Maderas. Ciencia y tecnología
ISSN: 0717-3644
ISSN: 0718-221X
Universidad del Bío-Bío

Belleville, Benoit; Lancelot, Kilva; Galore, Elaine; Ozarska, Barbara
Assessment of physical and mechanical properties of Papua New Guinea timber species
Maderas. Ciencia y tecnología, vol. 22, no. 1, 2020, pp. 3-12
Universidad del Bío-Bío

ISSN impresa 0717-3644
ISSN online 0718-221X

Maderas. Ciencia y tecnología 22(1): 3 - 12, 2020

DOI:10.4067/S0718-221X2020005000101

ASSESSMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF PAPUA NEW GUINEA TIMBER SPECIES

Benoit Belleville[1,♠], Kilva Lancelot[2], Elaine Galore[3], Barbara Ozarska[1]

ABSTRACT

A comprehensive testing program has been developed to assess different physical and mechanical properties of 26 commercial and lesser-known Papua New Guinea species from secondary and plantation forests. The impact of log position in a tree on the mechanical properties has also been assessed to optimize the utilization of timbers along the value chain. The results showed that stiffness and bending strength tend to decrease or remain unchanged along the stem. Shear strength and Janka hardness displayed a similar trend to a lesser extent where the position in the tree had a limited impact on compression strength properties. Thus, segregating based on log position can be of interest where desired mechanical properties and costs associated with segregating justify optimum mechanical properties for the intended end use. The properties of selected species from plantations and regrowth forests were generally lower than those found in the literature for timbers from old-growth forests. The size of specimens tested, the amount and provenance of tested material, and some adaptive traits for tropical tree species are some factors potentially explaining observed differences. However, a comparison with recent studies tends to confirm the overall reduction of physical and mechanical properties when compared with old-growth forests timbers.

Keywords: Compression strength, flexural bending strength, hardness, plantations, regrowth forests, shear, stiffness.

INTRODUCTION

Papua New Guinea (PNG) is an Oceanian country located in the south-western Pacific Ocean region. The country has a total land area of 46,3 million hectares of which 33,6 million ha is estimated to contain forest cover (FAO 2015). Primary and regenerated forests represent 52,4% and 47,6% of the forest area, respectively, accounting for a total growing stock of 5195 million m^3. According to the PNG Forest Authority, there are more than 2000 tree species in PNG, of which 20% are utilized in one way or another for commercial use (PNGFA 2007). Commercial forest plantations started in the 1960s with sporadic progress and currently covering 62277 ha. The country aims to develop 240000 ha of commercially viable and sustainable commercial forest plantations by the year 2030 to sustain 3,6 million m^3 of industrial timber currently harvested from natural forest annually.

Although the forest cover in PNG is large and diverse, knowledge of the current timber resource is scarce. In the 1970s, an exhaustive review of the mechanical properties of PNG timbers from native forests has been conducted by Bolza and Kloot (1976). However, the most valuable commercial timbers have since been harvested in large areas of the primary rainforest as a result of forest policies focussing on export logging. Second-

[1]The University of Melbourne, Faculty of Science, School of Ecosystem and Forest Sciences, Richmond, Victoria, Australia.
[2]PNG Forest Research Institute, Lae, Morobe Province, Papua New Guinea.
[3]Timber and Forestry Training College, Lae, Morobe Province, Papua New Guinea.
[♠]Corresponding author: benoit.belleville@unimelb.edu.au
Received: 12.12.2018 Accepted: 01.09.2019

ary forests are recovering in terms of merchantable timber and carbon stocks but much of the potential timber resource is of lesser-known timber species.

Recent studies by Edwin and Ozarska (2015) and Kotlarewski *et al.* (2016) determined selected mechanical properties of some PNG timber species. However, there are still many research and structural challenges, constraints, and opportunities at different levels which need to be addressed to support the development of competitive value-added wood industries. The influence of environmental conditions and other growth factors on wood mechanical properties and the challenges associated with using this material has been the subject of numerous studies worldwide. Barrett and Kellogg (1991) noted a reduction in the mechanical properties of second growth Douglas-fir (*Pseudotsuga menziesii*) when compared to old-growth timber. Other studies also demonstrated that properties of wood produced from managed trees are different from wood produced in natural stands (Bendtsen 1978, Pearson and Gilmore 1980).

Currently, most local wood processing in PNG is focused on primary conversion of logs to low-grade building materials. Technical knowledge and capacity about efficient processing of different native timber species and produce a broader range of wood products are very low. The variability in properties of the wood material and of the finalized timber products indicates a potential for optimization too. Consequently, there is a need to provide research and technology development to develop and implement commercially sustainable log supply chains, knowledge, and capacity in wood science and processing technologies, as well as the processing structures which support successful domestic value-adding wood processing enterprises.

The aim of the project was to increase the contribution that utilization of forest resources makes to national and local economies, including landowners and processors, through the development of domestic value-added wood processing methods. The specific objectives were to 1) enhance the knowledge of wood properties of PNG timbers to facilitate greater value adding; 2) identify any relationship between log position in a tree and the mechanical properties of timber products to optimize the utilization of PNG timbers at various stages of the chain. Therefore, a testing program has been developed including the assessment of physical and mechanical properties of selected commercial and lesser-known species from secondary and plantation forests.

MATERIALS AND METHODS

Harvesting

The testing program has been divided into two groups of species to facilitate harvesting and specimens' preparation logistic. Each group included 13 species from plantations and regenerated forests (also known as regrowth forests) located in the Morobe and West New Britain provinces, PNG (Table 1). Nine species were harvested from plantations and 17 from regenerated forests (3 softwoods, 23 hardwoods). A total of 130 trees, *i.e.* 5 trees per species, have been selected and harvested in accordance with ASTM D5536 (2010). The trees have been selected based on the following selection criteria: 1) the tree had to be more than 15 years old after regrowth or planting; 2) all trees for a specific species had to be from the same forest area; 3) the selected trees had to be representative of the population, with good form and merchantable height. Following harvesting, the total merchantable height of each tree has been further cut into 3 to 4 m-long logs, labeled as per height from ground (*i.e.* bottom, middle, and top section), and milled. The milled sawn boards were then kiln-dried to 12% moisture content.

Table 1: PNG studied species information.

Species	Trade Name	Origin	Age (years)	DBH (cm)
Plantations (9 species)				
Araucaria cunninghamii	Pine, Hoop	Bulolo, Morobe	28	39 (4)
Araucaria hunsteinii	Pine, Klinki	Bulolo, Morobe	43	63 (5)
Castanospermum australe	Blackbean	Kimbe, West New Britain	17	42 (4)
Eucalyptus deglupta	Kamarere	Kimbe, West New Britain	29	60 (14)
Eucalyptus pellita	Pellita	Lae, Morobe	18	36 (5)
Magnolia tsiampacca	Beech, Wau	Lae, Morobe	17	34 (4)
Pinus caribaea	Pine, Caribbean	Lae, Morobe	31	55 (6)
Pometia pinnata	Taun	Lae, Morobe	18	48 (6)
Terminalia brassii	Terminalia, Brown	Lae, Morobe	31	54 (8)
Secondary Forests / Regrowth (17 species)				
Alstonia scholaris	Cheesewood, White	Lae, Morobe	17 to 20	46 (12)
Anisoptera thurifera	Mersawa, PNG	Lae, Morobe	+20♠	46 (8)
Anthocephalus chinensis	Labula	Lae, Morobe	+20♠	51 (8)
Canarium oleosum	Canarium, Grey	Lae, Morobe	17 to 20	40 (2)
Elaeocarpus sphaericus	Quandong, PNG	Lae, Morobe	17 to 20	54 (15)
Endospermum medullosum	Basswood, PNG	Lae, Morobe	+20♠	47 (14)
Falcataria moluccana	Albizia, White	Lae, Morobe	+20♠	64 (9)
Homalium foetidum	Malas	Lae, Morobe	17 to 20	52 (16)
Hopea iriana	Hopea, Heavy	Lae, Morobe	+20♠	44 (4)
Intsia bijuga	Kwila	Lae, Morobe	+20♠	40 (4)
Octomeles sumatrana	Erima	Lae, Morobe	+20♠	55 (11)
Palaquium warbargianum	Cedar, Pencil	Lae, Morobe	17 to 20	43 (2)
Pangium edule	Pangium	Lae, Morobe	17 to 20	38 (3)
Pterocarpus indicus	Rosewood, PNG	Lae, Morobe	+20♠	51 (8)
Syzygium spp.	Gum, Water	Lae, Morobe	17 to 20	40 (4)
Vitex cofassus	Vitex, PNG	Lae, Morobe	+20♠	41 (9)
Xanthophyllum papuanum	Boxwood, PNG	Lae, Morobe	+20♠	42 (9)

♠No exact records of age are available in the harvested area. Species estimated age is +20 years old. Standard deviation in parentheses.

Machining specimens and mechanical testing

Specimens have then been machined in accordance with ASTM D143 (2009) and conditioned to 23°C and 65% relative humidity until constant mass prior to testing. Whenever possible and applicable, a 50 x 50-mm specimen cross-section size has been selected. The selected mechanical properties for the present study were stiffness (MOE), flexural bending strength (MOR), compression strength parallel and perpendicular to the grain, shear strength parallel to the grain, and hardness (Janka). All the tests have been conducted using a universal testing machine (Instron model 5569, MA, USA). Prior to testing, each specimen has been measured to determine the volume and weighted to determine mass at the time of testing.

After every test, a section has been taken from the specimen near the point of failure, weighted, and placed at 103°C for 24 hours to determine the oven-dry mass and moisture content.

Static bending test (MOE and MOR): 20 specimens of dimensions 50 x 50 x 760 mm have been prepared per species and tested using a 3-point bending rig. The specimens have been tested using a loading speed of 2,5 mm/min until failure.

Compression strength parallel to the grain: 20 specimens of dimensions 25 x 25 x 100 mm have been prepared and tested per species. The speed of testing was 0,3 mm/min.

Compression strength perpendicular to the grain: 20 specimens of dimensions 50 x 50 x 200 mm have been prepared per species. The speed of testing was 0,6 mm/min.

Shear strength parallel to the grain: 20 specimens of dimensions 50 x 50 x 63 mm have been prepared and tested per species. The speed of testing was 0,6 mm/min. The portion of the piece that was sheared off has been used as a moisture content specimen.

Janka hardness: 20 specimens of dimensions 50 x 50 x 150 mm have been prepared and tested per species. The number of test penetrations included two (2) on a tangential surface, two (2) on a radial surface, and one (1) on each end. Only indentations on tangential and radial surfaces have been used to calculate the Janka hardness value. The speed of testing was 6 mm/min.

Statistical analysis

The data were analyzed in Minitab statistical software (Minitab 18, Version 18.1) to evaluate the effect within species of the position in a tree on the mechanical properties. A fit mixed effects model and a Fisher pairwise comparisons analysis ($\alpha = 0,05$) were used. In the model, the tree identification number (tree #1 to #5) was used as a random factor where the species and position in the tree were the fixed factors.

RESULTS AND DISCUSSION

A total of 2,641 specimens from 26 species and 130 trees have been tested *i.e.* shear: 528 specimens; compression parallel: 526 specimens; compression perpendicular: 532 specimens; static bending: 525 specimens; hardness: 530 specimens. The total merchantable height of *Magnolia tsiampacca* trees was usually too short to obtain top sections. Therefore, only bottom and middle sections could generally be obtained for this species which has been excluded from the model.

Hopea iriana provided significantly higher mechanical testing results than any other species across all selected mechanical properties (Table 2). A group composed of *Eucalyptus pellita*, *Homalium foetidum*, and *Intsia bijuga* usually performed significantly better than the other tested species. *Xanthophyllum papuanum*, *Anisoptera thurifera*, and *Castanospermum australe* also typically performed above average. At the other end, a group formed of *Octomeles sumatrana*, *Falcataria moluccana*, *Endospermum medullosum*, *Alstonia scholaris*, *Palaquium warbargianum*, *Elaeocarpus sphaericus*, and *Magnolia tsiampacca* generally offered mechanical properties below the average.

Table 2: Summary of mechanical properties per species.

	MOE	MOR	Compression		Shear	Hardness
			Parallel to grain	Perpendicular to grain	Parallel to grain	Janka
Species	**GPa**	**MPa**	**MPa**	**MPa**	**MPa**	**N**
Alstonia scholaris	5,1	33,4	18,7	3,5	4,6	896
Fisher LSD	Q	R	M	MN	K	IJ
Anisoptera thurifera	14,6	86,0	51,2	9,3	10,4	3797
Fisher LSD	CD	EF	DE	F	D	E
Anthocephalus chinensis	7,7	56,5	31,4	6,8	7,5	2179
Fisher LSD	LMN	LMN	IJ	HI	HI	G
Araucaria cunninghamii	8,1	60,1	24,4	7,5	7,7	2229
Fisher LSD	LM	KLM	L	GH	GH	G
Araucaria hunsteinii	10,6	68,9	31,0	7,5	8,6	2121
Fisher LSD	HI	IJ	IJ	GH	EFG	G
Canarium oleosum	9,3	62,3	33,5	7,2	8,5	2177
Fisher LSD	JK	JKL	HI	GHI	EFG	G
Castanospermum australe	11,5	85,2	48,2	12,7	10,9	4490
Fisher LSD	FG	EF	EF	D	D	D
Elaeocarpus sphaericus	7,7	50,5	28,6	4,9	6,6	1554
Fisher LSD	LMN	NOP	JK	KL	I	H
Endospermum medullosum	7,8	44,9	29,5	4,2	5,4	1311
Fisher LSD	LMN	PQ	J	LM	JK	HI
Eucalyptus deglupta	8,6	62,1	31,3	9,5	8,6	3132
Fisher LSD	KL	JKL	IJ	F	EFG	F
Eucalyptus pellita	15,6	120,6	52,7	16,0	12,3	6215
Fisher LSD	B	C	D	C	C	C
Falcataria moluccana	6,7	42,7	25,5	4,1	5,6	1192
Fisher LSD	OP	Q	KL	LM	J	HIJ
Homalium foetidum	15,4	128,4	58,6	15,5	14,1	6893
Fisher LSD	BC	B	C	C	B	B
Hopea iriana	20,0	136,9	69,0	20,6	16,5	8753
Fisher LSD	A	A	A	A	A	A
Intsia bijuga	14,2	116,6	64,1	17,3	13,5	6361
Fisher LSD	D	C	B	B	B	BC
Magnolia tsiampacca	6,1	48,5	25,4	5,6	5,5	1273
Fisher LSD	P	OPQ	KL	JK	JK	HIJ
Octomeles sumatrana	4,8	31,5	18,5	2,7	3,6	735
Fisher LSD	Q	R	M	N	L	J
Palaquium warbargianum	7,5	50,8	25,4	4,5	5,5	1374
Fisher LSD	MNO	NOP	KL	KLM	JK	HI
Pangium edule	12,1	70,1	36,7	7,5	8,0	3091
Fisher LSD	F	HI	GH	GH	FGH	F
Pinus caribaea	8,0	67,2	29,1	8,3	9,0	2311
Fisher LSD	LM	IJK	JK	G	E	G
Pometia pinnata	11,1	91,1	36,9	12,7	11,2	4904
Fisher LSD	GH	DE	GH	D	D	D
Pterocarpus indicus	10,0	76,1	45,7	11,4	9,3	3239
Fisher LSD	IJ	GH	F	E	E	F
Syzygium spp.	9,6	68,1	38,3	8,2	8,7	2410
Fisher LSD	J	IJ	G	G	EF	G
Terminalia brassii	6,9	54,4	29,9	6,0	8,5	2518
Fisher LSD	NOP	MNO	IJ	IJ	EFG	G
Vitex cofassus	11,5	80,8	45,9	10,0	9,3	3327
Fisher LSD	FGH	FG	F	F	E	EF
Xanthophyllum papuanum	13,1	94,2	47,7	13,6	10,6	4899
Fisher LSD	E	D	EF	D	D	D

MOE: Modulus of elasticity or stiffness; MOR: Modulus of rupture or bending strength.

Effect of position in the tree on selected physical and mechanical properties

The physical and static bending properties per species based on the position in the tree are presented in Table 3. The statistical analysis demonstrated a very significant interaction (*P*-value <0,001) between species and position in the tree on the bending properties. Stiffness and bending strength tend to decrease or remain unchanged along the stem across all studied species. The average stiffness and bending strength values obtained from bottom and middle sections were significantly greater than those from top sections for 6 (*Araucaria cunninghamii*, *Canarium oleosum*, *Hopea iriana*, *Intsia bijuga*, *Pangium edule*, *Xanthophyllum papuanum*) and 5 (*Canarium oleosum*, *Homalium foetidum*, *Intsia bijuga*, *Pangium edule*, *Xanthophyllum papuanum*) species, respectively. Such a trend was not noticeable in species typically performing below the average of all tested species. This observation is in accordance with other studies reported in the literature (Harvald 1988, Shivnaraine 1989, Hojbo 1991, Kliger *et al.* 1995, Machado and Cruz 2005). In one case, *i.e. Eucalyptus pellita*, top sections provided significantly higher bending properties than bottom sections. Such a result might be explained by the fact that specimens were taken from logs without any consideration to the radial position within the tree. Consequently, some specimens obtained from bottom sections might have included a higher proportion of juvenile wood, usually not as strong as mature wood, if taken from the outer radial section of the tree and vice-versa. Kliger *et al.* (1995) also reported that strength and stiffness in butt logs usually tend to increase further away from the pith in the radial direction.

Table 3: Physical and bending properties per species and position in the tree (*i.e.* bottom, middle, or top section based on height from ground).

	Density (kg/m³) [a]				MOE (GPa)				MOR (MPa)			
Species	**Combined**	**Bottom**	**Middle**	**Top**	**Combined**	**Bottom**	**Middle**	**Top**	**Combined**	**Bottom**	**Middle**	**Top**
Alstonia scholaris	296[b] 43[c] 20[d]	295 25 6	278 35 8	321 57 6	5.1 1,2 20	4,7 0,7 6	4,8 1,0 8	5,8 1,4 6	33,4 6,6 20	32,6 5,2 6	31,4 6,7 8	36,9 7,5 6
Anisoptera thurifera	685 44 18	687 48 5	685 49 7	684 42 6	14,6 1,7 18	15,6 1,7 5	14,1 1,5 7	14,3 1,9 6	86,0 9,9 18	88,0 10,6 5	84,1 12,2 7	86,4 7,3 6
Anthocephalus chinensis	418 51 20	405 45 12	447 65 5	424 40 3	7,7 1,7 20	7,4 1,5 12	8,7 2,2 5	7,5 1,9 3	56,5 12,0 20	53,1 10,7 12	64,3 13,8 5	56,9 11,8 3
Araucaria cunninghamii	496 53 20	520 35 7	468 26 6	495 76 7	8,1 1,5 17	9,1 1,7 6	8,0 1,2 5	7,0 0,8 6	60,1 12,6 17	66,4 12,1 6	58,9 9,0 5	54,8 14,8 6
Araucaria hunsteinii	473 26 20	485 31 6	469 21 7	469 27 7	10,6 1,3 20	11,3 1,1 6	10,1 1,4 7	10,5 1,3 7	68,9 7,5 20	72,0 8,0 6	66,7 8,0 7	68,4 6,7 7
Canarium oleosum	464 44 20	475 53 8	465 22 6	447 50 6	9,3 1,6 20	9,7 1,7 8	10,3 0,8 6	7,8 1,0 6	62,3 12,7 20	64,0 12,7 8	71,2 5,0 6	51,0 10,2 6
Castanospermum australe	792 44 20	806 32 5	779 53 6	793 45 9	11,5 1,7 20	10,3 1,4 5	11,6 1,7 6	12,2 1,7 9	85,2 10,6 20	77,9 7,8 5	85,3 11,9 6	89,1 9,7 9
Elaeocarpus sphaericus	385 38 20	363 31 7	389 38 9	412 39 4	7,7 0,6 20	7,3 0,6 7	7,9 0,5 9	7,8 0,6 4	50,5 6,8 20	46,4 6,4 7	52,7 6,8 9	52,4 5,7 4
Endospermum medullosum	356 34 20	368 29 4	349 44 9	357 23 7	7,8 1,0 19	8,0 0,7 4	7,6 1,3 8	7,9 0,7 7	44,9 9,2 20	47,1 8,1 4	42,6 11,4 9	46,5 7,0 7
Eucalyptus deglupta	562 70 20	552 95 10	564 30 5	578 39 5	8,6 1,5 20	8,2 1,8 10	8,2 0,9 5	9,8 0,8 5	62,1 6,7 20	59,5 6,5 10	60,0 5,4 5	69,5 1,4 5
Eucalyptus pellita	779 48 22	758 59 7	780 44 9	804 30 6	15,6 1,7 22	14,2 1,3 7	15,8 1,6 9	17,0 1,1 6	120,6 15,0 22	107,8 14,8 7	122,6 11,7 9	132,6 7,1 6
Falcataria moluccana	321 45 20	320 54 5	297 24 8	349 46 7	6,7 0,8 20	6,8 0,7 5	6,2 0,7 8	7,2 0,8 7	42,7 9,5 20	39,2 10,5 5	45,0 8,0 8	42,4 11,0 7
Homalium foetidum	800 56 20	824 58 8	791 39 6	777 65 6	15,4 1,7 20	15,6 1,5 8	16,1 1,5 6	14,3 1,7 6	128,4 13,5 20	133,6 10,2 8	129,5 10,0 6	120,4 17,9 6
	Density (kg/m³) [a]				**MOE (GPa)**				**MOR (MPa)**			
Species	**Combined**	**Bottom**	**Middle**	**Top**	**Combined**	**Bottom**	**Middle**	**Top**	**Combined**	**Bottom**	**Middle**	**Top**
Hopea iriana	932[b] 43[c] 20[d]	934 49 9	928 29 6	931 55 5	20,0 2,5 20	20,6 2,7 9	20,1 2,8 6	18,7 2,6 5	136,9 9,6 20	137,9 10,1 9	135,9 10,2 6	136,4 10,2 5
Intsia bijuga	758 116 20	763 80 8	784 150 8	697 105 4	14,2 2,0 20	14,4 0,8 8	15,0 2,6 8	12,4 1,4 4	116,6 21,3 20	117,9 11,9 8	126,2 20,7 8	94,7 25,7 4
Magnolia tsiampacca	339 22 22	337 25 15	345 14 7	N/A	6,1 0,5 22	6,1 0,5 15	6,2 0,3 7	N/A	48,5 5,2 22	47,3 5,6 15	51,2 3,0 7	N/A
Octomeles sumatrana	276 38 20	280 39 6	267 35 10	294 45 4	4,8 0,8 20	4,7 0,9 6	4,7 0,7 10	5,5 0,5 4	31,5 5,5 20	31,0 7,4 6	30,7 4,4 10	34,1 5,5 4
Palaquium warbargianum	381 47 20	369 43 7	389 53 7	385 50 6	7,5 0,9 20	7,0 0,6 7	7,8 1,2 7	7,7 0,5 6	50,8 7,6 20	50,0 8,2 7	51,8 9,1 7	50,5 5,8 6
Pangium edule	618 33 20	621 32 8	634 25 6	597 35 6	12,1 2,1 20	12,6 1,6 8	13,2 1,0 6	10,3 2,5 6	70,7 16,6 20	76,2 9,6 8	76,2 5,7 6	57,8 24,4 6
Pinus caribaea	525 101 20	574 130 8	516 65 6	469 52 6	8,0 1,8 20	8,0 2,5 8	8,2 1,6 6	8,0 1,0 6	67,2 9,8 20	66,9 12,4 8	70,3 7,8 6	64,4 8,2 6
Pometia pinnata	664 111 22	697 109 12	626 113 9	612 * 1	11,1 1,2 22	11,1 1,1 12	11,1 1,4 9	11,5 * 1	91,1 14,9 22	92,1 14,0 12	89,7 17,7 9	92,2 * 1
Pterocarpus indicus	557 78 20	567 92 8	550 73 9	548 75 3	10,0 1,7 20	10,2 1,7 8	10,0 1,9 9	9,8 0,9 3	76,1 11,2 20	79,0 8,6 8	75,0 14,2 9	71,6 7,1 3
Syzygium spp,	495 36 20	510 34 8	493 37 6	478 38 6	9,6 1,0 20	9,8 0,5 8	9,6 1,1 6	9,3 1,3 6	68,1 7,8 20	70,8 5,4 8	66,4 7,5 6	66,2 10,7 6
Terminalia brassii	433 45 20	434 40 9	402 56 5	458 31 6	6,9 0,8 20	7,0 0,5 9	6,3 1,1 5	7,3 0,5 6	54,4 8,6 20	55,6 5,3 9	47,3 11,2 5	58,6 8,0 6
Vitex cofassus	591 44 20	597 36 6	587 56 9	591 35 5	11,5 1,1 20	11,7 0,9 6	10,8 1,1 9	12,4 0,4 5	80,8 9,8 20	81,9 7,5 6	75,0 9,7 9	90,1 3,7 5
Xanthophyllum papuanum	718 55 21	740 43 9	727 63 7	667 34 5	13,1 2,1 21	14,1 1,7 9	13,3 2,0 7	11,2 1,7 5	94,2 18,5 21	101,6 15,5 9	98,7 17,3 7	74,3 11,5 5

[a]Air dry density at 12% moisture content; [b]Mean; [c]Standard deviation; [d]Number of specimens.

The position in the tree had a more limited impact on the compression strength properties. The species and position in tree interaction significantly influenced the compression perpendicular to grain in the case of two species, *i.e. Eucalyptus deglupta* and *Pterocarpus indicus* (Table 4). In both cases, top sections provided significantly higher average values than bottom sections (*P*-value <0,020). In the case of compression parallel to the grain, the crushing strength was not significantly influenced by the position in the tree for any of the tested species. The Fisher pairwise comparisons analysis identified two species, *i.e. Castanospermum australe* and *Anisoptera thurifera*, where the bottom sections provided significantly higher results than the top sections.

Table 4: Compression parallel and perpendicular to the grain per species based on position in the tree (based on height from ground).

	Compression Parallel to Grain (MPa)				Compression Perpendicular to Grain (MPa)			
Species	Combined	Bottom	Middle	Top	Combined	Bottom	Middle	Top
Alstonia scholaris	18,7[a] 2,4[b] 20[c]	18,5 2,5 6	18,3 1,2 6	19,1 3,2 8	3,5 0,7 20	3,3 0,7 7	3,3 0,4 7	4,0 0,9 6
Anisoptera thurifera	51,2 3,9 20	54,8 3,0 8	49,5 2,2 7	47,9 2,5 5	9,3 2,0 20	10,1 2,0 7	9,3 2,6 7	8,4 0,5 6
Anthocephalus chinensis	31,4 6,7 20	28,0 6,6 5	32,8 6,4 7	32,3 7,1 8	6,8 1,9 20	6,4 2,4 7	7,1 1,3 9	7,2 2,6 4
Araucaria cunninghamii	24,4 3,8 20	25,5 5,0 5	22,6 3,4 7	25,2 3,2 8	7,5 1,5 20	7,9 1,5 7	6,5 1,2 6	8,0 1,5 7
Araucaria hunsteinii	31,0 2,2 20	31,4 1,6 7	31,3 3,0 5	30,4 2,3 8	7,5 0,6 20	7,5 1,0 6	7,7 0,4 8	7,2 0,4 6
Canarium oleosum	33,5 5,1 20	32,3 3,4 7	39,0 2,1 6	30,0 4,4 7	7,2 1,4 20	7,5 1,5 8	7,7 1,6 6	6,1 0,6 6
Castanospermum australe	48,2 12,4 20	53,6 17,3 8	44,7 8,3 6	44,7 4,9 6	12,7 1,2 20	13,3 1,5 6	12,5 1,1 7	12,4 0,7 7
Elaeocarpus sphaericus	28,6 2,6 20	26,0 0,7 5	29,4 2,2 9	29,6 3,1 6	4,9 1,2 20	4,1 0,7 7	5,1 1,5 7	5,6 1,0 6
Endospermum medullosum	29,5 5,0 20	28,6 6,2 7	28,9 5,0 8	31,6 3,1 5	4,2 0,8 20	4,5 0,6 8	3,5 1,2 4	4,1 0,7 8
Eucalyptus deglupta	31,3 9,5 20	31,2 3,6 7	30,5 8,0 8	32,8 17,2 5	9,5 2,5 21	8,4 2,0 11	10,3 1,1 5	11,1 3,8 5
Eucalyptus pellita	52,7 9,1 21	51,6 7,4 9	52,4 10,5 6	54,6 11,4 6	16,0 3,0 22	16,2 3,7 10	15,8 2,5 5	15,8 2,6 7
Falcataria moluccana	25,5 3,5 20	23,8 3,8 4	25,0 2,7 12	28,7 4,1 4	4,1 1,5 21	2,7 0,8 5	4,5 1,2 12	4,6 2,1 4
Homalium foetidum	58,6 8,8 20	59,9 7,3 7	58,7 14,1 6	57,3 5,0 7	15,5 2,5 20	16,4 2,5 7	15,4 2,4 7	14,5 2,7 6
	Compression Parallel to Grain (MPa)				**Compression Perpendicular to Grain (MPa)**			
Species	Combined	Bottom	Middle	Top	Combined	Bottom	Middle	Top
Hopea iriana	69,0[a] 6,8[b] 20[c]	69,5 10,0 6	68,3 5,8 7	69,4 5,3 7	20,6 0,5 20	20,7 0,5 8	20,6 0,5 7	20,4 0,5 5
Intsia bijuga	64,1 5,3 20	66,6 7,7 7	62,5 3,2 11	64,2 4,4 2	17,3 3,3 17	17,0 3,6 10	19,2 1,8 4	15,6 3,4 3
Magnolia tsiampacca	25,4 2,7 20	24,6 2,2 10	25,9 3,1 9	28,8 * 1	5,6 0,9 22	5,7 1,0 10	5,3 0,5 9	6,0 0,5 3
Octomeles sumatrana	18,5 3,2 19	17,1 3,1 7	19,1 2,6 5	19,5 3,6 7	2,7 0,9 20	2,6 0,7 6	2,6 0,8 10	3,2 1,2 4
Palaquium warbargianum	25,4 2,7 20	25,1 1,7 7	25,6 2,8 7	25,4 3,9 6	4,5 1,2 20	4,4 1,6 8	4,6 1,0 6	4,5 0,8 6
Pangium edule	36,7 7,6 20	37,5 9,0 6	39,2 6,4 7	33,5 7,3 7	7,5 1,2 20	8,0 1,4 8	7,6 0,4 5	6,8 0,9 7
Pinus caribaea	29,1 6,0 20	26,5 3,8 7	31,7 6,3 9	27,8 7,5 4	8,3 1,5 20	8,0 0,5 7	8,4 1,7 2	8,5 1,9 11
Pometia pinnata	36,9 4,9 21	37,3 6,0 8	35,6 5,5 5	37,3 3,8 8	12,7 3,3 22	12,2 2,7 12	14,1 3,9 8	10,5 3,2 2
Pterocarpus indicus	45,7 7,2 21	45,8 6,5 7	45,2 6,9 7	46,2 9,2 7	11,4 2,2 21	10,7 2,5 9	11,4 1,6 9	13,2 2,4 3
Syzygium spp	38,3 5,6 20	34,6 4,9 5	40,3 6,7 8	38,7 3,5 7	8,2 1,8 20	7,8 2,2 8	8,9 1,3 6	8,1 1,6 6
Terminalia brassii	29,9 4,4 20	29,0 5,2 10	29,9 3,5 6	32,0 3,5 4	6,0 1,3 20	5,5 1,2 9	3,7 0,1 2	6,9 0,6 9
Vitex cofassus	45,9 5,4 20	46,5 6,1 11	42,0 4,6 4	47,5 3,1 5	10,0 1,8 20	9,8 2,0 8	10,9 1,8 6	9,3 1,3 6
Xanthophyllum papuanum	47,7 6,6 22	45,4 3,7 9	52,4 5,2 5	47,3 8,8 8	13,6 1,7 21	15,1 1,7 6	12,7 1,4 7	13,2 1,1 8

[a]Mean; [b]Standard deviation; [c] Number of specimens *not applicable

Table 5: Shear parallel to the grain and hardness per species based on position in the tree (based on height from ground).

	Shear Parallel to Grain (MPa)				Janka Hardness (N)			
Species	Combined	Bottom	Middle	Top	Combined	Bottom	Middle	Top
Alstonia scholaris	4,6[a] 0,9[b] 20[c]	4,6 1,1 6	4,2 0,5 8	5,1 0,9 6	896 171 20	903 88 5	849 113 9	959 275 6
Anisoptera thurifera	10,4 1,5 20	11,0 1,8 7	9,7 1,2 7	10,4 1,1 6	3797 788 20	3892 692 6	3533 731 9	4158 975 5
Anthocephalus chinensis	7,5 1,4 20	7,6 1,3 8	7,1 1,7 8	7,8 0,8 4	2179 651 20	2021 886 8	2183 509 6	2383 404 6
Araucaria cunninghamii	7,7 1,2 20	8,1 1,5 8	7,1 0,5 6	7,9 1,2 6	2229 494 20	2444 398 7	2067 145 4	2133 623 9
Araucaria hunsteinii	8,6 1,6 20	8,6 1,9 6	8,7 1,7 8	8,3 1,3 6	2121 251 20	1987 219 7	2233 230 7	2146 273 6
Canarium oleosum	8,5 1,7 20	9,2 1,7 8	8,7 1,2 6	7,5 1,9 6	2177 494 20	2347 543 8	2335 388 6	1795 333 6
Castanospermum australe	10,9 1,1 20	11,3 0,7 6	10,8 1,4 6	10,5 1,1 8	4490 649 20	4274 630 6	4593 729 5	4577 660 9
Elaeocarpus sphaericus	6,6 1,4 20	6,0 1,3 7	6,7 1,3 8	7,2 1,7 5	1554 345 20	1313 282 6	1695 392 8	1608 228 6
Endospermum medullosum	5,4 0,9 20	5,4 0,7 8	5,7 1,3 6	5,2 0,9 6	1311 200 20	1387 183 8	1162 196 6	1356 169 6
Eucalyptus deglupta	8,6 1,4 20	8,1 1,7 9	9,2 0,9 5	8,8 1,3 6	3132 780 20	2655 791 8	3322 489 6	3579 742 6
Eucalyptus pellita	12,3 1,6 21	12,1 1,4 7	12,1 2,0 4	12,4 1,7 10	6215 916 22	6459 791 7	5829 340 5	6237 1166 10
Falcataria moluccana	5,6 1,5 22	5,0 1,4 7	5,8 1,4 13	6,0 2,1 2	1192 429 22	1275 642 6	1121 280 9	1213 426 7
Homalium foetidum	14,1 3,2 20	16,1 1,2 6	13,6 3,0 7	13,0 4,1 7	6893 1476 20	7404 1492 8	6847 1103 6	6257 1744 6
	Shear Parallel to Grain (MPa)				**Janka Hardness (N)**			
Species	Combined	Bottom	Middle	Top	Combined	Bottom	Middle	Top
Hopea iriana	16,5[a] 1,5[b] 20[c]	16,3 1,2 7	16,9 1,6 7	16,4 1,9 5	8753 1174 20	8949 707 6	8577 1030 9	8834 1914 5
Intsia bijuga	13,5 1,8 20	13,2 0,9 6	14,4 2,9 7	12,9 0,4 7	6361 2016 20	6894 1545 8	6175 2887 7	5769 1250 5
Magnolia tsiampacca	5,5 0,6 22	5,6 0,7 14	5,5 0,4 8	N/A	1273 276 23	1286 360 10	1264 206 13	N/A
Octomeles sumatrana	3,6 0,7 20	3,5 0,6 8	3,4 0,5 6	3,9 0,8 6	735 255 22	737 198 8	672 154 10	890 496 4
Palaquium warbargianum	5,5 0,7 20	5,7 0,5 7	5,5 0,7 10	5,3 1,0 3	1374 292 20	1350 288 6	1408 320 8	1352 309 6
Pangium edule	8,0 1,6 20	8,1 1,6 8	7,4 1,0 4	8,3 1,8 8	3091 409 20	3120 399 8	3435 370 5	2811 250 7
Pinus caribaea	9,0 1,4 20	9,5 1,9 5	8,9 1,6 7	8,8 0,9 8	2311 467 20	2091 477 5	2547 543 8	2199 254 7
Pometia pinnata	11,2 2,2 22	11,4 1,9 12	12,0 2,4 7	8,5 0,5 3	4904 2098 21	5532 2233 8	5495 1807 7	3379 1671 6
Pterocarpus indicus	9,3 1,2 20	9,4 0,9 7	9,1 1,6 9	9,6 1,0 4	3239 710 20	3175 727 8	3282 588 8	3282 1063 4
Syzygium spp.	8,7 1,4 20	9,3 1,6 7	9,0 1,3 6	7,7 1,0 7	2410 788 20	2920 974 7	2473 324 5	1925 531 8
Terminalia brassii	8,5 1,2 20	8,5 1,4 8	9,2 0,9 5	8,1 1,0 7	2518 232 20	2582 184 6	2319 294 5	2586 176 9
Vitex cofassus	9,3 1,2 21	8,9 1,2 9	9,3 1,1 6	9,7 1,3 6	3327 706 20	3392 769 7	3549 514 6	3073 797 7
Xanthophyllum papuanum	10,6 2,0 20	11,0 1,6 7	10,9 2,4 5	9,7 1,6 5	4899 1141 19	5568 939 4	4908 1452 9	4441 425 6

[a] Mean; [b] Standard deviation; [c]Number of specimens.

The position in the tree also had a limited effect on shear and hardness testing results (Table 5). The model only identified species as a very significant factor (*P*-value <0,001) influencing shear strength and hardness. The Fisher pairwise comparisons analysis allowed identifying five species where hardness was significantly lower in top sections than bottom sections, *i.e. Xanthophyllum papuanum*, *Homalium foetidum*, *Intsia bijuga*, *Syzygium spp.*, and *Pometia pinnata*. In the case of shear strength, four species could be identified as having significantly lower values in top sections versus bottom sections, *i.e. Canarium oleosum*, *Homalium foetidum*, *Pometia pinnata*, and *Syzygium spp.*. Like bending strength results, such a trend was usually noticeable in mid to high strength species.

Comparison between old-growth forests and regrowth forests or plantations

The mechanical properties of species obtained from plantations and regrowth forests were on average 24% lower than those from old-growth forests (Table 6, Bolza and Kloot 1976). However, it is not clear whether Bolza and Kloot (1976) used a primary (50 x 50 mm specimens) or secondary (25 x 25 mm or 20 x 20 mm) method for smaller size specimens. The authors also noted the extremely limited amount of test material to prepare specimens for many of the tested species, which suggested that smaller size specimens might have been considered here. Therefore, a length effect (Madsen 1990) where natural growth characteristics create cross sections with varying strengths along the length of a timber member might explain the lower mean values obtained in the present study. There was also no indication of tree age in the case of Bolza and Kloot (1976) which might have influenced the observed differences.

Octomeles sumatrana (-43%), *Magnolia tsiampacca* (-40%), and *Syzygium spp.* (-39%) were the most affected species when comparing mechanical testing results with their counterparts from old-growth forests. On the other end, *Anisoptera thurifera* (+4%), *Elaeocarpus sphaericus* (-10%), and *Araucaria hunsteinii* (-11%) were the least affected. The density variability observed between old-growth and regrowth or plantations timbers also support the differences observed between mechanical testing results. *Octomeles sumatrana* (-22%), *Magnolia tsiampacca* (-27%), and *Syzygium spp.* (-36%) were again some the species most affected a density reduction where *Anisoptera thurifera* (+7%), *Araucaria hunsteinii* (+5%), and *Elaeocarpus sphaericus* (0%) showed an increase or no difference. Overall, the density of plantations and regrowth forests timbers was 11% lower compared with old-growth forests. However, density alone does not seem to explain all the variability observed and other elements such as ring width might need to be considered (Kliger *et al.* 1995). Barr *et al.* (2015) also observed a weak correlation between the density and the bending strength for *Intsia bijuga*.

Table 6: Physical and mechanical properties of Papua New Guinea species from old-growth forests (Bolza and Kloot 1976).

	ADD at 12% MC	MOE	MOR	Compression		Shear	Hardness
				Parallel to grain	Perpendicular to grain	Parallel to grain	Janka
Species	kg/m^3	GPa	MPa	MPa	MPa	MPa	N
Alstonia scholaris	384	9,1	59,6	28,7	N/A	6,4	1736
Anisoptera thurifera	641	13,3	79,3	44,3	8,4	11,9	4406
Anthocephalus chinensis	465	9,8	74,5	41,3	N/A	11,3	N/A
Araucaria hunsteinii	449	11,9	76,5	43,9	8,5	9,7	2392
Canarium oleosum	561	11,7	89,6	49,0	N/A	12,8	3760
Elaeocarpus sphaericus	384	7,9	56,6	32,5	N/A	8,7	N/A
Endospermum medullosum	384	9,6	61,4	35,9	10,2	5,2	1713
Eucalyptus deglupta	673	14,1	105,5	69,6	14,5	10,7	5340
Homalium foetidum	897	19,2	151,7	84,1	N/A	24,2	9924
Hopea iriana	977	24,2	168,9	94,5	28,3	18,4	10213
Intsia bijuga	817	18,0	146,9	80,7	26,5	17,5	8566
Magnolia tsiampacca	465	9,8	79,3	45,3	N/A	11,2	N/A
Octomeles sumatrana	352	8,2	53,1	36,3	5,8	5,8	1580
Pometia pinnata	689	14,3	106,2	59,8	15,6	14,4	6542
Pterocarpus indicus	609	12,2	95,1	58,3	16,6	9,9	4,695
Syzygium spp.	769	16,3	110,3	67,7	N/A	13,7	N/A
Terminalia brassii	465	9,9	68,1	37,2	10,0	8,2	2759
Vitex cofassus	705	13,6	113,1	63,7	17,9	16,3	5585
Xanthophyllum papuanum	785	18,5	130,3	78,6	N/A	15,0	7432

ADD: Air dry density at 12% moisture content; MOE: Modulus of elasticity or stiffness; MOR: Modulus of rupture or bending strength. *Araucaria cunninghamii*, *Falcataria moluccana*, *Castanospermum austral*, *Eucalyptus pellita*, *Palaquium warbargianum*, *Pangium edule*, *Pinus caribaea* are not included in the list of studied species by Bolza and Kloot (1976).

Anisoptera thurifera was the only species from regrowth forests where the mechanical testing results were usually higher (+4%) across all selected mechanical properties than those from old-growth forests (Bolza and Kloot 1976). In the case of plantations species, *Magnolia tsiampacca* (-40%) and *Eucalyptus deglupta* (-35%) were the species showing the most important average decrease in terms of mechanical properties when compared with old-growth forests. *Araucaria hunsteinii* (-11%) and *Terminalia brassii* (-17%) were the two plantations species least affected when compared with their old-growth counterparts. Compression perpendicular to the grain (-31% on average across all species), hardness (-30%), and compression parallel to the grain (-29%) were the properties showing the highest drops when comparing with old-growth forests timbers. The bending stiffness (-23%) was the mechanical property least affected when compared with results from old-growth forests followed by bending strength and shear (-24% for both).

A study by Edwin and Ozarska (2015) support the observed decrease in mechanical properties of PNG timbers from regrowth forests and plantations when compared with old-growth forests. The physical and bending properties results of 6 hardwoods species from secondary forests in PNG are also in accordance with those obtained in the present study. A study by Haslett *et al.* (1991) on *Anthocephalus chinensis* from West Samoa also provided physical and bending properties fitting those of the present study with stiffness and bending strength of 6,8 GPa and 58 MPa, respectively, for an ADD of 340 kg/m^3. A lower compression parallel to the grain (25 MPa) might be related to a site factor for growth traits as reported by Leksono *et al.* 2008 and Hung *et al.* (2015) for *Eucalyptus pellita*. Multiple studies on *Eucalyptus pellita* also demonstrated the site impact on timber mechanical properties (Bootle 2005, Kelin *et al.* 2006, Hung *et al.* 2015). Interlocked grain as an adaptive trait for tropical tree species in the rainforest has also been suggested by Cabrolier *et al.* (2009) after the authors noticed strong variations between and within trees. Where special attention was taken in the selection of specimens for the present study, the presence of interlocked grain could explain some of the differences observed between old-growth and secondary growth timbers. Barr *et al.* (2015) studied the impact of interlocked grain on bending properties of *Intsia bijuga*. The authors noted that the grain can vary significantly from straight to interlocked and influence significantly the bending strength. Interestingly, stiffnesses and densities found in the present study are similar to those found by Barr *et al.* 2015 *i.e.* 758 and 812 kg/m^3 and 14,2 and 15 GPa, respectively. However, MOR values differed significantly (116,6 versus 152,5 MPa) potentially because of the presence of interlocked grain.

CONCLUSIONS

Six mechanical properties, namely bending strength, stiffness, compression parallel and perpendicular to the grain, shear parallel to the grain, and hardness, have been evaluated for 26 PNG species using 2641 small clear specimens from 130 trees.

The impact of the position in the tree on the selected mechanical properties has also been assessed. Stiffness and bending strength tend to decrease or remain unchanged along the stem across all studied species. Where shear and hardness testing results showed a similar trend to a lesser extent, the position in the tree had a much more limited impact on the compression strength properties. Further experiments where sampling would consider the radial position within the tree might accentuate observed trends. Therefore, segregating logs based on the position in the tree could be of interest where desired timber mechanical properties and costs associated with segregating is justifying optimum mechanical properties for the intended end use.

The mechanical properties of species obtained from plantations and regrowth forests were lower than those found in the literature from old-growth forests. Different factors including the size of specimens tested, the amount and provenance of tested material, and some adaptive traits for tropical tree species might explain some differences. However, comparisons of mechanical testing results with other recent studies tend to confirm a reduction of physical and mechanical properties when comparing with timbers from old-growth forests.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Australian Government for funding through the Australian Centre for International Agricultural Research (ACIAR) program, Project No. FST/2012/092. Gratitude is extended to the Timber and Forestry Training College and PNG Forest Research Institute for harvest and supply of material used in the study. Special thanks to Frank Asok, Markson Naki, and Grace So'on for their assistance with experimental and coordination activities.

REFERENCES

ASTM International. 2009. Standard test methods for small clear specimens of timber. ASTM D143. 2009. ASTM International: United States.

ASTM International. 2010. Standard Practice for Sampling Forest Trees for Determination of Clear Wood Properties. ASTM D5536. 2010. ASTM International: United States.

Barr, J.; Tippner, J.; Rademacher, P. 2015. Prediction of mechanical properties - Modulus of rupture and modulus of elasticity - of five tropical species by non-destructive methods. *Maderas-Cienc Tecnol* 17(2):239-252. http://dx.doi.org/10.4067/S0718-221X2015005000023.

Barrett, J.D.; Kellogg, R.M. 1991. Bending strength and stiffness of second-growth Douglas-fir dimension lumber. *Forest Prod J* 41 (10): 35-43.

Bendtsen, B.A. 1978. Properties of wood from improved and intensively managed trees. *Forest Prod J* 28(10):61-72.

Bolza, E.; Kloot, N.H. 1976. The mechanical properties of 81 New Guinea timbers. Technical Paper No. 11, Division of Building Research, CSIRO: Melbourne, Australia.

Bootle, K.R. 2005. *Wood in Australia*. 2nd Edition. McGraw-Hill: Australia. ISBN: 0071014012

Cabrolier, P.; Beauchene, J.; Thibaut, B. 2009. Is interlocked grain an adaptive trait for tropical tree species in rainforest?. 6th Plant Biomechanics Conference. Cayenne, French Guyana, 16-21-nov, 2009. pp.279-284.

Edwin, P.; Ozarska, B. 2015. Bending properties of hardwood timbers from secondary forest in Papua New Guinea. *Journal of Tropical Forest Science* 27(4): 456-461.

FAO. 2015. *Global Forest Resources Assessment 2015*. Food and Agriculture Organization of the United Nations: Rome, Italy. 253 p. ISBN 978-92-5-108826-5.

Harvald, C. 1988. Nåletraearternes tekniske egenskaper (Mechanical properties of softwoods, in Danish). Royal Veterinary and Agricultural Univ., Dept. of Forestry, Copenhagen, Denmark

Haslett, A.N.; Young, G.D.; Britton, R.A.J. 1991. Plantation grown tropical timbers. 2. Properties, processing and uses. *Journal of Tropical Forest Science* 3(3):229-237.

Hojbo, O.A. 1991. The quality of wood of Norway spruce (*Picea abies*) planted with different spacing. Ph.D. Thesis, Agricultural University of Norway, Norway. ISBN: 82-575-0141-7

Hung, T.D.; Brawner, J.T.; Meder, R.; Lee, D.J.; Southerton, S.; Thinh, H.H.; Dieters, M.J. 2015. Estimates of genetic parameters for growth and wood properties in *Eucalyptus pellita* F. Muell. to support tree breeding in Vietnam. *Annals of Forest Science* 72:205-217. https://doi.org/10.1007/s13595-014-0426-9.

Kelin, Y.; Xiaomei, J.; Jianxiong, L. 2006. Guide on utilization of eucalyptus and acacia plantations in China for solid wood products. Research Institute of Wood Industry. Chinese Academy of Forestry. Technical Report. Science Press: China. ISBN :7030194004. 195 p.

Kotlarewski, N.J.; Belleville, B.; Gusamo, B.K.; Ozarska, B. 2016. Mechanical properties of Papua

New Guinea balsa wood. *European Journal of Wood and Wood Products* 74:83-89. https://doi.org/10.1007/s00107-015-0983-0.

Kliger, I.R.; Perstorper, M.; Johansson, G.; Pellicane P.J. 1995. Quality of timber products from Norway spruce - Part 3. Influence of spatial position and growth characteristics on bending stiffness and strength. *Wood Sci Technol* 29: 397-410. https://doi.org/10.1007/BF00194198.

Leksono, B.; Kurinobu, S.; Ide, Y. 2008. Realized genetic gains observed in second generation seedling seed orchards of *Eucalyptus pellita* in Indonesia. *J For Res* 13:110-116. https://doi.org/10.1007/s10310-008-0061-0.

Madsen, B. 1990. Length effect in 38 mm spruce-pine-fir dimension lumber. *Can J Civ Eng* 17: 226-242.

Machado, J.; Cruz, H. 2005. Within stem variation of maritime pine timber mechanical properties. *Holz Roh Werkst* 63(2): 154-159. https://doi.org/10.1007/s00107-004-0560-4.

Pearson, R.G.; Gilmore, R.C. 1980. Effects of fast growth rate on the mechanical properties of Loblolly pine. *Forest Prod J* 30(5): 60-66.

PNGFA. 2007. Overview of PNG's Forests. Papua New Guinea Forest Authority. <http://www.forestry.gov.pg> (Accessed 3 February 2017).

Shivnaraine, C.S. 1989. Within stem variation in bending strength and stiffness of lumber from plantation grown white spruce. M.Sc. Thesis, University of New Brunswick, Fredericton, Canada.