TECHNICAL REPORT

REQUESTER:

Fazenda Ribeirão dos Paulas´ Farm – Cachoeira Alta/GO - Brazil

EXECUTED BY:

Bioenergy and Wood Quality Laboratory (LQMBio)

Forest Engineering Department

Federal University of Goiás, Goiânia - GO

PARTNERSHIP:

Forest Products Laboratory

Brazilian Forest Service

Ministry of Agriculture, Brasília - DF

1. OBJECTIVE

Evaluation of physical and mechanical properties and machining characteristics of African Mahogany wood

2. MATERIAL

Specie: *Khaya* sp. (Meliaceae); African Mahogany

Age: 8,6 years (103 months)

3. METHODOLOGY

STUDY AREA:

Ribeirão dos Paulas Farm – Cachoeira Alta/GO – Brasil
Geographic coordinates: 18º28'57''S; 51º08'21'' W
Climate: Aw (Tropical wet and dry climate) - Köppen & Geiger classification
Mean annual temperature: 24,2°C
Mean annual accumulated precipitation: 1521 mm (CLIMATE-DATA, 2018).

SAMPLING

Ten trees were selected for the study. Wood discs were obtained in five different longitudinal positions (0, 25, 50, 75 e 100% of commercial height) of the trunk. Also, 1 log of 50 cm in length per tree was cut between positions 0% 25%.

TESTS:

Wood general characteristics: organoleptic and macroscopic characteristics (IPT, 2007).

Physical properties: specific gravity, dimensional shrinkage (radial, tangential and volumetric (ABNT NBR 7190:1997) and coefficient (NOCK et al., 1975).

Mechanical properties: Compressive strength parallel to grain and impact bending (ABNT NBR 7190:1997).

Machining characteristics:

- Surfacing, sanding, turning, boring and mortising (ASTM D-1666-87);
- Nail splitting (IBAMA, 1997);
- Abrasive wear resistance (ABNT NBR 14535:2008).

EQUIPMENT:

- **Lathe:** Nardine, model Mascote MS 205 with speed of rotation of 2500 RPM, combined with its own cutting tool;
- **Planer:** Invictus, stationary straightener;
- **Drills:** Ferrari vertical drill with speed of 2800 RPM, equipped with a one inch drill bit and Invicta horizontal drill with a helical (spiral) 8 mm drill bit;
- **Sanding machine:** Makita electrical
- **Abrasion analytical** scale: Bel (0,0001 g of precision);
- **Comparative clock:** Mitutoyo;
- **Abraser:** Taber, tool with a H18 grindstone

EVALUATION OF MACHINING DEFECTS

After each test, the wood samples were visually evaluated by three wood specialists that assigned grades from 1 to 5 based on the presence of defects and roughness and finishing aspects (Table 1).

Table 1: Grade given to the wood samples for the machining properties

Grade	Classification	Defects
1	Very poor	Significant
2	Poor	Medium and Significant
3	Fair	Medium
4	Good	Light
5	Excellent	No defects

4. RESULTS

GENERAL CHARACTERISTICS OF THE WOOD

Macroscopic and organoleptic characteristics:

Heartwood and sapwood not very distinct. Heartwood of a light reddish tone. Non-detectable smell and light bitter taste. Straight grain. Medium texture. Growth rings boundaries poorly distinct. Vessels visible (10x) in radial multiples of 3 or 4. Diffuse porosity. Parenchyma absent or extremely rare. Distinct rays (10x), larger than 1 mm, and of non-stratified structure (Figure 1).

Figure 1. Macroscopic characteristics of *Khaya* sp heartwood. a) transversal; b) longitudinal tangential and c) longitudinal radial sections. Amplification: 8x.

PHYSICAL CHARACTERISTICS OF THE WOOD

Mean values for wood specify gravity and dimensional and coefficient shrinkage are presented in the Table 2.

Table 2. Mean values of wood specific gravity and shrinkage of *Khaya* sp trees.

ρ_{ap} (g/cm³)	Shrinkage (%)			Swelling (%)			ΔV (%)	A_r
	$\varepsilon_{r,tg}$	$\varepsilon_{r,rd}$	$\varepsilon_{r,lg}$	$\varepsilon_{i,tg}$	$\varepsilon_{i,rd}$	$\varepsilon_{i,lg}$		
0.49	4.52	2.46	0.27	4.76	2.54	0.26	7.16	1.96

ρ_{ap}: specific gravity; ε: deformation; tg:tangential; rd: radial; lg:longitudinal; ΔV: volumétric; A_r: coefficient

Mean specific gravity of wood was 0.49 (g.cm⁻³), classified as of light weight (Table 3), although very close to the next class (medium). This result is in accordance with Marques et.al. (1997).

Table 3. Specific gravity classes for *Khaya* sp wood (adapted from Marques et. al., 1997)

ρ_{ap} (g.cm⁻³)	Classification (weight)
< 0.50	Low
0.50 – 0.72	Medium
≥ 0.72	Heavy

Similar values (0.47 and 0.48 g.cm⁻³) were found by Carvalho et al. (2010) and Rezende et al. (2012) for the wood of *Khaya ivorensis* (10 years) in Brazil. In mature trees of the same species, Teixeira (2011) e Silva (2013) found values between 0.67 g.cm⁻³ (15 years) and 0.73 g.cm⁻³ (30 years).

In contrast, França et al. (2015) observed values closer to the ones found in this study of 0.49 g.cm⁻³ for *Khaya ivorensis* and superior (0,58 g.cm⁻³) for *Khaya senegalensis* at 19 years, in Espirito Santo, Brazil.

In comparison with some eucalyptus species, african mahogany wood samples of this study presents similar specific gravity of 0.48 g.cm⁻³ for *Eucalipytus globulus*, 0.51 g.cm⁻³ for *E. pellita* and 0,53 g/cm³ even though compared to trees that were 10 years old (TOMAZELLO FILHO 1985; 1987).

Mean values of specific gravity found were similar to other commercial tree species in Brazil, such as: Parana´s pine trees (*Araucaria angustifolia*), cedar (*Erisma uncinatum*), cedrorana (*Cedrelinga cateniformis*), pinus (*Pinus elliottii*), all widely used to produce shelves, backing for furniture, frames, templates and formwork, broom handles, pencils, popsicle sticks, toothpicks, matches, laminated wood panels, plywood, containers and boxes for transportation, etc. (IPT,2009). Also, freijo (*Cordia bicolor*), faveira (*Parkia pendula*) and achicá (*Sterculia speciosa*) (IBAMA, 1997).

As far as the shrinkage, the coefficient determined (1.96) allows us, in accordance with Nock et al. (1975), of this study and recommend the wood of *Khaya* spp. for uses that allows light dimensional movement, as exemplified in Table 4.

Mean values of volumetric shrinkage (7.16%) is considered low, below what was found by Oliveira et al. (2010) in wood samples of *Corymbia citriodora* (18.3%), *Eucaliptus tereticornis* (22,3%), *E. cloeziana* (16.5%) and *E. grandis* (15,9%), all obtained from trees with 16 years of age. Results also showed lower values in comparison with wood samples of trees 19 years of *K. ivorensis* (9,18%) and *K. senegalensis* (8,48%) (FRANÇA et al., 2015).

Mean values for the radial shrinkage (2.6%) as well as the tangential (4,8%) are lower than *K. ivorensis* (3.7%, 5,5% respectively) from trees of a native forest (FPL,2010; CIRAD,2012). The longitudinal shrinkage (2.6%) is considered despicable.

Radial and tangential shrinkages determined in this study are lower than for 148 tropical Brazilian´s species analyzed by Araujo (2007), such as: angelim pedra (*Dinizia excelsa*), canafistula (*Cassia fastuosa*), castanheira (*Bertholletia excelsa*) and cumaru (*Dipteryx odorata*), showing its excellent performance for this property.

Physical performance of the *Khaya* sp can be consider similar to the Brazilian Mahogany (*Switenia macrophylla*) that has specific gravity around 0.52g.cm³, radial (2.9%), tangential (4.7%) and volumetric (7.2%) shrinkage (LPF, 2001; GLASS and ZELINKA, 2010).

Table 4. *Khaya sp*. wood classification according to shrinkage coefficient

A_r	Wood quality	Uses
1.2 a 1.5	Excellent	Fine furniture, frames, boats, musical instruments, sports equipment, etc..
1.5 a 2.0	Normal	Shelves, tables, cabinets.
> 2.0	Low	Construction (observed mechanical characteristics), firewood, charcoal, etc.

Source: Nock et al. (1975); A_r: shrinkage coefficient

MECHANICAL CHARACTERIZATION OF THE WOOD

Compressive strength parallel to grain and impact bending

The results of the mechanical characterization of the wood of *Khaya* sp are presented in Table 5 (mean values).

The MOE and MOR values in both tests were lower than the reference samples *K. ivorensis* and *K. senegalensis* (19 years) in Brazil, possibly due to the young age (8 years) of the studied trees.

For the same parameters, results are similar to other commercial woods in Brazil from the genus Pinus such as *Pinus caribaeae hondurensis* and *P. elliotii* var. *elliottii*) (MORAES NETO et al., 2009)

Table 5. Mean values of static modulus of elasticity (MOE), modulus of rupture (MOR) for compressive strength parallel to grain and impact bending tests for the *Khaya* sp. wood samples (8 years)

Test	Maximum load (kgf)	Proporcional limit (MPa)	MOE (MPa)	MOR (MPa)
Impact bending	112.2	30.7	7609.2	70.2
Strength parallel to grain	8076.5	17.4	3195.3	32.1

The MOR mean value obtained on strength parallel to grain test allow us to classify the wood of *Khaya* sp. as C30 (NBR 7190/97) (Table 6), of medium strength, therefore, of restrict structural use.

Table 6. Resistance classes for dicotyledonous angiosperms (NBR 7190/97)

Class	MOE (MPa)	MOR (MPa)	ρ_{ap} ($g.cm^{-3}$)
C20	9500	20	0.50
C30	14500	30	0.65
C40	19500	40	0.75
C60	24500	60	0.80

MOE: modulus of elasticity; MOR: modulus of rupture; ρ_{ap}: specific gravity

MACHINING CHARACTERISTICS:

In general a median performance in the tests for machining/workability for the wood of *Khaya* sp., getting a 3.3 (fair) grade, which is equivalent to a REGULAR definition (Table 7).

A detailed description of the defects observed in *Khaya* sp. wood samples submitted to machining tests is presented in table 8.

Table 7. Evaluation and classification of the wood quality of *Khaya* sp. after the machining tests

Test	Grade (mean)	Classification	Defects
Turning	3.1	Fair	Medium
Surfacing	2.9	Fair	Medium
Boring	2.8	Fair	Medium
Sand paper 80	3.4	Fair	Medium
Sand Paper 120	4.3	Good	Light
Mortising	3.1	Fair	Medium
Mean	**3.3**	.	.

In the **turning test** medium defects was observed in the samples, 78% of them showed fuzzy grain, 91% rough surface and 4% of peeled off grain.

In the **surfacing test** medium defects were also observed in the samples, 58% of them showed fuzzy grain, 53% raised grain and 11% of peeled off grain.

In the **boring test** and in 44% of them peeled off grain. It was not observed in any of the samples burn or smashing of the grain.

In the **sanding test** with 80 grift size sandpaper, the wood was classified FAIR, where 100% of the sample showed no sandpaper marks and 47% showed fuzzy grain. In the tests with the 120 grift size sandpaper, all samples presented light defects and therefore judged as GOOD, with 100% of the samples with no sandpaper marks and 42% with fuzzy grain.

In the **mortising test** medium defects were also observed in the samples. In 100% of the samples was observed raised grain.

Table 8. Defects observed in *Khaya* sp. wood samples submitted to machining tests

Test	Grain				Surface			Lifting of the fibers
	Fuzzy	Peeled	Raised	Smashed	Roughed	Burned	Marked	
Turning	78	4	.	.	91	.	.	.
Surfacing	58	11	53	.	.	.	.	.
Boring	100	44	.	0	.	0	.	.
Sand paper 80	47	.	.	.	.	.	0	.
Sand Paper 120	42	.	.	.	.	.	0	.
Mortising	.	.	.	.	.	.	.	100

Samples with defects (%)

In the **nail splitting** test, the results were satisfactory for the superior face of the board samples. For the inferior face of the board samples, a significant rate of splitting of 41% (Table 9) was observed. It is important to note that the norm applied to the tests (ASTM D-1666-87) considers only the facing results for its evaluation.

Table 9. Results of nail splitting test of the wood of *Khaya* sp.

Test	Samples (%)	
	Superior face	Inferior face
Nails withdrawal resistance	83	59
Splitting	17	41

In the **abrasive wear resistance test**, the wood presented a medium wear-off rate of 0.067 mm. Martins et al. (2012) found medium values of 0.050 mm for *E. cloeziana*, 0.073 for *E. microcorys* and 0,076 mm for *C. maculate*, all values proximity to the observed in this study. The authors of the mentioned studies have highlighted the importance of abrasion for wood flooring in general. The woods that are more resistant to abrasion suffer less wear-off overtime, adding longer useful life to wood flooring.

5. CONCLUSIONS

The results of this study allow us to conclude that the wood tested has the following characteristics and possible applications:

- Medium-low density
- Medium shrinkage with low tendency for defects such as warping and twisting;
- Intermediate mechanical performance, with implications for its structural use (restrict to C30 class);
- Regular performance in surfacing, boring and mortising operations;
- Good nail withdrawal resistance; splitting happens mostly in the inferior face of the board samples;
- Sanding was considered regular with 80 grift size sandpaper and good with 120 grift size sandpaper.
- Good resistance to abrasion, showing results close to ones observed in woods normally utilized in flooring.
- Recommended for light structural purposes, furniture making, partition walls, wood frames and window frames, tool handles, and possibly in the making of plywood.

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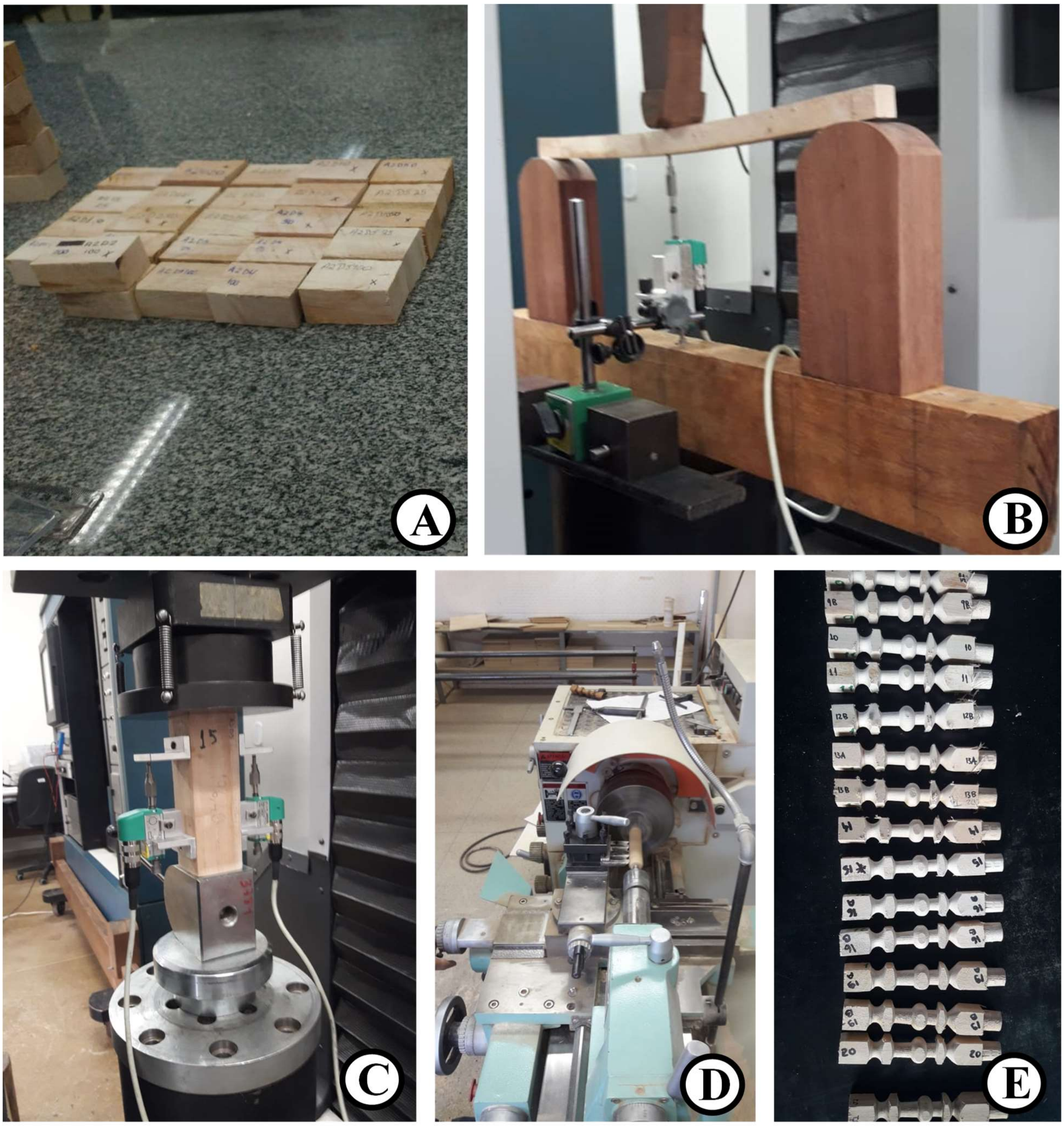
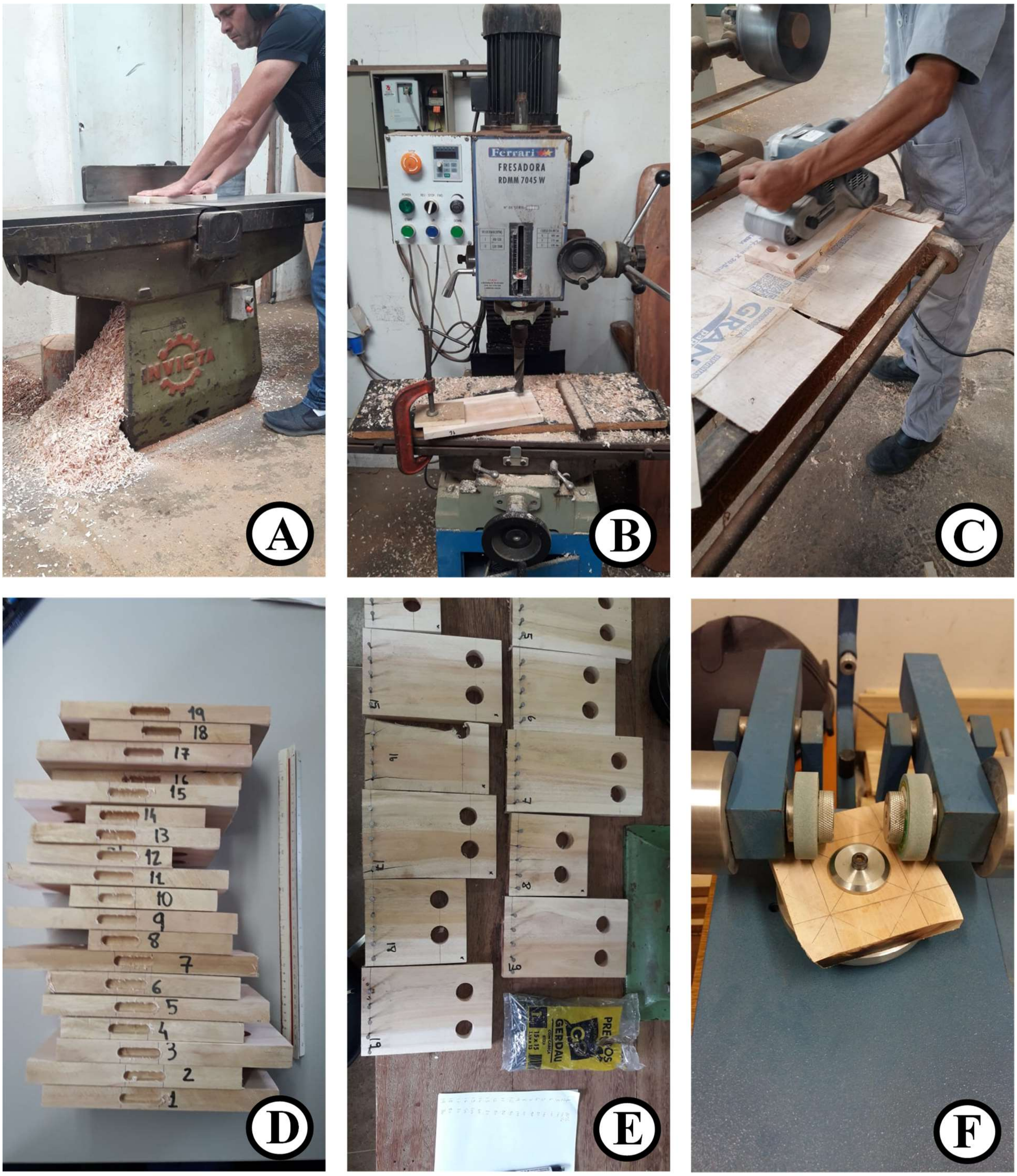
APPENDIX

Appendix 1. Sampling and preparation of wood samples of *Khaya* sp. trees. A: Wood discs and log sampling; B: Samples identification and demarcation; C and D: Wood samples preparation and E: Wood samples read for tests.



Appendix 2. Physical and mechanical tests in *Khaya* sp wood samples. A: Specific gravity and shrinkage; B: Impact bending; C: Compressive strength parallel to grain; D and E: Turing.



Appendix 3. Machining tests in Khaya sp. wood samples. A: Surfacing; B: Boring; C: Sanding; D: Mortising; E: Nail splitting and F: Abrasive wear resistance