UNIVERSITI PUTRA MALAYSIA

WOOD QUALITY OF PLANTATION GROWN AZADIRACHTA EXCELSA (JACK) JACOBS FROM MALAYSIA

LATHSAMY BOUPHA

FH 1998 11

WOOD QUALITY OF PLANTATION GROWN *AZADIRACHTA EXCELSA* (JACK) JACOBS FROM MALAYSIA

BY

LATHSAMY BOUPHA

Dissertation Submitted in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Faculty of Forestry Universiti Putra Malaysia

July 1998

Dedicated to
My Beloved Father Sing Boupha and
Mother Vene Keo Boupha,
Whose dream comes true

ACKNOWLEDGEMENT

I am greatly indebted to Associate Professor Dr. Mohd. Hamami Sahri, Chairman of the Supervisory Committee, for his constant guidance, assistance and suggestions throughout the preparation of this thesis. I would also like to express my profound gratitude to Dr. Sim Heok Choh and Associate Professor Mohd. Zin Jusoh for their invaluable suggestions and constructive comments.

Sincere appreciation is also directed to the Vientiane Forestry College and Lao Forestry Department for their kind permission to grant a study leave at the Universiti Putra Malaysia (UPM).

Sincere gratitude is due to the Director General of Forest Research Institute Malaysia (FRIM) and his staff for the scholarship grant, for their kindly providing the research materials and for their permission to use the research facilities. Acknowledgements are extended to Dean Faculty of Forestry, UPM for their permission to use the facilities available. Cooperation from other staff members of these organisations is also greatly appreciated.

Heartiest gratitude is also due to my colleagues, fellow Laotian students and others for their constant support and encouragement.

To my husband, son and relatives, I render my gratitude and thanks for their patience, concern, support and sacrifices.

TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENT		iii
LIST OF CONTENTS		v
LIST OF TABLES		x
LIST OF FIGURES		xii
LIST OF PLATES		xiv
LIST OF ABBREVIATION		xv
ABSTRACT		xv
ABSTRAK		xviii
CHAPTER		
I	INTRODUCTION	1
	Introduction	1
	Problem Statement	3
	Objectives	4
II	LITERATURE REVIEW	6
	General Characteristics on *Azadirachta excelsa*	6
	Flower	10
	Fruit	10
	Bark	11
	Wood	11
	Growth and yield	14
	Wood Structure	17
	Vessel	17
	Fibre	19
	Parenchyma	20
	Ultrastructure of Wood Cell Wall	24
	Cell Wall Pitting	26
	Deposits	27
	Physical Property	29
	Density and Specific Gravity	29
	Moisture Content	30

Shrinkage 31

Mechanical Properties 32
Static Bending..... 32
Compression Parallel to the Grain 33
Shear Parallel to the Grain 34

Concept of Wood Quality 35

Factors controlling the quality of Wood 35
Specific Gravity 36
Uniformity and Ring Width 37
Knots 37
Tension Wood 40
Juvenile Wood 41
Fibre Dimensions 42
Fibril Angle 43
Spiral Grain 44
Moisture Content 45
Chemical Constituent 46

Effect of Management Practices on Wood Quality 46
Effect of Intensive Silviculture 47
Effect of Initial Spacing 48
Effect of Thinning 49
Effect of Fertilisation 51
Effect of Pruning 52

Relationship of Wood Structure to
Physical and Mechanical Properties 52

III **MATERIALS AND METHODS** 56

Field Sampling 56
Sample Preparation 58
Analysis of Results..... 59

IV **ANATOMICAL PROPERTIES AND THEIR VARIATIONS OF PLANTED *A. EXCELSA*** 61

Introduction 61
Materials and Methods 62
Light Microscope 62

Softening and Sectioning of Wood Blocks 62
Dehydration and Staining Process 63
Mounting Process 65
Maceration Process 65

Quantification of Wood Anatomical
Characteristics Using the Image Analysis System 66
Wood Tissue Proportion 67
Vessel Diameter 69
Fibre Characteristics 70

Scanning Electron Microscope (SEM)..... 70
Samples Preparation 70
Examination and Description 71

Results and Discussion 71
Macroscopic Features 71
Microscopic Features 75
Vessel Elements 75
Fibre 77
Parenchyma 79

Between Growth-rates Variations of *A. excelsa* 81
Tissue Proportion 83
Fibre Dimensions 83

Within-tree Variation 86
Vertical Variations 87
Radial Variations 89

V **PHYSICAL PROPERTIES ANDTHEIRVARIATIONS OF PLANTED *A. EXCELSA* (JACK) JACOBS**..... 93

Introduction 93
Materials and Methods 95
Sample Preparation 95
Specific Gravity Determination 96
Green Moisture Content Determination 96
Shrinkage Determination 97

Results and Discussion 98
Variations in Physical Property of Planted *A. excelsa* 99

Specific Gravity 101
Green Moisture Content 107
Tangential Shrinkage 108
Radial Shrinkage 110
Longitudinal Shrinkage 113
Volumetric Shrinkage 114

VI **MECHANICAL PROPERTIES AND THEIRVARIATIONS OF PLANTED *A. EXCELSA* (JACK) JACOBS** 118

Introduction 118
Materials and Methods 119
Preparation of Strength Test Specimens 119
Static Bending 120
Compression Parallel to the Grain 121
Shear Parallel to the Grain 122
Hardness Determination 123

Results and Discussion 123
Variations in Mechanical Property 125

VII **RELATIONSHIP BETWEEN WOOD ANATOMY, PHYSICAL AND MECHANICAL PROPERTIES OF *A. EXCELSA*** 134

Introduction 134
Materials and Methods 135
Correlation Analysis 135
Regression Analysis 135

Results and Discussion 136
Correlation Analysis 136
Anatomical Properties 136
Physical Properties 139

Regression Analysis 141
Relationship between Specific Gravity and Anatomical Properties 141
Relationship between Mechanical Properties, Specific Gravity, and Anatomical Properties 144

VIII GENERAL CONCLUSION AND RECOMMENDATIONS 153

General Conclusion 153

Recommendations 156

BIBLIOGRAPHY 158

APPENDIX A **Analysis of Variance on Physical and Mechanical Properties of Planted 41-year-old *A. excelsa*** 175

A_1 Vertical Variations of Physical Properties of 41-year-old *A. excelsa* 176

A_2 Radial Variations of Physical Properties of 41-year-old *A. excelsa* 176

A_3 Between Growth-rates Variations of Mechanical Properties of Planted 41-year-old *A. excelsa* 177

A_4 Vertical Variations of Mechanical Properties of Planted 41-year-old *A. excelsa* 177

VITA 178

LIST OF TABLES

Table		Page
1	Comparative Wood Properties of Several Fast-growing Species.....	13
2	Wood Utilisation of Several Fast-growing Species.....	15
3	Growth-rate of *A. excelsa* by Different Age Classes.....	16
4	Growth-rate of some Commercial Planted Species.....	16
5	The Relationship between Specific Gravity and the Relative Proportion of Vessels, Fibres and Parenchyma Cells in Four Hardwoods.....	54
6	Characteristics of the Sampled Trees of *A. excelsa*	58
7	Average of Tissue Proportions and Tissue Dimensions of *A. excelsa*	72
8	Analysis of Variance of Anatomical Properties of *A. excelsa*.....	82
9	Between Growth-rates Variations of Anatomical Properties of *A. excelsa*.....	82
10	Vertical Variations in Anatomical Properties of *A. excelsa* for all Types of Growth-rate.....	87
11	Radial Variations in Anatomical Properties of *A. excelsa* for all Types of Growth-rate	89
12	Physical Properties of 41-years-old Planted *A. excelsa*.....	99
13	Analysis of Variance of Physical Properties of 41-year-old Planted *A. excelsa*.....	100

14	Variation bentween Growth-rate of Physical Properties of Planted 41-year-old *A. excelsa*.....	100
15	Kiln Schedule for *A. excelsa*.....	120
16	Average of Mechanical Properties of 41-year-old *A. excelsa*	123
17	Comparison of Mechanical Properties between *A. excelsa* and some Light Hardwood Species.....	124
18	Analysis of Variances of Mechanical Properties of 41-year-old Planted *A. excelsa*.....	125
19	Radial Variation of Mechanical Properties of 41-year-old Planted *A. excelsa*	131
20	Correlation Coefficient and Significance Levels of Tissue Proportion.....	137
21	Correlation Coefficient and Probability of Significance Levels of Fibre characteristics.....	137
22	Correlation Coefficient and Significance Levels of Physical Properties	139
23	Multiple Linear Regression Equations of Specific Gravity as a Function of Anatomical Characteristics.....	142
24	Multiple Linear Regression Equations of MOE as a Function of Anatomical Characteristics and Specific Gravity.....	145
25	Multiple Linear Regression Equations of MOR as a Function of Anatomical Characteristics and Specific Gravity.....	147
26	Multiple Linear Regression Equations of Shear Parallel to the Grain as a Function of Anatomical Characteristics and Specific Gravity	149
27	Multiple Linear Regression Equations of Compression Parallel to the Grain as a Function of Anatomical Characteristics and Specific Gravity.....	150

LIST OF FIGURES

Figure		Page
1	Geography Distribution of *A. excelsa*	8
2	The Structure of the Plant Woody Cell Wall and the Orientation of the Cellulose Microfibrils within the Various Layers	25
3	Map of Peninsular Malaysia Showing the Location of Source of Raw Material	57
4	Vertical Sampling Points within a Selected Tree.....	59
5	Schematic Flow Chart of Double Staining Process Using Safranin-0 and Fast Green	64
6	Arrangement of Thin Wood Sections	65
7	The Sampling Fields for Wood Tissues.....	68
8	Vertical Variations of Mean Specific Gravity	106
9	Radial Variations of Mean Specific Gravity	106
10	Vertical Variations of Mean Green Moisture Content	109
11	Radial Variations of Mean Green Moisture Content	109
12	Vertical Variations of Mean Tangential Shrinkage	112
13	Radial Variations of Mean Tangential Shrinkage	112
14	Vertical Variations of Mean Radial Shrinkage	112
15	Radial Variations of Mean Radial Shrinkage	112

16	Radial Variations of Mean Longitudinal Shrinkage	116
17	Vertical Variations of Mean Volumetric Shrinkage	116
18	Radial Variations of Mean Volumetric Shrinkage	117
19	Between Growth-rates Variations of Shear Parallel to the Grain	127
20	Between Growth-rates Variations of Modulus of Elasticity	127
21	Between Growth-rates Variations of Compression Parallel to the Grain and Modulus of Rupture	127
22	Between Growth-rates Variations of Hardness	127
23	Vertical Variations of Shear Parallel to the Grain	130
24	Vertical Variations of Modulus of Elasticity	130
25	Vertical Variations of Compression Parallel to the Grain and Modulus of Rupture	130
26	Vertical Variations of Hardness	130
27	Height x Radial Position Variations of Hardness.....	132
28	Height x Radial Position Variations of Shear Parallel to the Grain	132
29	Height x Radial Position Variations of Compression Parallel to the Grain.....	133
30	Height x Radial Position Variations of MOR.....	133
31	Height x Radial Position Variations of MOE.....	133

LIST OF PLATES

Plates		Page
1	Quantimet 520 (Q 520) Image Analysis System	67
2	Diffuse-porosity with Dried Extractive Deposits	73
3	Procumbent Ray Parenchyma Cells in Radial Section	74
4	Multiseriate Rays in *A. excelsa* in Tangential Longitudinal Section.....	74
5	Vessel with Dried Extractive Deposits	75
6	Vessel Members Joined End to End with a Simple Perforation Plate Between Vessel Members.....	76
7	Helical Thickenings on Vessel Element Wall Enlarged View from Inside the Vessel of *A. excelsa* (Jack) Jacobs.....	76
8	The Fibre Wall Structures of *A. excelsa* (Jack) Jacobs.....	78
9	Tension Wood of *A. excelsa*.....	78
10	Axial Parenchyma Cells in Cross Section.....	79
11	Procumbent Ray Parenchyma Cells in Cross Section. Secondary Walls are Present with Simple Pits.....	80
12	Multiseriate Rays in *A. excelsa* in Tangential Longitudinal Section. The Wall of the Ray Cells with Simple Pits	80

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BS	British Standard
Comp	Compression parallel to the grain
DBH	Diameter at Breast Height
DMRT	Duncan's Multiple Range Test
F	Fibre
FD	Fibre Diameter
FL	Fibre Lenght
FLUM	Fibre Lumen Diameter
FRIM	Forest Research Institute Malaysia
G	Gelatinous
GMC	Green moisture content
ITTO	International Tropical Timber Organisation
MAI	Maximum annual increment
M	Middle lamella
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
Ns	Non significant
P	Primary wall
R	Ray Proportion
RH	Relative Humidity
S_1	Outer layer of the Secondary wall
S_2	Middle layer of the secondary wall
S_3	Inner layer of the secondary wall
SEM	Scanning electron microscope
SG	Specific gravity
Sh	Shear parallel to the grain
SL	Longitudinal Shrinkage
SR	Radial Shrinkage
ST	Tangential Shrinkage
SV	Volumetric Shrinkage
V	Vessel Proportion
W	Warty layer
WTH	Fibre Wall Thickness

Abstract of dissertation submitted to the Senate of the Universiti Putra Malaysia in fulfillment of the requirements for the degree of Doctor of Philosophy.

WOOD QUALITY OF PLANTATION GROWN *AZADIRACHTA EXCELSA* (JACK) JACOBS FROM MALAYSIAN

By

LATHSAMY BOUPHA

July 1998

Chairman : Associate Professor Mohd. Hamami Sahri, Ph. D.

Faculty : Forestry

Azadirachta excelsa is a fast growing tree, with tall and straight clear bole. Six planted *A. excelsa* trees of three growth rates (dominant, co-dominant and suppressed) under the same site conditions and the same age were sampled at three height levels and three radial positions to provide specimens to investigate among growth-rates and within tree variations of anatomical, physical and mechanical properties. Mean vessel, ray and fibre contents were 18.99%, 19.08% and 62.74% respectively. Mean fibre length was 1.12 mm, fibre diameter 24.17μm, fibre lumen diameter 11.55μm, and fibre wall thickness 6.31μm. Mean specific gravity (SG) was 0.59, green moisture content 96.30%, tangential shrinkage 5.64%, radial shrinkage 2.61% and volumetric shrinkage of 9.3%. Mean shear parallel to the grain was 13.34 MPa, compression parallel to the grain 41.95 MPa, modulus of elasticity (MOE)

6862 MPa, modulus of rupture (MOR) 83.85 MPa and hardness 3.03 kN. The anatomical, physical and mechanical properties of *A. excelsa* evaluated in this study were comparable to many of the light hardwood species. Therefore, the tree is suitable for a wide range of utilisation.

Between growth-rate variations of all properties analysed showed significant difference. In general, dominant trees have thicker fibre wall, higher specific gravity and strength properties than the co-dominant and suppressed trees. The considerable variations in specific gravity, in strength and in anatomical parameters among trees, if genetically controlled, offers possibilities for selection of breeding stock from seed or cuttings with desirable wood quality. Within tree variations was more pronounced in radial than in vertical direction, suggesting that diameter growth is an important factor contributing to the variations than the height growth. Samples from the mid-point between the pith and the bark were found to have highest specific gravity and also more dimensionally stable in dimension compared to the outer and inner part.

Significant correlations were found among tissue proportion, fibre characteristics and physical properties. The best regression equation for predicting SG is in terms of fibre length and fibre proportion, but the best single predictor is the fibre length. SG is the best single and most important factor influencing all mechanical properties of wood. MOE could be best predicted as a function of SG and fibre lumen diameter, whereas the main factors influencing MOR are SG and

fibre diameter. Shear parallel to the grain could best be predicted as a function of SG and ray proportion, while compression parallel to the grain could be predicted as a function of SG and fibre wall thickness.

Results of this study showed that specific gravity provides the most valuable contributing factor on the strength of wood.

Abstrak disertasi yang dikemukakan kepada senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ljazah Doktor Falsafah.

KUALITI KAYU *AZADIRACHTA EXCELSA* (JACK) JACOBS DARI HUTAN LADANG DI MALAYSIA

Oleh

LATHSAMY BOUPHA

Julai 1998

Pengerusi: Profesor Madya Mohd. Hamami Sahri, Ph.D.

Fakulti: Perhutanan

Azadirachta excelsa merupakan pokok cepat tumbuh, mempunyai batang yang lurus dan panjang. Sebanyak enam pokok *A. excelsa* telah disampel daripada tiga kategori pertumbuhan (dominan, ko-dominan dan terencat) diperolehi daripada tapak dan umur yang sama. Sampel diperolehi daripada tiga paras ketinggian dan kedudukan radial yang berbeza untuk mendapatkan spesimen untuk kajian mengenai kadar pertumbuhan dan variasi ciri-ciri anatomi, fizikal dan mekanikal pokok. Purata peratusan vesel, ruji dan gentian masing-masing adalah 18.99%, 19.08% dan 62.74%. Purata panjang gentian 1.12 mm, diameter gentian 24.17 µm, diameter lumen gentian 11.55 µm, dan ketebalan dinding gentian ialah 6.31 µm. Purata spesifik graviti (SG) adalah 0.59, kandungan lembapan segar 96.30%, kadar pengecutan tangen 5.64%, kadar pengecutan radial 2.61% dan kadar pengecutan isipadu ialah 9.3%. Purata kekuatan ricih selari dengan ira ialah 13.34 MPa, mampatan selari dengan ira, 41.95 MPa, modulus kekenyalan (MOE) 6862 MPa,

modulus kepecahan (MOR) 83.85 MPa, dan nilai kekerasan adalah 3.03 kN. Sifat-sifat anatomi, fizikal dan mekanikal *A. excelsa* yang diperolehi dalam kajian ini adalah setanding dengan kebanyakan spesis kayu keras ringan yang lain. Oleh yang demikian, pokok ini sesuai untuk julat kegunaan yang luas.

Variasi antara kadar pertumbuhan bagi semua ciri-ciri yang dianalisis telah menunjukkan perbezaan yang bererti. Pokok dominan mempunyai gentian lebih panjang dan dinding lebih tebal berbanding dengan pokok-pokok ko-dominan dan terencat. Variasi dalam spesifik graviti, sifat kekuatan dan parameter anatomi di antara pokok, sekiranya dalam kawalan genetik, memungkinkan pemilihan stok baka daripada biji benih atau keratan dari kualiti kayu yang elok. Variasi di antara pokok adalah lebih konsisten pada arah mendatar berbanding dengan arah menegak, yang membuktikan bahawa pertumbuhan di arah mendatar menjadi faktor yang penting kepada variasi, berbanding pertumbuhan menegak. Sampel daripada titik tengah di antara empulur dan kulit kayu mempunyai nilai spesifik graviti yang tinggi dan dimensi gentian yang lebih stabil.

Perkaitan yang bererti telah diperolehi di antara bahagian-bahagian tisu, sifat gentian dan ciri-ciri fizikal. Persamaan regresi yang terbaik bagi meramalkan SG ialah panjang gentian dan perkadaran gentian, tetapi kaedah ramalan tunggal terbaik ialah panjang gentian. SG ialah faktor tunggal terpenting yang mempengaruhi kesemua ciri-ciri mekanikal kayu. Kaedah terbaik meramalkan nilai MOE adalah

sebagai fungsi SG dan diameter lumen gentian, manakala faktor-faktor utama yang mempengaruhi MOR adalah SG dan diameter gentian. Ricih selari ira boleh diramalkan dengan baik sebagai fungsi SG dan perkadaran ruji, manakala kekuatan mampatan selari dengan ira boleh diramalkan sebagai fungsi SG dan ketebalan dinding gentian.

Keputusan daripada kajian ini menunjukkan bahawa spesifik graviti merupakan faktor paling penting yang mempengaruhi kekuatan kayu.

CHAPTER I

INTRODUCTION

Most of the tropical forests are being fallen for some forms of agricultural development, for human settlement, for fuel wood or for the wood industry. The remaining forests must now be used more efficiently and species for forest plantation must be selected carefully and appropriately to meet the ever-increasing demand of wood from the various sectors of the society.

The remaining undeveloped forest resources often contain large number of species, many of them relatively unknown and yet to be fully utilised. The increasing demand of forest produces globally would need to focus on many species rather than a few popular species. Accordingly, knowledge on properties and characteristics of these species in relation to their suitability for particular end-uses needs to acquire to improve utilisation efficiency and assist in the marketing of these species. When establishing plantations more consideration must be given towards the provision of the optimum wood quality for a particular end-use.

Certain wood characteristics are desirable in one product, but not in the other. Wood has many different uses, and the assessment of wood quality of a species or provenance, or even of individual tree, may involve the consideration of a large number of physical and mechanical properties and other characteristics.

In the past, the descriptive aspects of the anatomy of the wood from various indigenous forest and botanical families parallel the emphasis on particular species for worldwide use. Greater attention is now being given to intra-specific variability of wood structure and properties including those of fast-growing indigenous species. That information is applicable to many species and in addition, points to the need for careful sampling within species. The data collected can assist the prediction of end-uses for lesser known species and the grouping and rating of species for their optimal utilisation. The most useful structural parameter for end-use needs to be chosen first and the expensive and time-consuming improvement in precision and determination of the other parameters can proceed as the need arises (Hillis, 1989).

Traditionally, a large proportion of the Asian tropical timber supply has come from a very limited number of species such as ramin (*Gonystylus bancanus*) and meranti (S*horea spp.*) but now more attention is being given to the numerous lesser known indigenous species. Critical steps towards the commercial use of these species are the acquisition of information on their characteristics and processing properties. This information facilitates the grouping of different species for processing, marketing, end-use, and ultimately ensure acceptance by the customer.

Azadirachta excelsa (Jack) Jacobs is a fast growing tropical tree species belongs to the family Meliaceae. It grows very well in moist tropical rain forest, and it may also grow well in tropical dry evergreen forest. This species can reach a height of up to 50 m with a round and straight trunk. The species can be harvested after five years of planting. Its diameter then is expected to be around 20-30 cm (Kijkar and Boontawee 1995). This species is being aggressively promoted for commercial plantation forest in Malaysia (Anon, 1997a). A report by International Tropical Timber Organisation (ITTO) (1997) also considered *A. excelsa* as one of the four important commercial plantation species besides teak, acacia and rubber wood.

Problem Statement

In Thailand and the Philippines, the tree is used for house and boat building, as door and window frames, columns and stiles (Schumuttere and Doll, 1993). In addition, presence of attractive figures makes this timber suitable for veneer and plywood production. From preliminary test carried out in Sandakan, Sabah, the timber was found to peel well with standard settings without pre-treatment, and the veneer dried without serious defects (Burgess, 1966; Kijkar and Boontawee, 1995). Ratiwanich *et al*., (1992; 1994) reported that *A. excelsa* can also be used very successfully for pulp production.

Though this species is found in abundance in Malaysia, it has yet to make its way into the processing mills. Nevertheless, as the supplies of the prime natural