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INVESTIGATIONS ON THE SORPTION BEHAVIOUR OF SELECTED WOOD SPECIES FROM CAMEROON

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ABSTRACT

The sorption isotherms during adsorption and desorption of 25 wood species from Cameroon (included 3 species from plantation in Togo) were determined. In addition, the chemical compositions of these wood species were tested. The equilibrium moisture contents in a normal climate varied between 10,55 % and 15,6 %. A clear influence of the proportion of extractives can be seen. The maximum differences between adsorption and desorption varied between 2,3 % and 3,6 %.

Keywords: African wood species, Cameroon, chemical composition, equilibrium moisture content, sorption.

INTRODUCTION

Wood as a porous system adsorbs water from the air by sorption and liquid water or other liquids such as varnishes or adhesives by capillary forces. Free water is stored in the voids or cavities, and bound water is found in the cell walls. If the cell wall system is fully filled with water but there is no water in lumens or macro voids, this is called fibre saturation, whereas, if the cell wall and macrosystem are saturated to the maximum with water, this is called water saturation (Hernandez 2007, Niemz 1993, Niemz and Sonderegger 2021, Keylwerth 1969, Popper *et al* 2006, Almeida and Hernandez 2007). The fibre saturation range lies between 22% and 35% and is strongly dependent on the wood species. Many tropical woods have a very low equilibrium moisture content under normal climatic conditions (20°C/65%RH), which is often due to their high extractives content (Willeitner and Schwab 1981, Popper *et al*. 2006).

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The sorption varies greatly between individual wood species. Tropical wood species and also selected wood species occurring in Europe with a high extractives content such as yew (*Taxus baccata*) or Black locust (*Robinia pseudoacacia*), have a significantly lower equilibrium moisture content at the same RH and temperature in comparison to most European wood species such as spruce or copper beech (Willeitner and Schwab 1981, Keunecke 2008, Keunecke *et al*. 2007). Keylwerth (1969) investigated the sorption behaviour of 124 different wood species as well as the dimensional change with moisture changes in the hygroscopic range. This finding is probably one of the most complete overviews of the sorption behaviour of different wood species. Several percent of difference were observed between the adsorption and desorption equilibrium moisture content, where the desorption equilibrium moisture content was higher than the adsorption one. Popper *et al*. (2009) determined the sorption behaviour of selected European and overseas wood species in adsorption and desorption. The clear differences in the sorption behavior were found among the investigated wood species. A clear influence of the extractives content on the equilibrium moisture content was also found in Popper *et al.* (2006). The equilibrium moisture content tends to decrease with increasing extractives content.

Simo-Tagne *et al.* (2016) investigated the sorption behavior of 4 tropical wood species by means of DVS at adsorption and desorption at 20 ºC and 40 ºC. The results were analyzed using the HH model. Almeida and Hernandez (2007) investigated the influence of the pore structure on the sorption behavior. Hernandez (2007) discusses the influence of the extract substances on the sorption behavior of wood from Peru. Both factors influence the sorption behavior.

Within the scope of the present study, the sorption behaviour during adsorption and desorption as well as the chemical composition were determined for 25 different wood species from Cameroon, and the influence of the extractives on the sorption behaviour was determined. For this purpose, a complex analysis of the chemical composition was carried out. Only a few studies have been conducted on the wood species investigated in this study, and the aim is to close this gap.

MATERIALS AND METHODS

Material

Twenty-five African selected wood species made up with 21 natural forest species and 1 plantation specie (Eucalyptus/ *Eucalyptus saligna* Smith) from Cameroon, 3 plantations species (Cedrela/ *Cedrela odorata* L., Gmelina/ *Gmelina arborea* Roxb.ex Sm., Teak/ *Tectona grandis* L. f.) from Togo (Table 1). For each wood species, 3 test specimens of sapwood in the format 20 mm (radial) x 20 mm (tangential) x 20 mm (longitudinal) were used to measure the equilibrium moisture according to DIN EN 13183-1 (DIN 2002). Each specimen was free of natural defects, such as, knots and resin canals.

Method

Moisture content

From green condition, the specimens were cut and air dried in a climate chamber (circulating air mode) at a temperature of 20 ºC. Prior to the test, the specimens were dried in a box containing silica gel (SiO_2), which may reach to 5 % RH ± 5 %. After one month, the specimens were moved to a chamber which accurately controlled the relative humidity and temperature. While the temperature was maintained at 20 °C, the relative humidity was changed stepwise from 20 % to 95 % with a step of 15 % for the adsorption test and then directly followed by a desorption test by changing the RH from 95 % to 20 % with the same RH step of 15 %. At each humidity level, the specimens were stored for at least 30 days until the equilibrium moisture contents of the specimens were reached. At the end of the experiment, the oven-dry mass of the specimens was determined, and the wood moisture can be calculated accordingly (Equation 1).

$$\omega = \frac{m_\omega - m_0}{m_0} \; x \; 100 \quad (1)$$

ω = moisture content in %

m_ω = mass wet in g

m_0 = mass oven dry in g

Raw density and oven-dry density

The density at a certain in level of moisture content (ω) ρ_ω and the oven-dry density ρ_0 were determined according to DIN 52182 (1976). The following applies (Equation 2):

$$\rho = \frac{m}{V} \qquad (2)$$

Depending on the reference quantity of mass and volume, a distinction is made between the following types of density:

- the ρ_ω at defined wood moisture content (often at 20 ºC and 65 % relative humidity, referred to as normal raw density).

- the oven-dry density ρ_0 (in the absolutely dry state)

Chemical composition

The chemical composition of all wood species was determined in the Laboratory of Pulp and Paper of the Universidad Austral de Chile in Valdivia/Chile. For this purpose, the wood was milled and then the following characteristic values were determined according to the Tappi standards.

- Ethanol-toluene extract: (TAPPI T204),

- Hot water extract (TAPPI T207),

- Total extracts (TAPPI T264),

- Solubility in 1 % NaOH (TAPPI T212)

- Lignin content: (TAPPI T222)

- Cellulose and hemicellulose content: according to Polyak's method

- pH value: measurement in solution in water at 20 °C.

RESULTS AND DISCUSSION

Table 1 shows all the tested wood species in this study, their density at normal climatic condition (20 °C/ 65 % RH) and oven-dry density. The dry density varies between 309 kg/m^3 (cedrela wood) and 1113 kg/m^3 (ebene wood). The equilibrium moisture contentin the normal climate varies between 10,7 % (doussie wood) and 15,6 % (kosipo wood). Figure 1a and 1b shows an overview of the sorption isotherms during adsorption and desorption of the 25 wood species. Table 3 shows the chemical composition of the wood species, which also varies greatly, especially the proportion of extractives. The total proportion of extractives varies from 3,3 % for ebiara to 20,3 % for doussie the proportion of hemicelluloses and lignin also varies greatly.

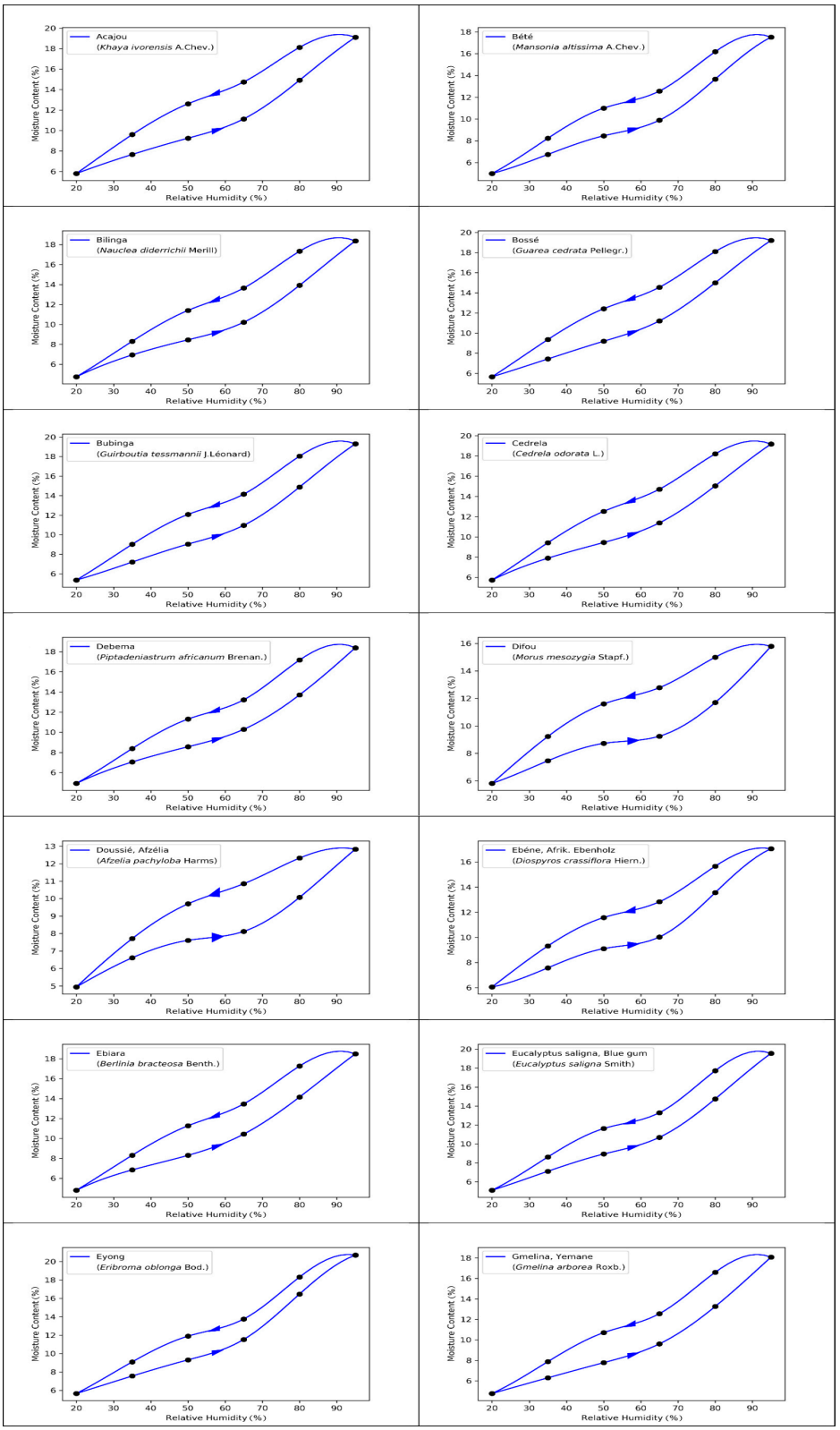

Figure 1a: Sorption isotherm with adsorption and desorption of the tested wood species.

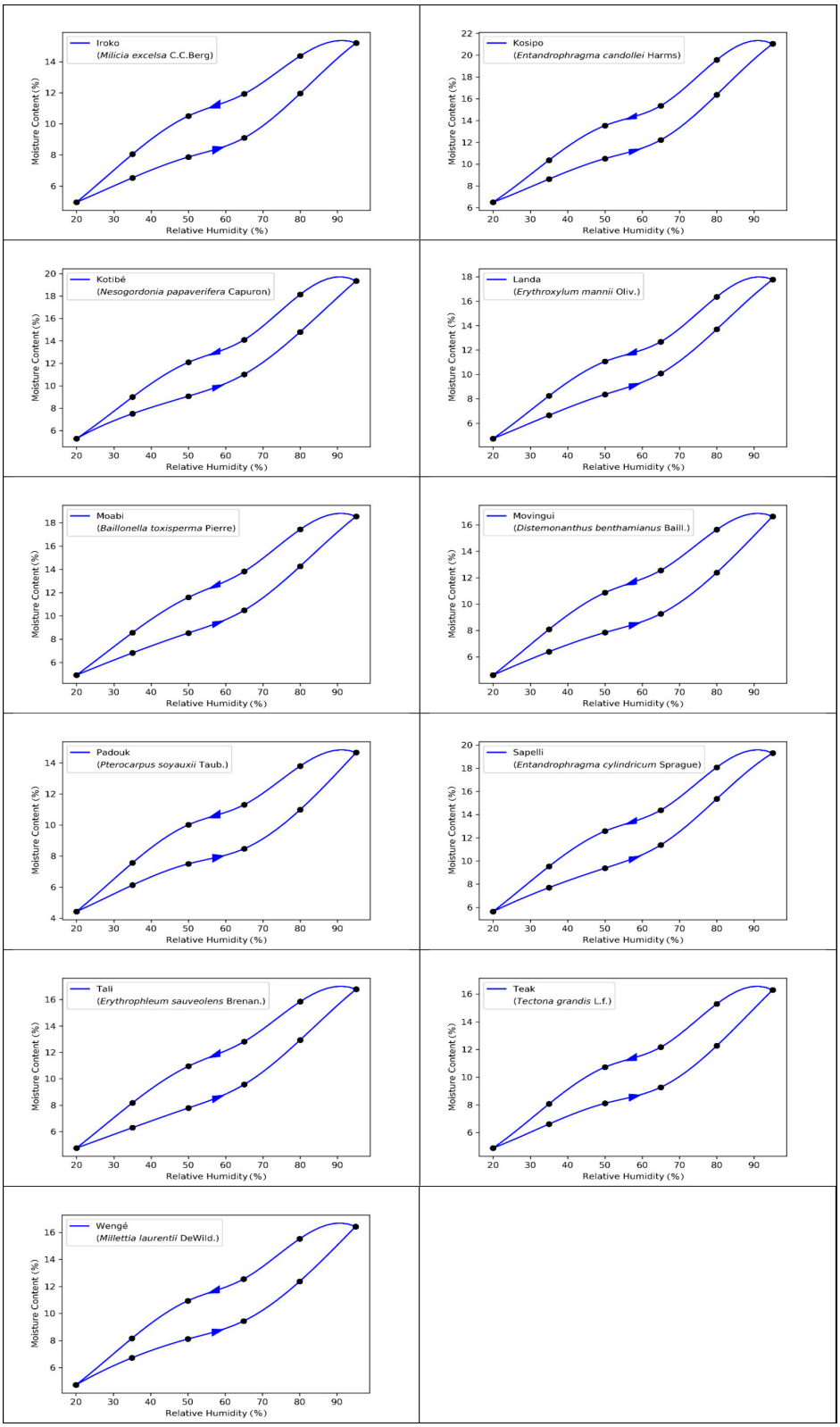

Figure 1b: Sorption isotherm with adsorption and desorption of the tested wood species.

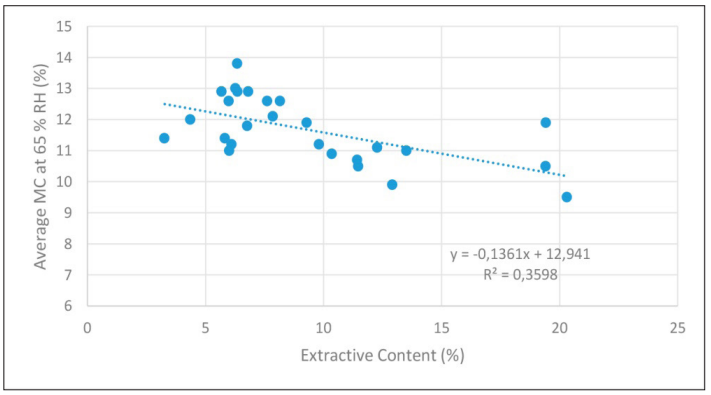

Figure 2: Relation total extractive content and moisture content for 20 °C/65 %RH.

The equilibrium moisture content in the normal climate decreases with increasing extractives content (total extractives content) (Figure 2). However, a strong variability of the moisture content was observed, e.g. at high extractives contents. Here, further detailed chemical analyses including the pore structure are necessary. An influence of the density is neither recognisable on the equilibrium moisture in the normal climate nor on the maximum differences in the sorption isotherm between adsorption and desorption. Furthermore, it can be also observed that the maximum difference between adsorption and desorption varies between 2,3 % and 3,6 % (Table 2). The influence of density on the equilibrium moisture content and the maximum difference between adsorption and desorption was small (Figure 3 and Figure 4).

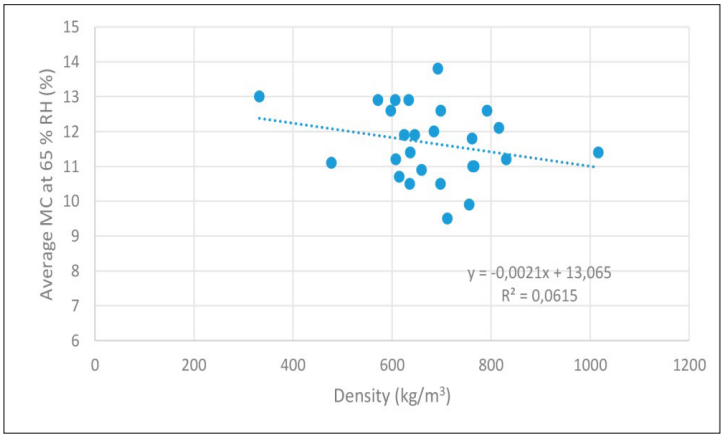

Figure 3: Relation between density and moisture content (20 °C/65 %RH) for the 25 species.

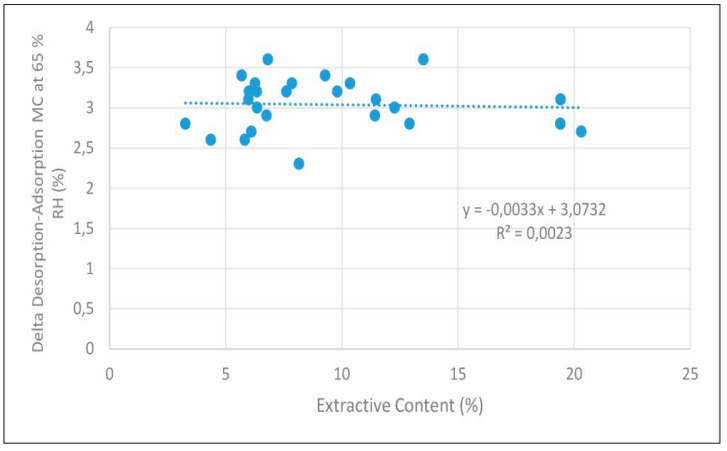

Figure 4: Relation between max delta for ad- and desorption for the 25 species.

Table 1: Overview about the tested species.

specie	Scientific names	Code	MC (%)	ρ_{ω} (kg/m^3)	ρ_0 (kg/m^3)
Acajou	Khaya ivorensis A. Chev	AJ	13,00	591	555
Beté (Masoinia)	Mansonia altissima A. Chev	BT	12,46	627	599
Bilinga (Opepe)	Nauclea diderrichii Merill	BL	13,64	677	635
Bossé	Guarea cedrata Pellegr.	BS	15,10	660	617
Bubinga	*Guirboutia tessmannii* J. Leonard	BG	14,12	848	795
Cedrela	*Cedrela odorata* L.	CD	13,49	342	309
Dabema	*Piptadeniastrum africanum* Brenan	DB	13,50	787	748
Difou	*Morus mesozygia* Stapf	DF	13,52	800	757
Doussie (Afzelia)	*Afzelia pachyloba* Harms	DS	10,70	745	696
Ebene	*Diospyros crassiflora* Hiern	BN	14,19	1198	1113
Ebiara (Berlina)	*Berlinia bracteosa* Benth	EB	13,10	651	616
Eucalyptus	*Eucalyptus saligna* Smith	ES	12,01	812	791
Eyong (White Stercilia)	*Eribroma oblonga* Bod	EY	14,56	625	591
Gmelina	*Gmelina arborea* Roxb. ex Sm.	GM	12,87	500	464
Iroko	*Milicia excelsa C.C.* Berg	IK	10,90	656	623
Kosipo (Omu)	*Entandrophragma candollei* Harms	KS	15,56	721	675
Kotibé (Danta)	*Nesogordonia papaverifera* C.	KB	13,53	725	745
Landa	*Erythroxylum mannii* Oliv.	LD	13,25	671	632
Moabi	*Baillonella toxisperma* Pierre	MB	12,57	846	805
Movingui (Ayan)	*Distemonanthus benthamianus* Baill	MV	12,81	691	648
Padouk (African Padouk)	*Pterocarpus soyauxii* Taub	PZ	11,88	827	786
Sapelli (Sapele)	*Entandrophragma cylindricum* S.	SP	14,90	635	596
Tali (Missanda)	*Erythrophleum suaveolens* Brenan	TL	14,07	862	822
Teak	*Tectona grandis* L. f.	TK	11,81	736	672
Wengé	*Millettia laurentii* De Wild	WG	13,08	794	752

ρ_{ω} is the density at moisture content ω; ρ_0 is the oven dry density.

Table 2: Average moisture content in normal climatic conditions (20 °C/65 %RH) and maximal delta EMC between and-and desorption.

Specie	ΔEMC ad--and desorption for 65%RH	average MC (%) at RH 65%
Acajou	3,6	12,9
Beté (Masoinia)	3,4	11,9
Bilinga (Opepe)	3,4	12,9
Bossé	3,2	12,6
Bubinga	2,7	11,2
Cedrela	3,3	13
Dabema	2,9	11,8
Difou	3,6	11
Doussie (Afzelia)	2,7	9,5
Ebene	3,1	11,9
Ebiara (Berlina)	2,8	11,4
Eucalyptus, salignia	2,6	12
Eyong (White Stercilia)	2,3	12,6
Gmelina	3	11,1
Iroko	2,8	10,5
Kosipo (Omu)	3,2	13,8
Kotibé (Danta)	3,1	12,6
Landa	2,6	11,4
Moabi	3,3	12,1
Movingui (Ayan)	3,3	10,9
Padouk (African Padouk)	2,8	9,9
Sapelli (Sapele)	3	12,9
Tali (Missanda)	3,2	11,2
Teak	3,1	10,5
Wengé	3,2	11

Table 3: Chemical composition.

Species	Solubles	Extractives	Lignin	Holocellulose	Hot water extractives (%)		NaOH 1%	ash
	Etl/Tol ovendry wood (%)	Total ovendry wood (%)	Ovendry wood without extractives (%)	Ovendry wood without extractives (%)	Ovendry wood (%)	pH	Ovendry wood (%)	Ovendry wood (%)
Acajou	2,9	6,8	29,0	67,2	5,4	5,07	17,2	0,72
Beté (Masoinia)	7,6	9,3	31,7	63,0	6,9	4,60	15,2	0,,9
Bilinga (Opepe)	3,4	5,7	34,48	59,8	5,4	4,51	8,5	0,14
Bossé	3,7	7,6	33,4	58,6	2,9	4,34	15,7	1,51
Bubinga	3,5	6,1	33,8	59,1	2,7	4,07	15,2	0,73
Cedrela	2,9	6,3	32,3	56,9	3,7	5,04	13,0	1,66
Dabema	4,3	6,8	31,1	62,0	3,8	4,22	14,3	0,47
Difou	8,9	13,5	33,2	57,2	9,7	5,12	23,9	0,98
Doussie (Afzelia)	18,2	20,3	31,5	59,7	13,7	4,39	29,7	0,31
Ebene	13,7	19,43	40,8	not tested	17,0	4,81	21,2	2,12
Ebiara (Berlina)	0,5	3,3	39,3	55,5	0,7	4,25	13,7	0,45
Eucalyptus	2,6	4,4	29,6	62,1	2,7	3,94	15,0	0,29
Eyong (White Stercilia)	1,5	8,2	24,0	67,5	2,5	4,60	13,7	3,09
Gmelina	8,1	12,3	27,8	69,1	6,5	5,38	14,2	2,81
Iroko	14,3	19,4	30,9	60,5	6,0	5,64	27,3	1,92
Kosipo (Omu)	2,6	6,4	33,4	56,5	2,7	4,83	16,6	0,60
Kotibé (Danta)	2,6	6,0	35,8	56,0	3,8	4,80	18,1	1,06
Landa	4,0	5,8	25,0	66,9	1,8	4,35	9,4	0,91
Moabi	5,0	7,9	35,2	59,1	6,8	4,48	16,1	0,81
Movingui (Ayan)	8,2	10,4	33,0	62,5	2,2	4,47	14,4	2,19
Padouk (African Padouk)	11,4	12,9	35,1	58,7	2,0	3,61	15,5	0,72
Sapelli (Sapele)	3,3	6,36	31,0	60,4	4,1	4,93	18,1	1,01
Tali (Missanda)	7,01	9,81	34,17	61,1	4,4	3,85	12,4	0,22
Teak	9,7	11,58	33,47	57,4	2,46	4,24	14,4	0,79
Wengé	3,2	6,01	32,94	59,0	3,58	4,50	13,8	0,65

CONCLUSIONS

The equilibrium moisture content was determined for 25 wood species from Cameroon (including 3 species from plantations in Togo) at 20 °C and varying relative humidity. The proportion of extractives was also determined. The extractives content varied between 3,3 % and 20,3 %, the density in a normal climate between 309 kg/m^3 and 1113 kg/m^3. A very strong variability of the equilibrium humidity (e.g. in the normal climate at 20 °C/65 % rel. humidity) but also in the maximum of the hysteresis between adsorption and desorption is shown. A gap existing in this field for these wood species has been closed. The equilibrium moisture content and the extractives content are important for the processing of the wood, such as bonding, surface coating but also fungal resistance.

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