently only a small part of this huge potential is processed into wooden products for specific application while a greater part is processed into low value products, e.g. pallets, packaging, formwork, scaffolding, among others (USAID/USFS 2021) or not used at all. In Perú, the Andes mountains separate the Amazonian Forest from the densely populated coastal regions where the major part of the wood processing and furniture manufacturing companies are located. In the Amazonian part of Perú the sawmills are located close to the rivers. Log supply is almost to 100 % based on upstream rafting and ship transport. All sawn timber products for export or for being used in the densely populated coastal regions need to be transported by trucks over the Andes (Mejía 2015, CNF 2015, DIREPRO 2012).

Most of the Peruvian timber production is consumed domestically. According to recent estimates no more than 10 % of national production is exported (USAID 2019). According to FAO statistics (FAO 2020) 735000 m^3 non-coniferous sawn timber were produced in Perú in 2020, of which 72000 m^3 were exported, representing an export value of US$ 45 million. Perú imported 122000 m^3 coniferous sawn timber in 2020, representing an import value of US$ 35 million. This coniferous timber is mainly used by the furniture industry, even though there is an abundance of broadleaved forest resources which could be used for the same purposes (USDA 2017).

For increasing the commercial utilization of the Peruvian wood resources, there is an urgent need to improve the knowledge about the properties and technical features of the lesser-used species. Information about wood/water relations, such as shrinkage properties, sorption characteristics, and electrical properties are crucial when searching for fields of application and establishing appropriate methods of harvesting, sawing, drying, processing, storage prior to further processing, and long-distance transport of wood products in case of export.

MATERIALS AND METHODS

Selection of species

Due to the huge number of lesser-used tree species in the Amazonian part of the Peruvian forests and due to the limited resources in terms of time and manpower, a selection of species had to be carried out to conduct the research tasks. In this study, a multi-criteria decision analysis approach (Saaty 1990) was used for the selection process of 15 species out of several hundreds. First, a long list of selection criteria was set up. The five most important criteria and the associated weighing factors were defined by five experts attending a consensus meeting. The selection criteria and the corresponding weighing factors were: frequency of occurrence (30), lack of physical and mechanical information (30), possible implications for local markets (15), possible importance for export (15), and market price (10). The numbers in round brackets are the weighting factors (sum = 100). The experts rated the five criteria for each of the species on the list by giving up to 10 points (0 = not relevant, 10 of utmost importance) to each criterion. Multiplication of points with weighing factor yielded the total score (max = 1000). For this study, the 15 species with the highest scores were selected. To make sure that the natural variability between different trees and in individual stems is considered in the determination of the wood properties, the test material for production of the specimens had to comprise: sections from at least three different trees, sections from butt and middle locations in the stem, specimens taken from both, sapwood and heartwood, no previous treatment with preservatives, no prior drying at elevated temperatures. The list of selected species is presented in Table 1.

Table 1: List of selected Peruvian species.

N°	Common name	Scientific name	Family
1	Yacushapana	*Terminalia parvifolia* (Ducke) Gere & Boatwr.	Combretaceae
2	Yacushapana	*Anthodiscus amazonicus* Gleason & A.C.Sm.	Caryocaraceae
3	Huayruro	*Andira macrothyrsa* Ducke	Fabaceae
4	Huayruro	*Andira cf. Surinamensis* (Bondt) Pulle	Fabaceae
5	Aguanillo	*Otoba glycycarpa* (Ducke) W. A. Rodrigues & T. S. Jaram.	Myristicaceae
6	Caimitillo	*Pouteria guianensis* Aubl.	Sapotaceae
7	Aguanillo	*Otoba parvifolia* (Markgr.) A. H. Gentry	Myristicaceae
8	Tornillo	*Cedrelinga cateniformis* (Ducke) Ducke	Fabaceae
9	Almendro	*Caryocar glabrum* (Aubl.) Pers.	Caryocaraceae
10	Favorito	*Osteophloeum platyspermum* (A. DC.) Warb.	Myristicaceae
11	Marupa	*Simarouba amara* Aubl.	Simaroubaceae
12	Cachimbo	*Allantoma decandra (Ducke)* S.A.Mori, Ya Y.Huang & Prance	Lecythidaceae
13	Ana caspi	*Apuleia leiocarpa* (Vogel) J.F.Macbr.	Fabaceae
14	Mashonaste	*Clarisia racemosa* Ruiz & Pav.	Moraceae
15	Shihuahuaco	*Dipteryx micrantha* Harms	Fabaceae

Physical properties

Investigations focused on the wood/water relations with the following properties and behaviors examined: sorption characteristics, shrinkage behavior, electrical properties. Standardized methods for determination of moisture content (ISO 13061-1 AMD 1:2017-06 2017), density (ASTM D2395:2017 2017, ISO 13061-2:2014-10 2014) and shrinkage properties (ISO 13061-13:2016-11 2016, DIN 52184:1979-05 1979) were used.

Sorption characteristics

According to standard procedures, scanning sorption isotherms at 23 °C+/-2 °C were determined by exposing small specimens (20 mm x 20 mm and 6 mm in longitudinal direction) to a series of constant climate conditions starting with an average moisture content (MC) of approximately 12 %. For each species 10 specimens were tested (n=10). Absorption was carried out in several absorption steps ending at 98 % relative humidity (RH), followed by various desorption steps ending with 33 % RH. Finally, after determination of the oven dry weight of the samples, the equilibrium moisture content of the samples at the end of each climate step was calculated and the sorption isotherms were visualized.

Parallel to this standard procedure, a dynamic water vapor sorption device for determining sorption isotherms (ProUmid, Germany) was used by a project partner. Here, small samples of wooden particles (millings) comprising a mix of various trees and locations in the stems were placed in small containers. 19 samples from different tree species were placed onto a rotating rack (round table) and exposed to a series of pre-programed climate conditions. By continuous sequential weighing of the loaded containers moisture equilibrium of their content was determined.

Shrinkage behavior

To describe the shrinkage behavior quite a number of different measures can be chosen (Noack *et al.* 1973). Sargent (2019) gives an overview about procedures and characteristic values which are described in various standards and textbooks.

Climate chambers are indispensable to determine wood/water relations. However, climate chambers are expensive due to high cost for investment, maintenance and energy. In order to conduct the investigation in a reasonable time span, several climate chambers were required to provide different climate conditions at the same time. As neither several climate chambers nor sufficient funds for purchasing additional chambers were available, two insulated chambers with internal air circulation and temperature control were allocated in a laboratory room with well controlled temperature. In each chamber six small, and hermetically sealed, removable containers were positioned. Each container was equipped with a small fan for internal circulation of air. The relative humidity of the circulating air was conditioned by means of a basin filled with a saturated salt solution placed at the bottom of the container. The wooden samples were positioned on a rack approximately 4 cm - 5 cm above the surface of the saturated salt solution. By keeping the temperature of the chamber constant and keeping the salt solutions in saturated condition, various constant relative humidity (RH) conditions could be provided at the same time. Figure 1 shows the overall setup, Figure 2 the design of the small climate containers. In Table 2 the salt solutions used and their corresponding relative humidity are listed.

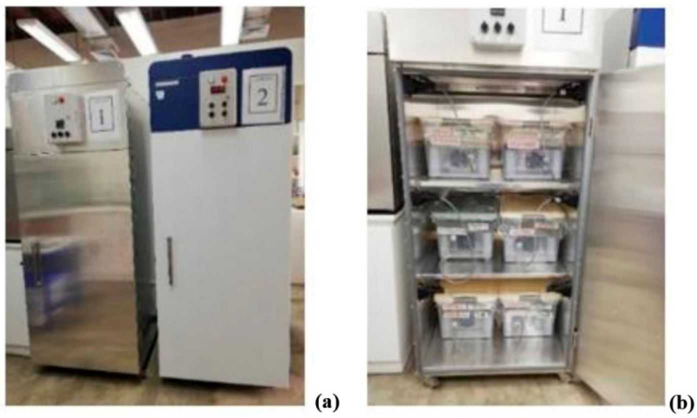

Figure 1: Experimental set-up for sorption tests; (a) two insulated and temperature-controlled chambers, (b) insight view of the chamber with six hermetically sealed containers to provide various different relative humidity conditions.

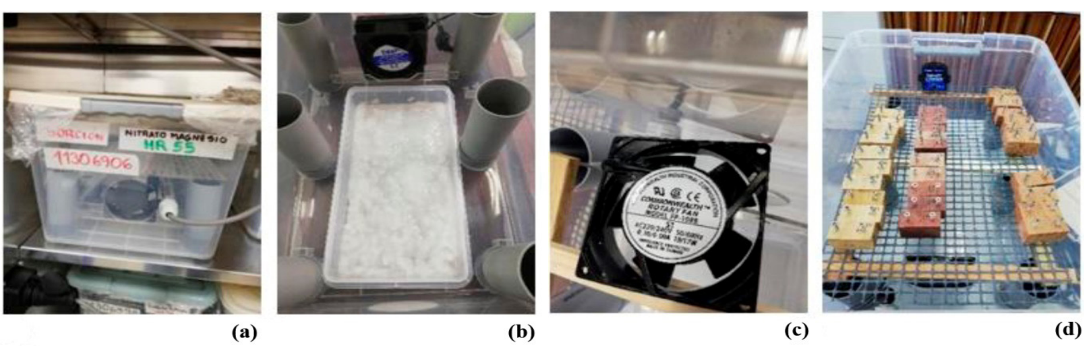

Figure 2: Components for variable climates; (a) Climate box, (b) basin filled with saturated salt solution, (c) ventilator for internal circulation, (d) wood specimen placed on rack above basin with saturated salt solution.

Table 2: Inorganic salts for providing various relative humidity levels.

Salt	Relative humidity (%)
Potassium sulfate (K_2SO_4)	98
Potassium chloride (KCl)	85
Sodium chloride (NaCl)	76
Magnesium Nitrate ($Mg(NO_3)_2$)	55
Magnesium chloride ($MgCl_2$)	33

For determination of shrinkage behavior, specimens (n=10 for each species) with dimension 20 mm x 20 mm x 10 mm were submitted to the conditioning steps illustrated in Figure 3. To identify the point of reaching equilibrium condition in the specimens, consecutive weighing of the test samples was carried out. Dimensional changes were measured using calipers when equilibrium was reached.

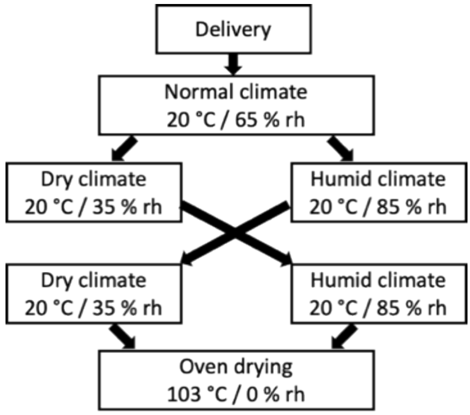

Figure 3: Conditioning steps for determination of shrinkage behavior.

Saturation with water to guarantee maximum swelling was achieved by submerging the specimens under water in a vacuum-tight container and extracting air by several vacuum cycles as shown in Figure 4.

Figure 4: Saturation was reached in approximately 60 min compared to several days submersion without vacuum support.

Oven drying according to ASTM D4442-20 (2020) at the end of all climate steps was applied to calculate moisture content (MC) at various climate conditions.

The following features were determined:

1) Maximum tangential shrinkage (Ct_{tan}) in percent (between MC_{sat} and MC_0)

2) Maximum radial shrinkage (Ct_{rad}) in percent (between MC_{sat} and MC_0)

3) Maximum volumetric shrinkage (Ct_{vol}) in percent (between MC_{sat} and MC_0) is achieved by calculating the sum of tangential, radial, and longitudinal shrinkage. But, because of the very small values of longitudinal shrinkage, the sum of tangential and radial shrinkage will deliver almost the same result.

4) Coefficient of shrinkage *h* in percent/percent RH

5) Ratio of shrinkage *q* in percent/percent MC

6) Shrinkage anisotropy (ratio of tangential to radial shrinkage)

Electrical properties

For measuring moisture content (MC) with hand-held MC-meters the functional relation between electrical resistance and moisture content must be known. Electrical resistance was determined by placing stainless steel screws spaced 30 mm in small wooden blocks. Electrical resistance was measured using a commercial wood moisture meter (Brookhuis FMD6) equipped with the feature that indicates absolute values of electrical resistance instead of transformed moisture content readings. The instrument's accuracy was checked by comparing the instrument readings with those of a high precision tera-ohm-meter (Knick H12) while measuring the electrical resistance of six fixed resistors ranging from 1,87 MOhm to 5000 MOhm.

To establish the electrical resistance / moisture content relation, wooden blocks (n=10) of each species (15) with the dimensions 30 mm x 45 mm x 25 mm were exposed to five different climates, which cover the whole range of indoor climates experienced in furniture or building applications. The absolute electrical resistance values obtained were transformed into ln (resistance). For establishing the functional relation, the statistical functions of MS-EXCEL were used. Selecting the logarithmic function yielded the best results.

RESULTS AND DISCUSSION

Sorption characteristics

Figure 5 shows the sorption isotherms of the 15 Peruvian wood species included in the investigation comparing the results achieved by the standard method. All sorption isotherms show the typical shape of isotherms of hygroscopic materials. Between approximately 35 % and 85 % a hysteresis between absorption and desorption is visible. The hysteresis determined in our experiments ranged between 1,6 % and 2,6 % at 65 % relative humidity. These average hysteresis values are lower than those reported by other researchers (Fredriksson and Thybring 2018, Simo-Tagne *et al.* 2016) who determined sorption isotherms of other wood species. This probably is due to the fact that in our experiments some fluctuations in temperature and relative humidity could not be avoided. As a consequence, our desorption and absorption lines did shift towards the mean line between de- and absorption. In the lower range of relative humidity (until approx. 55 %) all species examined showed almost the same behavior. The mean values between desorption and absorption at 65 % relative humidity (EMC_65) and 98 % humidity (EMC_98) are listed in Table 3. Pronounced differences between the 15 species are only present at higher relative humidity (98 %). Here the equilibrium moisture contents (EMC) vary between 16,6 % (*Andira macrothyrsa*) and 23,0 % (*Otoba parvifolia*).

Table 3: Characteristic values of the sorption isotherms of 15 Peruvian wood species.

	Terminalia parvifolia	*Anthodiscus amazonicus*	*Andira macrothyrsa*	*Andira cf. Surinamensis*	*Otoba glycycarpa*	*Pouteria guianensis*	*Otoba parvifolia*	*Osteophloeum platyspermum*	*Caryocar glabrum*	*Cedrelinga cateniformis*	*Simarouba amara*	*Allantoma decandra*	*Clarisia racemosa*	*Apuleia leiocarpa*	*Dipteryx micrantha Harms*
EMC_65	10,9	10,9	10,8	12,5	12,5	13,0	12,7	11,0	12,3	12,9	11,9	12,7	11,7	10,9	11,3
Hysteresis_65	2,2	2,1	1,6	2,3	2,3	2,3	2,2	2,2	2,3	2,1	1,9	2,1	1,4	1,4	1,6
EMC_98	17,0	18,8	16,6	21,0	23,1	19,1	23,0	20,1	21,0	21,5	20,6	21,0	17,4	17,3	17,6

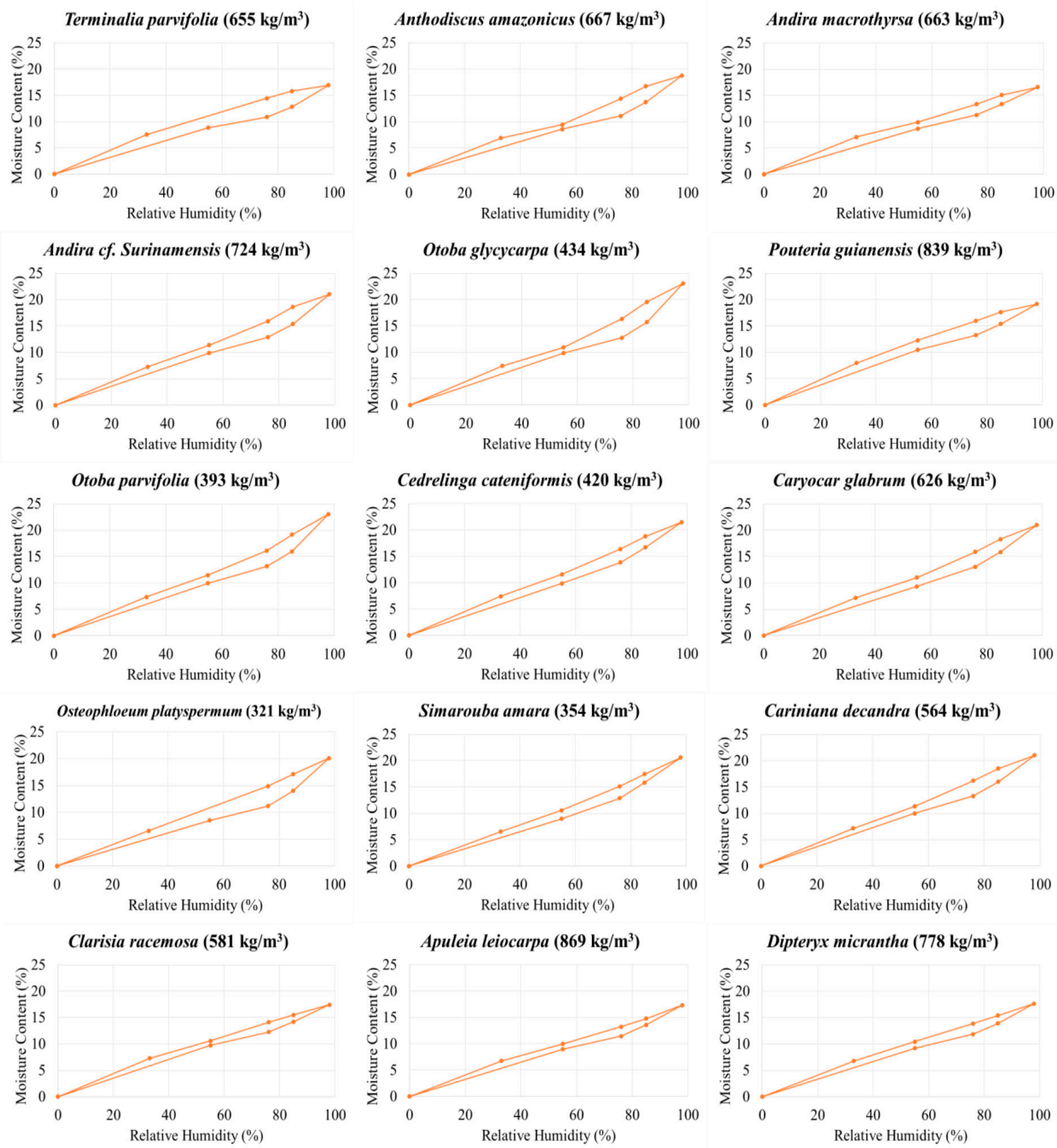

Figure 5: Sorption isotherms of 15 lesser-used Peruvian wood species.

Shrinkage behavior

Table 4 lists the results of the various properties describing the shrinkage characteristics of 15 Peruvian wood species. In many cases documentation for lesser-used species only provides information about maximum shrinkage values in tangential and radial direction. Sometimes, only information on volumetric shrinkage without differentiating the anatomical direction is provided. For practitioners the use of *h*- and *q*-values is more important as its use is to predict the dimensional changes of wooden parts during usage. The ratio of tangential and radial characteristic values is a good measure for anisotropy and dimensional stability. Low absolute shrinkage values in combination with low tang/rad-ratios characterize wood species with excellent dimensional stability, while high tan/rad-ratios indicate a high propensity for distortion and dimensional change under use conditions in regions with pronounced fluctuations of relative humidity (e.g. low indoor RH in winter due to central heating or RH variations due to alternating dry and humid seasons). Low equilibrium moisture contents at high relative humidity combined with good dimensional stability qualify species for high quality indoor and outdoor applications.

Electrical properties

In Table 5 the regression parameters of the functional relation between electrical resistance and wood moisture content for 15 Peruvian lesser-used species are presented. In Figure 6a and Figure 6b examples of the graphical presentation of measured values and the corresponding curve fitting is shown for the two species *Clarisia racemosa* (Mashonaste) and *Apuleia leiocarpa* (Ana caspi). What can easily be seen from the graphical presentation is that there is some scattering of values around the regression curve, even though the correlation coefficient R^2 is very high. This scattering reflects the natural variation of electrical properties, both within a species and between individual specimens, due to the varying location in the stem and sapwood/hardwood fraction.

Table 4: Shrinkage characteristics of 15 Peruvian lesser-used species.

Species	Basic density (kg/m³)	density_0 (kg/m³)	Ct_tan (%)	Ct_rad (%)	Ct_vol (%)	Ct_tang/ Ct_rad	h_tan (%/%RH)	h_rad (%/%RH)	h_tan/ h_rad	q_tan (%/%MC)	q_rad (%/%MC)	q_tan/ q_rad
Terminalia parvifolia	655	743	7,7	4,0	11,7	1,9	0,066	0,039	1,7	0,38	0,22	1,7
Anthodiscus amazonicus	667	759	8,0	3,1	11,1	2,7	0,057	0,028	2,0	0,33	0,17	2,0
Andira macrothyrsa	663	725	5,4	2,7	8,1	2,2	0,048	0,029	1,6	0,32	0,2	1,6
Andira cf. surinamensis	724	849	9,7	5,1	14,8	1,9	0,085	0,047	1,8	0,49	0,27	1,8
Otoba glycycarpa	434	499	8,5	4,6	13,1	1,9	0,065	0,041	1,6	0,34	0,21	1,6
Pouteria guianensis Aubl.	839	951	7,7	4,0	11,7	1,9	0,07	0,041	1,7	0,43	0,25	1,7
Otoba parvifolia	393	449	8,7	3,9	12,6	2,2	0,061	0,03	2,0	0,33	0,16	2,1
Osteophloeum platyspermum	321	346	5,5	1,8	7,3	3,3	0,041	0,016	2,7	0,25	0,09	2,6
Caryocar glabrum	626	737	9,7	4,9	14,6	2,0	0,067	0,04	1,7	0,33	0,2	1,7
Cedrelinga cateniformis	420	461	5,7	3,2	8,9	1,8	0,048	0,025	1,9	0,24	0,13	1,9
Simarouba amara	354	389	5,5	2,3	7,8	2,4	0,047	0,026	1,8	0,25	0,14	1,8
Allantoma decandra	564	632	5,8	4,5	10,3	1,3	0,051	0,041	1,3	0,27	0,22	1,3
Clarisia racemosa	581	638	5,7	3,1	8,8	1,9	0,051	0,031	1,6	0,34	0,21	1,6
Apuleia leiocarpa	869	983	7,3	3,5	10,8	2,1	0,065	0,037	1,8	0,41	0,23	1,8
Dipterix micrantha	778	919	9,6	6,3	15,9	1,5	0,067	0,049	1,4	0,46	0,34	1,4

Table 5: Regression coefficients of the functional relation between electrical resistance and wood moisture content. (MC = a * ln(lnresistance) + b)

Scientific name	a	b	R^2
Terminalia parvifolia	-32,96	110,03	0,9662
Anthodiscus amazonicus	-29,57	100,18	0,9295
Andira macrothyrsa	-23,50	84,141	0,9521
Andira cf. surinamensis	-28,02	97,481	0,9681
Otoba glycycarpa	-32,64	110,55	0,9448
Pouteria guianensis	-30,03	104,65	0,9637
Otoba parvifolia	-33,53	113,41	0,9602
Cedrelinga cateniformis	-34,81	118,61	0,9766
Caryocar glabrum	-32,02	110,81	0,9560
Osteophloeum platyspermum	-26,51	92,745	0,9845
Simarouba amara	-29,87	102,65	0,9814
Allantoma decandra	-31,80	108,05	0,9835
Apuleia leiocarpa	-25,99	89,717	0,9684
Clarisia racemosa	-23,98	84,167	0,8999
Dipteryx micrantha	-28,24	97,893	0,9663

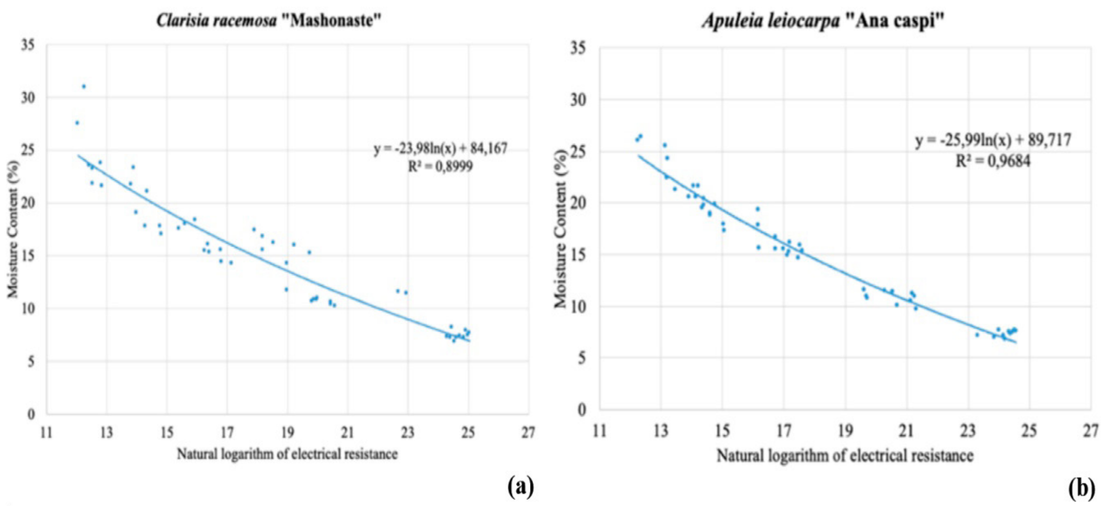

Figure 6: Functional relation between electrical resistance ($x=\ln_{resistance}$) and wood moisture Content; (a) *Clarisia racemosa* (Mashonaste), (b) *Apuleia leiocarpa* (Ana caspi).

In industrial practice, measuring uncertainty results from the fact that boards and wooden products often exhibit moisture gradients. As a consequence, when measuring moisture content with resistance type moisture meters, obtained results are strongly influenced by the presence of moisture gradients, type of measuring electrodes used (insulated or non-insulated) and penetration depth of the electrodes. In order to avoid such uncertainties in the present investigation a lot of attention was given to avoid moisture gradients in the test specimen. Only when equilibrium conditions determined by securing constant weight between consecutive weight measurement were achieved, the electrical resistance measurement was carried out. Therefore, scattering of values in the graphical presentations is only attributable to natural variation of electrical properties within the species and not to moisture gradients.

For practitioners, knowledge about the functional relation between electrical resistance and wood moisture content is less relevant. The practitioner wants to know how to adjust the setting of his moisture meter to obtain reliable results. To secure this, the functional relations shown in Table 5 must be compared with the functional relations of the setting parameters of the instrument. The manufacturers of the commercial wood moisture meters provide a list of species and recommend corresponding setting parameters for proper use of the instrument. Many of the instruments provide the option of choosing Group 1, 2, 3, or 4. Others offer more choices either by a two-parameter X/Y-setting or by numerical codes each of which may represent a specific resistance/moisture content relation.

Figure 7 shows two examples of species for which (a) an almost perfect fit between instrument setting and functional resistance /moisture content relation could be found, while for (b) the best fitting instrument setting or code only results in good moisture content values around 12 % moisture content. Using a non-appropriate instrument setting will result in false moisture readings.

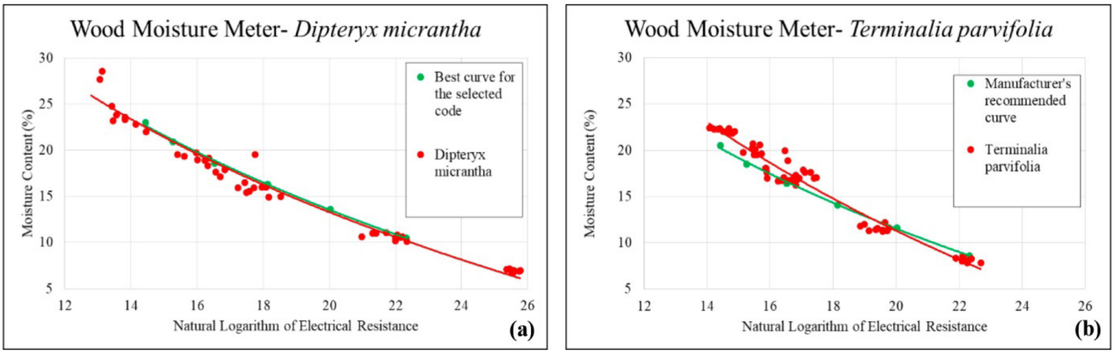

Figure 7: Comparison of specific species resistance curves (red) with a) resistance curve of an almost perfect fitting instrument setting code (green), and b) resistance curve of a setting code, recommended by the manufacturer of the instrument, with poor fit (green).

CONCLUSIONS

Determination of wood/water relations is important for describing the behavior of wood during drying, and also during further processing and usage. Proposing and introducing lesser-used species to the market will only be successful if potential users can judge the suitability of a species for a specific application. Data on physical properties and wood/water relations (e.g. density, shrinkage behavior and sorption characteristics) as presented in this research study can help to fill the gap on information for the 15 lesser used Peruvian species. Such data can be incorporated in data bases like macroHOLZdata (GFF-Holzwissenschaft 2022), Holzdatenbank (TU-Dresden 2018), or Wood Properties Techsheets (USDA 2022), which already provide information on wood properties for a large number of species. However, for proposing applicability of a lesser-used species for specific end-uses, wood/water relations are only part of the information needed. Without data on mechanical behavior, chemical composition and durability against fungi and wood destroying insects, the picture is not complete, thus further research is needed. Detailed wood property tables are necessary to support the search for alternative species for specific uses and to replace endangered species on the timber markets.

AUTHORSHIP CONTRIBUTIONS

J. W.: Conceptualization, Formal Analysis, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing; J. A. B. C.: Formal Analysis, Investigation, Software, Validation, Visualization, Writing – review & editing; J. C. S. B.: Investigation, Software; J. L. A. C.: Methodology, Resources, Software, J. A. U. O.: Conceptualization, Funding acquisition, Project administration, Resources.

ACKNOWLEDGEMENTS

This research has been financed by CONCYTEC-World Bank Project 8682-PE "Mejoramiento y Ampliación de los Servicios del Sistema Nacional de Ciencia Tecnología e Innovación Tecnológica", through its executing unit PROCIENCIA (Contract Nº 046-2019-FONDECYT-BM-INC.INV). The study was carried out at the Centro de Innovación Productiva y Transferencia Tecnológica de la Madera (CITEmadera Lima) of the Instituto Tecnológico de la Producción (ITP).

The authors would like to thank the members of the entire working group at CITEmadera Lima for their support, without which the successful implementation of the project in times of the COVID pandemic would not have been possible.

REFERENCES

ASTM. 2020. Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials. ASTM D4442-2020. ASTM: West Conshohocken, PA, USA.

ASTM. 2017. Standard Test Methods for Density and Specific Gravity (Relative Density) of Wood and Wood-Based Materials. ASTM D2395:2017. ASTM: West Conshohocken, PA, USA.

Cazzolla Gatti, R.; Reich, P.B.; Gamarra, J.G.P; Crowther, T.; Hui, C.; Morera, A.; Bastin, JF; de-Miguel, S.; Nabuurs, GT; Svenning, JC; Serra-Diaz, J.M.; Merow, C.; Enquist, B.; Kamenetsky, M.; Lee, J.; Zhu, J.; Fang, J.; Jacobs, D.F.; Pijanowski, B.; Banerjee, A.; Giaquinto, R.A.; Alberti, G.; Almeyda Zambrano, A.M; Alvarez-Davila, E.; Araujo-Murakami, A.; Avitabile, V.; Aymard, G.A.; Balazy, R.; Baraloto, C.; Barroso, J.G.; Bastian, M.L.; Birnbaum, P.; Bitariho, R.; Bogaert, J.; Bongers, F.; Bouriaud, O.; Brancalion, P.H.S.; Brearley, F.Q.; Broadbent, E.N; Bussotti, F.; Castro da Silva, W.; César, R.G.; Češljar, **G.; Chama Mosco, V.; Chen, H.Y.H.; Cienciala, Emil; Clark, C.J.; Coomes, D.A.; Dayanandan, S.; Decuyper, M.; Dee, L.E.; Del Aguila Pasquel, J.; Derroire, G.; Djuikouo, M.N.K.; Van Do, T.; Dolezal, J.;** Đorđević, I.Đ.; **Engel, J.; Fayle, T.M.; Feldpausch, T.R.; Fridman, J.K.; Harris, D.J. ; Hemp, A.; Hengeveld, G.; Herault, B.; Herold, M.; Ibanez, T.; Jagodzinski, A.M.; Jaroszewicz, B.; Jeffery, K.J.; Johannsen, V.K.; Jucker, T.; Kangur, A.; Karminov, V.N.; Kartawinata, K.; Kennard, D.K.; Kepfer-Rojas, S.; Keppel, G.; Khan, M.L.; Khare, P.K.; Kileen, T.J.; Kim, H.S.; Korjus, H.; Kumar, A.; Kumar, A.; Laarmann, D.; Labrière, N.; Lang, M.; Lewis, S.L.; Lukina, N.; Maitner, B.S.; Malhi, Y.; Marshall, A.R.; Martynenko, O.V.; Monteagudo Mendoza, A.L.; Ontikov, P.V.; Ortiz-Malavasi, E.; Pallqui Camacho, N.C.; Paquette, A.; Park, M.; Parthasarathy, N.; Peri, P.L.; Petronelli, P.; Pfautsch, S.; Phillips, O.L.; Picard, N.; Piotto, D.; Poorter, L.; Poulsen, J.R.; Pretzsch, H.; Ramírez-Angulo, H.; Restrepo Correa, Z.; Rodeghiero, M.; Rojas Gonzáles, R. del P.; Rolim, S.G.; Rovero, F.; Rutishauser, E.; Saikia, P.; Salas-Eljatib, C.; Schepaschenko, D.; Scherer-Lorenzen, M.;** Šebeň, **V.; Silveira, M.; Slik, F.; Sonké, B.; Souza, A.F.; Stereńczak, K.J.; Svoboda, M.; Taedoumg, H.; Tchebakova, N.; Terborgh, J.; Tikhonova, E.; Torres-Lezama, A.; van der Plas, F.; Vásquez, R.; Viana, H.; Vibrans, A.C.; Vilanova, E.; Vos, V.A.; Wang, H.F; Westerlund, B.; White, L.J.T.; Wiser, S.K.; Zawiła-Niedźwiecki, T.; Zemagho, L.; Zhu, Z.X.; Zo-Bi, I.C.; Liang, J. 2022.** The number of tree species on Earth. *Proceedings of the National Academy of Sciences* 119(6): e2115329119. https://doi.org/10.1073/pnas.2115329119

CNF. 2015. Apoyo para mejorar la productividad de la industria maderera peruana para elaborar productos con mayor valor agregado. Informe final PD 540/09 Rev. 2 (I). https://www.itto.int/files/itto_project_db_input/2801/Competition/PD-540-09-R2-I-Completion Report.pdf?v=1445304983

DIN. 1979. Prüfung von Holz; Bestimmung der Quellung und Schwindung. (Testing of wood; determination of swelling and shrinkage). DIN 52184:1979-05. Berlin, Germany.

DIREPRO. 2012. Diagnóstico Industrial de la Región Madre de Dios. Puerto Maldonado, Perú. 53p. https://www.itto.int/files/itto_project_db_input/2801/Technical/DIAGN%C3%93STICO%20INDUSTRIAL%20%202012.pdf?v=1389941377

FAO. 2020. FAOstat. https://www.fao.org/faostat/en/#data/FO

Fredriksson, M.; Thybring, E.E. 2018. Scanning or desorption isotherms? Characterising sorption hysteresis of wood. *Cellulose* 25: 4477-4485. https://doi.org/10.1007/s10570-018-1898-9

GFF-Holzwissenschaft. 2022. *macroHOLZdata*. GFF-Holzwissenschaft: Germany. https://apps.apple.com/at/app/macroholzdata/id112092239

ISO. 2017. Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 1: Determination of moisture content for physical and mechanical tests; Amendment 1. ISO 13061-1 AMD 1:2017-06. Geneva, Switzerland.

ISO. 2014. Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 2: Determination of density for physical and mechanical tests. ISO 13061-2:2014-10. Geneva, Switzerland.

ISO. 2016. Physical and mechanical properties of wood - Test methods for small clear wood specimens - Part 13: Determination of radial and tangential shrinkage. ISO 13061-13:2016-11. Geneva, Switzerland. https://apps.apple.com/de/app/macroholzdata/id1120922391

Mejía, E.; Cano, W.; de Jong, W.; Pacheco, P.; Tapia, S.; Morocho, J. 2015. Actores, aprovechamiento de madera y mercados en la Amazonía peruana. Documentos ocasionales 145. CIFOR: Bogor, Indonesia. https://www.cifor.org/publications/pdf_files/OccPapers/OP-145.pdf

Noack, D.; Schwab, E.; Bartz, A. 1973. Characteristics for a judgment of the sorption and swelling behavior of wood. *Wood Science and Technology* 7: 218-236. https://doi.org/10.1007/BF00355552

Saaty, T.L. 1990. Multicriteria decision making: the analytic hierarchy process: planning, priority setting, resource allocation. RWS Publications: Pittsburgh, Pa., USA.

Sargent, R. 2019. Evaluating dimensional stability in solid wood: a review of current practice. *Journal of Wood Science* 65: e36. https://doi.org/10.1186/s10086-019-1817-1

SERFOR. 2016. Lista oficial de especies forestales maderables aprovechables con fines comerciales. https://www.serfor.gob.pe/portal/wp-content/uploads/2018/09/Lista-de-especies-maderables

Simo-Tagne, M.; Rémond, R.; Rogaume, Y.; Zoulalian, A.; Perré, P. 2016. Characterization of sorption behavior and mass transfer properties of four central africa tropical woods: Ayous, Sapele, Frake, Lotofa. *Maderas. Ciencia y Tecnología* 18(3): 403-412. https://dx.doi.org/10.4067/S0718-221X2016005000020

TU-Dresden. 2018. Holzdatenbank. Institut für Holztechnik und Faserwerkstofftechnik. https://holzdatenbank.int.mw.tu-dresden.de

USDA. 2022. Wood Properties Techsheets. https://www.fpl.fs.usda.gov/research/centers/woodanatomy/techsheets_display.php?geo_category_id=1&genus_commonname_criteria=c&sorting_rule=1a

USAID. 2019. USAID/PERU Pro-Bosques Private Sector Landscape Analaysis - PSLA. Tetra Tech: Burlington, Vermont, USA. https://pdf.usaid.gov/pdf_docs/PA00Z6F9.pdf

USAID/USFS. 2021. Estimando y mejorando la legalidad de la madera en el Perú. Flujos I Oferta, demanda y características de la cadena de suministro de madera. Lima, Perú. 84p. https://cdn.www.gob.pe/uploads/document/file/1756175/03%20-%20Flujos%3A%20oferta%2C%20demanda%20y%20caracter%C3%ADsticas%20de%20la%20cadena%20de%20suministro%20de%20madera.pdf

USDA. 2017. Peru: Wood and Wood Product Trade in Peru Remains Strong. https://www.fas.usda.gov/data/peru-wood-and-wood-product-trade-peru-remains-strong