MINISTRY OF EDUCATION AND TRAINING

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DO HUU SON

RESEARCH ON EFFECTS OF MOTHER TREE SPECIES, GENETIC VARIATION AND HEREDITY OF GROWTH AND WOOD PROPERTIES IN NATURAL ACACIA HYBRID TO SUPPORT BREEDING AND CLONAL SELECTION

Specialty: Forest genetics and tree breeding

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SUMMARY OF DOCTORAL THESIS

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This thesis was completed in Vietnamese Academy of Forest Sciences

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INTRODUCTION

1. Rationale

Acacia hybrid is the abbreviated name for natural hybrid varieties between *Acacia mangium* and *A. auriculiformis*. This is a fast-growing variety with good stem quality, high adaptability, high soil fertility improvement capacity and higher pulp potential than either *A. mangium* or *A. auriculiformis* (Le Dinh Kha et al., 2003). Acacia hybrid is currently the major forest plantation species in many parts of the country, especially the provinces in Central coastal region and Southeast region with total annual new planting area of 50,000 - 70,000 ha.

Up to now, although numerous acacia hybrid varieties have been selected and developed into commercial plantations, this number is still limited for such large plantation area. On the other hand, most of acacia hybrid varieties were derived from Acacia mangium's mother trees while the hybrid derived from *A. auriculiformis*'s mother trees have not been well attended. Moreover, research in breeding of acacia hybrid up to now has mainly focused on increased growth rate and some wood quality related to pulp production while demand for sawlog plantations is large, therefore research incorporating growth and wood quality for sawn timber is necessary.

In order to meet the goal of acacia hybrid selection and breeding for increased productivity and quality of timber, increasing genetic diversity and resilience, and further contribution to scientific bases to the genetic improvement research, issues such as the effects of mother tree species, genetic variation and heredity in growth and some wood properties are important to address. Therefore, the thesis ***"Research on effects of mother tree species, genetic variation and heredity of growth and wood properties in natural acacia hybrid to support breeding and clonal selection"*** is really necessary, meaningful in science as well as practice.

2. Research objectives

+ General objectives

Enriching knowledge for genetic improvement research of natural acacia hybrid variety *(Acacia mangium x A. auriculiformis and A. auriculiformis x A. mangium).*

+ Specific objectives

- To understand and quantify clonal variation, genetic parameters and genotype - environmental interactions in growth characteristics, stem quality and some wood properties of natural acacia hybrid.

- To understand effects of mother tree species and family in growth characteristics, stem quality and some wood properties of natural Acacia hybrid.

- To select some promising natural Acacia hybrid clones.

3. Research subjects

Natural acacia hybrid varieties derived from *A. mangium* as mother and *A. auriculiformis* as father (*A. mangium x A. auriculiformis)* and from *A. auriculiformis* as mother and *A. mangium* as father *(A. auriculiformis x A. mangium)*.

4. Research scope

Research contents

Research content of the thesis focus on main following themes:

- Clonal variation of growth, stem quality and wood properties of natural Acacia hybrid varieties in clonal trials.
- Effects of mother tree species and family in growth, stem quality and wood properties.
- Estimation of genetic parameters, genotype - environment interactions and correlations between traits.
- Selection of new clones.

Research sites

+ Clonal screening trials at Ba Vi (Hanoi), Yen The (Bac Giang), Dong Ha (Quang Tri) and Bau Bang (Binh Duong), each trial consists of 150 – 240 treatments, in which wood properties were evaluated in 03 sites which are Ba Vi, Yen The, Bau Bang.

+ Clonal trials at Dong Ha (Quang Tri) and Quy Nhon (Binh Dinh), each consists of 40 – 60 treatments.

5. Scientific and practical meaning of the thesis

- Scientific meaning

To understand clonal variation, genetic parameters, correlations between traits, genotype - environment interactions, effects of mother tree species and family in growth and some wood properties, contributing to scientific bases for selection and breeding of natural Acacia hybrid.

- Practical meaning

Research results on effect of mother tree species provide scientific bases for selecting suitable mother tree species for hybridization and to select hybrid variety for differing environments.

23 promising clones have been identified (*20 clones from AmxAa and the 03 clones from AaxAm)* from which 05 clones have been proven of best growth in certain environments and meet criteria for new variety recognition under standard 04 TCN 147 – 2006 were selected, supplementing to variety group for forest planting.

6. New points of the thesis

Understand the effects of mother tree species and family on growth and wood properties in clone’s performance that support selection and breeding of natural Acacia hybrid.

Understand clonal variation, genetic parameters, correlations between traits genotype by environment interactions in growth, stem quality and some wood properties of natural Acacia hybrid.

CHAPTER 1
OVERVIEW OF RESEARCH ISSUE

1.1. Natural Acacia hybrid in the world

1.1.1. Planting situation and development potential

Total Acacia hybrid plantation area is about 600,000 ha by 2013, of which Acacia hybrid has just been grown in large scale in Vietnam. In other countries, Acacia hybrid has just been grown in small scale for experiment.

1.1.2. Situation of research for variety improvement

a. Research for variety selection

During the period 1995-1996, Sabah Softwood Berhad Company conducted to select nearly 40 Acacia hybrid clones (*A. mangium* as mother species) for testing. Evaluation results at six years showed a significant difference among clones, according to the results 03 clones of best performance were selected for further research (Kien, 2016).

In the state of Karnataka, India, MPM Company has also conducted a Acacia hybrid variety selection program from 1992 by selecting hybrid trees in the *A. mangium* and *A. auriculiformis* plantation area. The clonal testing results also showed the strong genotype - environment interactions between dry and humid regions (Amanulla et al., 2004).

In Thailand, a trial that tested 20 acacia clones, of which 06 clones are acacia hybrid (04 Vietnam's clones which *A. mangium* as mother tree species and 02 Thailand's clones which *A. auriculiformis* as mother tree species) and 14 clones of *A. auriculiformis*. The evaluation results at the 36 months showed a significant difference between the clones, the acacia hybrid clones were significantly growing faster than *A. auriculiformis* clones. Acacia hybrid clones from *A. auriculiformis's* mother species showed good adaptability during dry season (Diloksumpun et al., 2014).

b. Research on wood properties

Research by Yong et al. (2013) showed that acacia hybrid has the alpha - cellulose content of 40.7%, lower than that of *A. mangium* (45%) and equivalent to that of *A. auriculiformis* (40.5%), but it has a lower extractives content compared to the extractives content of the above two species. At the same age, its wood fibers (1.19 mm) is longer than those of *A. mangium* and Acacia auriculiform which are 17.7 and 26.4% respectively.

Research on using wood of Acacia hybrid as sawlogs had been conducted in Bangladesh by Rokeya et al. (2010) on the trees aged 9 to 12 years in comparison with Teak aged 40 years. The research results showed that the wood of acacia hybrid at the humidity of 12% has density of 560 kg/m^3, total shrinkage of 13%, modulus of elaticity of 120 kg/cm^2 and modulus of static bending of 867 kg/cm^2.

c. Research on pests and diseases and selecting pests and diseased resistant seeds

The research on pests and diseases in acacia hybrid showed that the pests and diseases in parental plants can also be detected in acacia hybrid. In which, the most regular diseases causing serious damages to acacia hybrid include pink disease caused by *Erythricium salmonicolor*, heart rot, root-rotting disease caused by *Garnoderma sp.* and wilt disease caused by *Ceratocystis sp*. (Old et al., 2000).

1.2. Natural Acacia hybrid in Vietnam

1.2.1. Planting situation and development potential

Acacia hybrid plantation area in our country until 2015 is about 520,000 ha (Agriculture News, 2016). This area also tends to increase with an annual plantation area of about 50,000 to 70,000 ha, mainly in the North, North Central region and South Central region provinces with MAI of 15-35 m^3/ha/year depending on site conditions.

1.2.2. Situation of research for seed improvement

a. Research for selecting clones

In 1993, the Research Centre for Forest Tree Improvement conducted of trial that tested 20 clones of natural Acacia hybrid selected in plantations in Ba Vi (Ha Noi). The research results at age 5 years indicated that clones BV5, BV10, BV16, BV32, BV29 and BV33 were most promising with stem volume of 161 to 204 dm^3, 1.6 to 4 times better than that of the parental species (Le Dinh Kha, 1999c, 2001). Natual Acacia hybrid were also selected and tested in the Southeast region, the results selected a number of promising clones such as TB3, TB5, TB6, TB12 (Lưu Ba Thinh, 1999). In 2000, Ministry of Agriculture and Rural Development recognized clones BV10, BV16, BV32, BV33, TB3, TB5, TB6 and TB12 as national varieties and technically advanced varieties.

Phu Ninh Forest Research Center has also conducted selection and testing of acacia hybrid since 2000. Two best performing clones namely KL2 and KLTA3 have been recognized as technically advanced varieties (Le Dinh Kha, 2001).

Ha Huy Thinh et al. (2015) evaluated a clonal trial at Quy Nhon (Binh Dinh) at the age of 6.5 years old. The results showed that recognized clones such as BV10, BV16, BV32 and BV33 still maintained their superiority with MAI of 30.4 - 33.7 m^3/ ha/ year. In this trial, the two most productive clones were BV73 and BV71 that had been previously recognized as technologically advanced varieties with MAI from 34.6 to 38.5 m^3/ ha/ year.

b. Research on wood properties

Le Dinh Kha et al. (1995) showed that wood of acacia hybrid has density was intermediate between *A. auriculiformis* and *A. mangium*. Acacia hybrid clones have different density and wood shrinkage. Clones BV32 and BV33 have the highest wood density, and wood of clone BV16 is not cracked when dried.

Nguyen Tu Kim et al. (2008) evaluated the wood properties of 06 natural acacia hybrid clones BV5, BV10, BV16, BV29, BV32 and BV33 at 8 years showed significant difference between clones on growth and some wood properties. The distribution model for wood density shows that there are different high and low density in different areas on a log. Density at the position 1.3 m is appropriate to predict the density of the whole stem, and the clone BV5 has good growth and highest density.

c. Research on pests and diseases and selecting pests and diseased resistant varieties

Research by Nguyen Hoang Nghia et al. (2005, 2010, 2015) identified main pathogenic organisms and serious fungus to acacia species in East Northern region, Central region, The Central, Central highland, and Southeast region. The authors also conducted the research to select pest and disease resistant varieties, some natural Acacia hybrid clones were selected which *A. auriculiformis*'s mother such as AH7 and AH1 which have rapid growth, reaching 30 - 34.9 m^3/ha/year in Binh Duong, the average disease index is zero.

1.3. General perception

Research on selecting varieties of natural acacia hybrid has achieved a lot of success. Many acacia hybrid varieties were selected and developed into production by cutting – tissue culture technology. However, besides the results achieved, research and development in acacia hybrid variety selection and breeding in the past also revealed a number of limitations such as:

- Although many varieties have been selected and developed in production so far, with a large plantation area, the number of varieties is still limited. Large-scale plantation with limited number of varieties reduces the genetic background, and plantations are easy to be damaged by biotic and abiotic threats such as pests and diseases, winds and storms, droughts. It is therefore urgent to increase the number of varieties in plantations to minimize the risk of pests and diseases as well as other extreme environmental stress.
- In actual production today, most of acacia hybrid varieties is derived from the *A. mangium*'s mother, acacia hybrid derived from *A. auriculiformis*'s mother has not been much concerned for research. Therefore, it is neccessary to research and evaluate the growth capability, wood quality as well as tolerability of pests and diseases of acacia hybrid whose mother trees is *A. auriculiformis* in order to select acacia hybrid varieties which has good growth capability and combining advantages of *A. auriculiformis* such as good disease resistance and wood quality.
- So far, research on acacia hybrid in Vietnam have mainly focused only on growth studies and some wood properties related to pulp, there has not been much research on variety selection for different end use purpose,

especially the wood properties that meet the requirements of large timber production. In order to plant acacia hybrid forest for large timber supply, it is really necessary to study the variety selection with combination of growth and wood properties suitable for making sawlogs.

In order to address above mentioned limitations, research contents of the thesis were performed to enrich knowledge for proper scientific bases to support breeding and clonal selection strategy of acacia hybrid in Vietnam.

CHAPTER 2
RESEARCH CONTENT, MATERIALS AND METHODS

2.1. Research content

i. To research clonal variation of growth characteristics, stem quality and some wood properties of natural Acacia hybrid clones *(A. mangium x A. auriculiformis and A. auriculiformis x A. mangium)* in some locations.

ii. To research effects of mother tree species and family on grow capability, stem quality and some wood properties of natural Acacia hybrid clones in some locations.

iii. To estimate the genetic parameters, genotype - environment interactions of growth characteristics, stem quality, some wood properties and correlations between traits in some places.

iv. To select promising clones for production forest planting.

2.2. Research material

- Materials for research in clonal variation of growth and stem form were 550 newly selected acacia hybrid clones, of which 215 clones derived from *A. mangium* as mother and *A. auriculiformis* as father, and 335 clones derived from *A. auriculiformis* as mother and *A. mangium* as father. These clones were field tested in 4 clonal screening trials at Ba Vi, Bau Bang, Dong Ha and Yen The, each consists of 150 – 240 treatments that include both newly selected clones and controls.

- Evaluation of clonal variation in wood property was performed in 3 clonal screening trials at Ba Vi, Bau Bang, Dong Ha and Yen The. In each trial, 66 – 95 clones were randomly selected for sampling with a total of 264 - 465 trees felled in each trial.

- Research on selecting clones was performed in 2 clonal trials at Dong Ha and Quy Nhon with a total of 56 newly selected clones and some controls.

2.3. Natural features of research regions

- Clonal screening trials were established in 4 sites that the climate conditions are characterized for 04 regions: Red River Delta, the Northeast region, North Central region, and Southeast region.
- The clonal trials were established in 2 sites that climate conditions are characterized for North Central region and South Central region.

2.4. Research methods

2.4.1. Hybrid plant and plus tree selection method

Hybrid plant selection method according to Le Dinh Kha (1999c).

Plus tree selection method according to standard 04 TCN 147-2006.

2.4.2. Experimental design

The trials are designed under row - column incomplete random block (Williams et al., 2002) using software Cycdesign 2.0, details as follows:

- Clonal screening trials at Ba Vi, Yen The, Dong Ha and Bau Bang: including 150 – 240 clones per site; 5 – 11 replicates; 1 – 2 trees/plot, spacing is 3 m x 1,5 m and 3 m x 2 m.
- Clonal trials at Dong Ha and Quy Nhon: including 40 – 60 clones per site; 4 – 5 replicates; 10 trees/plot; spacing is 3 m x 2 m.

2.4.3. Data collection methods for growth and stem quality

- Growth characters such as diameter at breast height ($D_{1.3}$), height (H) were measured by popular methods in forest investigation of Vu Tien Hinh and Pham Ngoc Giao (1997).
- Axis persistence (Dttt) was performed by scoring method of Luangviriyasaeng V. and Pinyopusarerk K. (2002).
- Stem straightness (Dtt) was performed by scoring method of Le Dinh Kha et al. (1998).

2.4.4. Sampling method for wood property evaluation

In clonal screening trials at Ba Vi, Yen The and Dong Ha, clones were randomly selected for wood sampling, and 4-5 trees per clones in different replicates were sampled. On each selected tree, sound transmission in wood data was measured using Fakopp microsecond timer (unit µs) according to method by Ross (1999) and Phi Hong Hai (2015). Followed by Fakopp’s sound transmission data, the trees were cut at ground and a 5 cm disk was collected at 1.3 m height. Wood samples were numbered, bark removed, cleaned and green weight determined, then wrapped by wet cloth and covered in plastic bag to prevent from surface dry-out; the wood samples were then transported to the laboratory for data measurement.

2.4.5. Method for identifying wood properties

- Wood basic density was determined by water displacement method (Olesen, 1971).
- Modulus of elasticity (MoE_d) of wood is indirectly evaluated by Fakopp's transmission data and green weight of wood samples (Ross, 1999).

2.4.6. Data analysis

Data were analysed using statistics software including Genstat 12.0 and ASREML 3.0 developed by VSN International; graph illustration performed by R3.2.2 developed by R development core team.

CHAPTER 3
RESULTS AND DISCUSSIONS

3.1. Clonal variation in growth, stem quality and wood properties

3.1.1. Clonal variation in growth and stem quality in clonal screening trials

The results of the evaluation of the clonal screening trials at the four sites were summarized in Table 3.1. The results showed that the trials conducted at the three sites of Ba Vi, Yen The and Dong Ha at 3 year old and Bau Bang (2 years old) have a significant difference between the clones (Fpr <0.001). Among the three trials in Ba Vi, Yen The and Dong Ha, the growth rate of acacia hybrid in Yen The is highest, followed by Ba Vi and finally Dong Ha. The trial at Bau Bang at 2 years old also grew relatively well with average diameter of 5.8 cm and height of 8.5 m.

At three locations Ba Vi, Yen The and Dong Ha at age 3 years, the recognized clones used as control varieties retain fast-growing ability in the group of from the best to average-good clones in the trial. In Ba Vi, the best 10 clones consist of all new acacia hybrid clones with superior growth compared to the trial average and control variety. In Yen The, among the 10 clones with the best volume growth, there are 9 new acacia hybrid clones and clone BV73 ranked 6th in the trial. In Dong Ha, all acacia hybrid clones are in the best growth group, ranked first to thirteen in the trial and 10 new selected acacia hybrid clones have the same volume with the clones recognized as varieties and are superior to the overall average of the trials.

Table 3.1. Level of difference and variation of clone mean in clonal screening trials (2-3 years)

Trial	**Number of clones**	**Trait**	**Unit**	**Mean**	**Fpr**	**Clone mean range**
Ba Vi (3 years old)	240	$D_{1.3}$	cm	7.8	<0.001	3.7 - 13.3
		H	m	8.8	<0.001	4.9 - 13.2
		V	dm^3	27.8	<0.001	3.5 - 83.7
		Dtt	point	3.1	<0.001	2.2 - 4.8
		Dttt	point	3.2	<0.001	1.2 - 5.1
		TLS	%	71.6	<0.001	0 - 100
Yen The (3 years old)	150	$D_{1.3}$	cm	8.3	<0.001	4.2 - 12.0
		H	m	11.4	<0.001	3.2 - 14.5
		V	dm^3	35.7	<0.001	2.3 - 80.1
		Dtt	point	3.1	<0.001	2.1 - 4.0
		Dttt	point	3.2	<0.001	1.8 - 4.5
		TLS	%	88.1	<0.001	41.6 - 100
Dong Ha (3 years old)	240	$D_{1.3}$	cm	5.9	<0.001	3.4 - 9.8
		H	m	7.3	<0.001	4.1 - 9.3
		V	dm^3	11.6	<0.001	2.8 - 37.7
		Dtt	point	3.2	<0.001	1.0 - 4.6
		Dttt	point	3.2	<0.001	1.0 - 4.9
		TLS	%	79.2	<0.001	0 - 100
Bau Bang (2 years old)	160	$D_{1.3}$	cm	5.8	<0.001	2.5 - 7.9
		H	m	8.5	<0.001	3.5 - 10.3
		V	dm^3	13.9	<0.001	1.6 - 25.2
		Dtt	point	3.4	<0.001	2.7 - 4.0
		Dttt	point	4.9	<0.001	3.6 - 5.9
		TLS	%	83.2	<0.001	30 - 100

Based on the assessment of growth and stem quality, 23 promising lones including 20 clones from *A. mangium's* mother trees and 3 clones from *A. auriculiformis's* mother trees have been initially selected. These clones showed fast growth, equivalent to or better than the recognized varietíe. These acacia hybrid clones had growth rates and stem quality equivalent to or higher than the recognized varieties of 10 to 40% and superior to *A. auriculiformis* and *A. mangium*. However, this result is only preliminary, evaluated on a small scale, so it can not reflect the ability of the clones. Therefore, there is a need for larger scale assessments to determine the true ability of these clones.

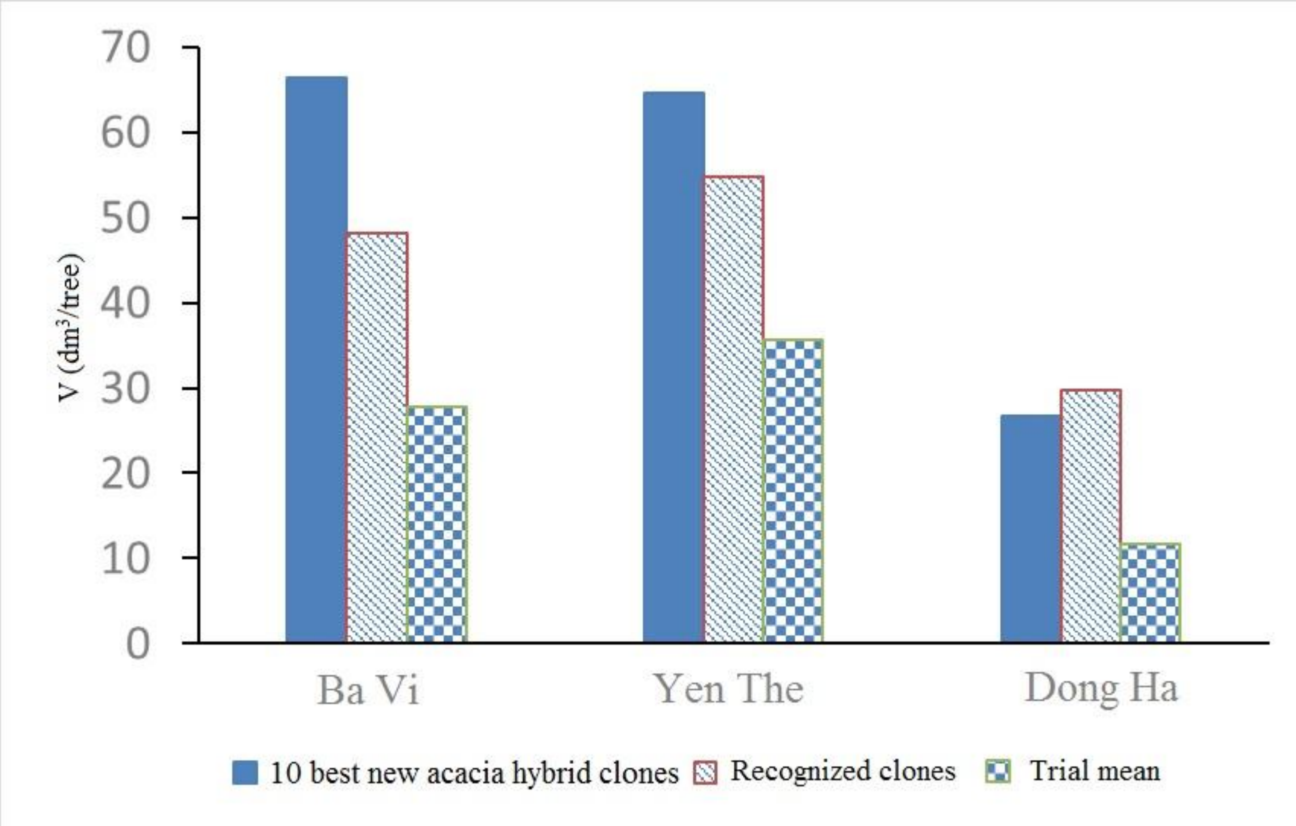

Figure 3.1. Growth of 10 promising new acacia hybrid clones in clonal screening trials in Ba Vi, Yen The and Dong Ha

3.1.2. Clonal variation in wood properties of clones in clonal screening trials

Both wood basic density (KLR) and modulus of elasticity (MoEd) were statistically different between acacia hybrid clones in all trials (Fpr <0.001). The basic density of the acacia hybrid clones at Ba Vi and Yen The is higher than that of Bau Bang, respectively 0.418, 0.430 and 0.382 g/cm^3, which can be explained by the sampling of new acacia hybrid at the age of 3 years in Ba Vi and Yen The and at the age of 2 years in Bau Bang.

The variation range in the three trials of density is quite large, from 0.3 to 0.5 g/cm^3 with low genotypic coefficient of variation (<10%), for three trials in Ba Vi, Yen The and Bau Bang is 5.9%, 7.7% and 9.5% respectively, indicating that the ability to select individuals that are superior in density is not high.

Unlike the growth in which acacia hybrid clones from the mother tree species, *A. mangium*, occupy majorly in the group of 10 best clones, more number of clones from *A. auriculiformis's* mother tree were recorded of high basic density. In Ba Vi, the clones of high basic density were in the middle growth group only, but in Yen The and Bau Bang there are some clones that have both good growth and high basic density.

Modulus of elasticity:

The modulus of elasticity of the clones in the three trials has averaged value of 7.16 – 9.72 Gpa, ranging from 4.7 to 16.6 Gpa, with low genotypic coefficient of variation (<10%) in Ba Vi and Yen The (9.2% and 7.4%, respectively) but higher in Bau Bang (19.5%).

Based on the above analysis, acacia hybrid clones from the *A. mangium's* mother trees still prevail over the Acacia hybrid from the *A. auriculiformis's* mother tree species in group of clones with highest density and elastic modulus in the trials. Of the fast growing clones in Ba Vi and Yen The, only a few clones have high wood density while no clones have high modulus of elasticity.

The results of the assessment of wood properties in this study are only preliminary, not yet reflecting the value of mature wood. Many research results confirmed that in fast growing species, wood basic density tends to increase with age and has very strong age – age correlation (Le Dinh Kha et al., 1996, Nguyen Duc Kien et al. 2009, Phi Hong Hai et al., 2009). This proves that not only density but also modulus of elasticity tends to increase with age and strong age – age correlation, so it can be expected that the clones with good wood properties at this age will also remains its superiority at older ages.

Selection of clones with fast growth and good wood properties:

Of the 16 clones that have good growth rate in Ba Vi and Yen The, only seven clones have good growth with one or two of the wood properties reaching the average or higher values in the trials. Among these, only 3 clones BB064, BV469 and BV575 are fast-growing and have both good wood properties, ranked relatively high in the trials. These are potential clones that need further evaluating in order to grow in the direction large timber for high quality saw logs.

Table 3.2. The stem volume, basic density and modulus of elasticity of some new potential acacia hybrid clones

Clone	**V (dm^3)**	**KLR (g/cm^3)**	**MoE_d (Gpa)**
Trial in Ba Vi			
BV175	75.8 (2)	0.426 (35)	7.33 (34)
BB042	67.4 (4)	0.420 (43)	7.47 (30)
BB064	65.0 (5)	0.446 (18)	7.51 (28)
BB095	58.6 (10)	0.430 (31)	6.80 (53)
Trial in Yen The			
BV536	67.0 (2)	0.395 (54)	9.95 (27)
BV469	66.2 (3)	0.468 (7)	9.74 (31)
BV575	64.0 (6)	0.468 (9)	10.09 (24)

Note: the number in brackets is the ranking order of clones

3.2. Effects of mother tree species and family on growth, stem quality, and wood properties

3.2.1. Effects of mother tree species species on growth and stem quality

The results from four trials in different sites show significant differences in growth and stem quality between groups (Fpr <0.001), indicating that the mother tree species have a huge influence on the growth of hybrid varieties. In all four trials, recognized varieties still ranked best in stem volume, and outperformed the rest. The new acacia hybrid clones from *A. mangium's* mother trees have remarkable growth, with stem volume of 1.6 to 2 times higher than the acacia hybrid clones from *A. auriculiformis* and stem quality index is also considerably higher.

When examining the fast-growing acacia hybrid clones on Ba Vi, Yen The and Dong Ha, most of the clones grown in the good group are derived from the *A. mangium*'s mother trees. Specifically, among the best growing clones in Ba Vi, most of them are originated from *A. mangium*, only two acacia hybrid clones are derived from *A. auriculiformis* (BV106 and BV175) ranked 1st and 3rd in terms of growth. In Yen The, none of the clones derived from *A. auriculiformis* ranked in the 10 best clones. Among 20 good clones in Yen The, only BV471 ranked 22nd and BV466 ranked 20th on stem volume. The group of the worst performing clones belongs to the acacia hybrid clones from the *A. auriculiformis*'s mother trees. This indicates that Acacia hybrid from *A. auriculiformis* has not grown well (except BV106 and BV175), which partly reflects the effect of mother tree species on the growth of hybrid clones.

Table 3.3. Stem volume and stem quality index of acacia hybrid clones and control varieties

No.	Group	Ba Vi (3 years old)		Yen The (3 years old)		Dong Ha (3 years old)		Bau Bang (2 years old)	
		V (dm^3)	Icl	V (dm^3)	Icl	V (dm^3)	Icl	V (dm^3)	Icl
1	Aa x Am	19.5	10.3	17.0	8.1	9.2	10.3	10.2	16,2
2	Am x Aa	39.3	11.1	38.9	10.5	17.5	12.7	16.1	17,6
3	GCN	48.2	9.3	54.8	10.9	29.6	14.7	17.5	19,7
4	Aa seed	22.2	9.7	18.5	11.5	10.2	11.6		
5	Am seed	63.4	17.1	23.9	10.8	19.9	16.5		
Average		27.7	10.7	35.7	10.2	11.6	11.6	13.9	17.1
Fpr		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Lsd		3.5	0.9	11.8	1.7	2.1	1.5	3.4	1.9

In Bau Bang at the 2-year-old stage, the acacia hybrid clones recognized as varieties are still on the lead in growth, but there is no significant difference from the new acacia hybrid clones from the mother tree species namely *A. mangium* with volume of 16.1 dm^3/tree. The acacia hybrid clones from mother tree species namely *A. auriculiformis* have the lowest growth with the stem volume is only 10.2 dm^3/tree (Fpr <0.001 and Lsd = 3.4).

Acacia hybrid clones from *A. mangium* also has higher stem quality index than *A. auriculiformis*. The difference in this trial compared to the other three ones is that in the group of acacia hybrid clones from the *A. auriculiformis*'s mother trees, up to 25% of the clones has the same growth as the group with average to good growth of the Acacia hybrid clones from the *A. mangium*'s mother trees and some clones even exceed the recognized varieties.

This result is very important contributing to save effort, time and buget for selection and breeding of natural Acacia hybrid varieties. For areas with warm climatic conditions throughout the year such as in the

Southeast, acacia hybrid clones from the *A. auriculiformis*'s mother trees and *A. mangium* can be selected. In contrast, in the North and North Central Coast where climate conditions are not suitable for *A. auriculiformis,* the hybridization and selection of acacia hybrid from the *A. mangium*'s mother trees should be concentrated on.

3.2.2. Effects of mother tree species on wood properties

At Ba Vi, the results showed that wood basic density of hybrids were similar to those of parental species while modulus of elasticity were the average of the parental species. At Yen The, both density and modulus of elasticity of hybrid varieties were superior to the two parental species. At Bau Bang, in the absence of parental seedlot controls, there was no difference between the groups in terms of wood basic density. The clones with the mother tree species as *A. auriculiformis* have the highest basic density (0.389 g/cm^3), while the clones with the mother tree species as *A. mangium* have lower basic density (0.380 g/cm^3) than recognized varieties. Unlike basic density, the elastic modulus showed differences between groups (Fpr <0.001), but as in Yen The, the recognized verieties exhibit superiority in modulus of elasticity.

Table 3.4. Wood basic density and modulus of elasticity (MoE_d) of acacia hybrid groups and control varieties

Group	**Ba Vi (3 years old)**		**Yen The (3 years old)**		**Bau Bang (2 years old)**	
	KLR (g/cm^3)	**MoE_d (Gpa)**	**KLR (g/cm^3)**	**MoE_d (Gpa)**	**KLR (g/cm^3)**	**MoE_d (Gpa)**
Aa x Am	0.424	7.29	0.434	9.37	0.389	7.73
Am x Aa	0.412	7.06	0.420	9.85	0.380	8.00
GCN	0.419	6.87	0.468	11.69	0.384	10.49
Aa seed	0.413	7.58	0.415	7.66		
Am seed	0.409	6.82	0.410	9.20		
Average	0.418	7.16	0.430	9.72	0.382	8.02
Fpr	0.051	<0.001	<0.001	<0.001	0.069	<0.001
LSD	0.025	0.38	0.030	1.34	0.046	1.54

Unlike growth indicators, there is no clear difference between acacia hybrid clones from *A. auriculiformis*'s mother trees and *A. mangium*'s mother trees in both basic density and modulus of elasticity at 2 – 3 years old. This result suggests that the effect of mother tree species on the wood properties of acacia hybrid is not clear. However, this result is only preliminary at early ages, so it should continue to be evaluated at higher age in order to have more accurate conclusions.

3.2.3.Effects of the family on the clones' growth and wood properties

The analysis shows that in the clonal screening trial in Ba Vi, the family variance component was very low in the total phenotypic variance and was not significant for all growth traits and wood characteristics (ns: significance level of the value $\chi^2 > 0.05$). The results indicate that effects of family on the growth and wood characteristics of Acacia hybrid are low and insignificant. It can be seen that the contribution proportion of the family is 0-4.47%, very low compared to the contribution of the clonal and residual. This proportion is expressed in all indicators and at different ages, but increases with age for the diameter and the height; with the highest proportion belongs to KLR and the proportion of 0 belongs to MoE_d.

Table 3.5. Effects of variance components on total phenotypic variance of traits

Ba Vi (3 years old)								
	$D_{1.3}$		**H**		**KLR**		**MoE_d**	
	Value	Proportion	Value	Proportion	Value	Proportion	Value	Proportion
Family	0.052	**1.11^{ns}**	9.78	**3.17^{ns}**	79.6	**4.47^{ns}**	0	**0^{ns}**
Row	0	0	0.01	0.53	30.3	1.7	0	6.05
Column	0.12	2.59	0.008	0.28	0	0	0	0
Clone	1.0	21.49	0.53	17.44	964.5	54.09	0.001	27.52
Error	3.51	74.82	2.42	78.58	708.7	39.74	0.003	66.43
Total		100		100		100		100
Dong Ha (3 years old)								
Family	0.015	**0.91^{ns}**	0.037	**5.13^{ns}**				
Row	0.003	0.17	0	0				
Column	0.14	8.41	0.09	13.08				
Clone	0.52	30.33	0.21	28.82				
Error	1.04	60.18	0.38	52.96				
Total		100		100				

Notes: Proportion: % of the total phenotypic variance, ns: not significant difference

The trial at Dong Ha also showed that the contribution of family component to the total phenotypic variance of the growth indicators was not significant. Similar to Ba Vi, the contribution of family in the trial in Dong Ha occupies 0.91 - 5.13%, which is very low compared to the contribution of the clonal factors and errors; such percentage is shown in all indicators and in different ages.

The effect of family on the growth of Acacia hybrid clones is nonsignificant, suggesting that there is possibility to select good clones in in a poor family and vice versa. Therefore, the selection of Acacia hybrid clones with fast growth should be conducted in many families. However, the results of this evaluation are only preliminary, and more age-related evaluation with more clones/families are needed to make more accurate conclusions.

3.3. Estimation of genetic parameters, genotype–environment interactions and genetic correlation among traits

3.3.1. Broad-sense heritability and genotypic coefficient of variation of growth and stem quality

Table 3.6. Broad-sense heritability (H^2) and genotypic coefficient of variation (CV_G) of growth and stem quality

Trait	**Unit**	**Average**	**Heritability (H^2)**	**CV_G (%)**
Ba Vi (3 years old)				
$D_{1.3}$	cm	8.27	0.19 ± 0.02	11.72
H	m	8.84	0.16 ± 0.02	7.92
Dtt	points	3.2	0.10 ± 0.02	6.70
Dttt	points	3.2	0.08 ± 0.02	7.84
Yen The (3 years old)				
$D_{1.3}$	cm	8.34	0.36 ± 0.03	13.08
H	m	11.47	0.39 ± 0.03	10.17
Dtt	points	3.45	0.17 ± 0.02	8.30
Dttt	points	3.25	0.14 ± 0.02	12.31
Dong Ha (3 years old)				
$D_{1.3}$	cm	5.92	0.33 ± 0.02	13.19
H	m	7.35	0.32 ± 0.02	7.77
Dtt	points	3.36	0.20 ± 0.02	7.93
Dttt	points	3.27	0.20 ± 0.02	12.23

Bau Bang (2 years old)				
$D_{1.3}$	cm	5.79	0.42 ± 0.03	19.99
H	m	8.39	0.33 ± 0.03	11.74
Dtt	points	3.42	0.09 ± 0.02	5.15
Dttt	points	4.99	0.07 ± 0.02	5.81

Analysis results showed that the heritabilities of growth traits were high, either stable or increased with age, such as in Yen The where the heritability of height at age 1 was 0.07 and increased to 0.35 and 0.39, respectively, at ages 2 and 3, while the heritability of diameter did not increase much but stabilized at all ages. At 3 years of age, the heritabilities of both diameter and height are high.

3.3.2. Broad-sense heritability and genotypic coefficient of variation of wood characteristics

The evaluation of the broad-sense heritability of the basic density at the sites shows that except for Ba Vi with the moderate heritability (H^2 = 0.26), the heritability in 2 other sites were high (H^2 = 0.47   0.49). The genotypic coefficient of variation of basic density were relatively low at all 3 sites (6.0   9.5%).

The evaluation of the broad-sense heritability and genotypic coefficient of variation of MoE_d shows that except for high values in Bau Bang (H^2 = 0.38; CV_G = 19.5%),the value at 2 other sites were low (H^2 = 0.20   0.29; CV_G = 7.4   9.2%).

Table 3.7. Broad-sense heritability and genotypic coefficient of variation of wood characteristics in Acacia hybrid clones

Trait	**Unit**	**Average**	**Heritability (H^2)**	**CV_G (%)**
Ba Vi (3 years old)				
KLR	g/cm^3	0.42	0.26 ± 0.05	5.98
MoE_d	GPa	7.16	0.29 ± 0.05	9.19
Yen The (3 years old)				
KLR	g/cm^3	0.43	0.47 ± 0.06	7.71
MoE_d	GPa	9.72	0.20 ± 0.07	7.42
Bau Bang (2 years old)				
KLR	g/cm^3	0.38	0.49 ± 0.05	9.49
MoE_d	GPa	8.02	0.38 ± 0.06	19.52

3.3.3. Genotype–environment interactions

Results of analysis of diameter and height growth of Acacia hybrid clones between pairs of sites Ba Vi - Yen The, Ba Vi - Bau Bang and Ba Vi - Dong Ha showed that genotypic correlations of growth trait between the 2 sites ranged from 0.03 to 0.69, indicating a strong genotype–environment interaction. This suggests that selection for increased growth should be site dependent to maximize genetic gains. Genotypic correlations between sites in height reduced with age from 1 to 3, while genotypic correlations between sites increased in diameter at age 3.

Correlation in wood density was very high between Ba Vi and Yen The (correlation coefficient = 1), relatively high between Ba Vi and Bau Bang (correlation coefficient = 0.51). The high correlation between the trials demonstrates the low level of interactions, which suggests that the clonal ranking order in basic density is not significantly different, especially between Ba Vi and Yen The. Unlike wood density, the correlation in MoE_d was 0.40 between Ba Vi and Yen The and 0 between Ba Vi and Bau Bang. This result shows that MoE_d is strongly influenced by site conditions.

3.3.4. Correlations between traits

Results of the analysis showed that the phenotypic and genotypic correlations between diameter and KLR and MoE_d were weak and non-significant at all sites, with phenotypic correlation coefficient r_p = -0.05 ÷ 0.29 and genotype correlation coefficient r_g = -0.29 ÷ 0.41.

Table 3.8. Genotypic correlation coefficient and phenotypic correlation coefficient in breeding trials in Ba Vi, Yen The and Bau Bang

Trait	**$D_{1.3}$**	**KLR**	**MoE_d**
Trial in Ba Vi			
$D_{1.3}$	*	0.41 ± 0.14	-0.29 ± 0.13
KLR	0.29 ± 0.05	*	0.45 ± 0.15
MoE_d	-0.05 ± 0.06	0.32 ± 0.04	*
Trial in Yen The			
$D_{1.3}$	*	0.26 ± 0.13	0.17 ± 0.29
KLR	0.10 ± 0.02	*	0.45 ± 0.14
MoE_d	-0.05 ± 0.05	0.41 ± 0.10	*
Trial in Bau Bang			
$D_{1.3}$	*	0.24 ± 0.28	0.03 ± 0.31
KLR	0.20 ± 0.05	*	0.57 ± 0.19
MoE_d	-0.01 ± 0.06	0.49 ± 0.04	*

Notes: Genotypic correlation coefficient (r_g - upper triangle data field) and phenotypic correlation coefficient (r_p - lower triangle data field).

Genotypic correlation tended to be higher than phenotypic coefficients in absolute values but with greater standard errors. The weak correlation between diameter and wood properties indicates that selection for increased growth would not significantly affect the wood properties. It further suggests the low possiblity to select some fast growing clone with good wood properties.

The phenotypic correlation and genotype correlation in KLR and MoE_d in all three trials were relatively high and positive (+), with phenotypic correlation coefficient $r_p = 0.32 \div 0.49$ and genotype correlation coefficient $r_g = 0.45 \div 0.57$ which indicates that increasing the basic density may also increase MoE_d.

3.4. Selection of new Acacia hybrid clones

Evaluation results at the 35-month age stage in the clonal trials at Dong Ha and Quy Nhon showed that there was a significant difference in growth and stem quality between the clones (Fpr < 0.001).

The best-growing group of Dong Ha trials included 16 clones with stem diameters of 24.80 - 35.20 dm^3/tree and the least significant difference in volume Lsd = 11.31 dm^3. Among them, the new Acacia hybrid clones BV523, BV585, BV564, BV268 and BV584 have an average stem volume of 32.3 dm^3, 38.6% higher than the average figure of the recognized varieties and 59.1% higher than the average figure of the entire experiment.

The fast growing group in the trial in Quy Nhon included 14 clones with the stem size of 25.20 - 34.00 dm^3/tree and least significant difference in volume Lsd = 9.48 dm^3, among them, the new Acacia hybrid clones BB055, BB026, BV376, BV586, BB033 had the average stem volume of 29.36 dm^3, 28.2% higher than the average figure of the recognized varieties (22.9 dm^3) and 48.3% higher than the average figure of the trial.

New Acacia hybrid clones grow fast, have the stem volume exceeded the recognized varieties with high stem quality index. The above study showed that 5 clones BV523, BV585, BV564, BB055, BB026 grow fast, have the stem volume of 28-38% higher than that of recognized varieties and need further consideration for recognition.

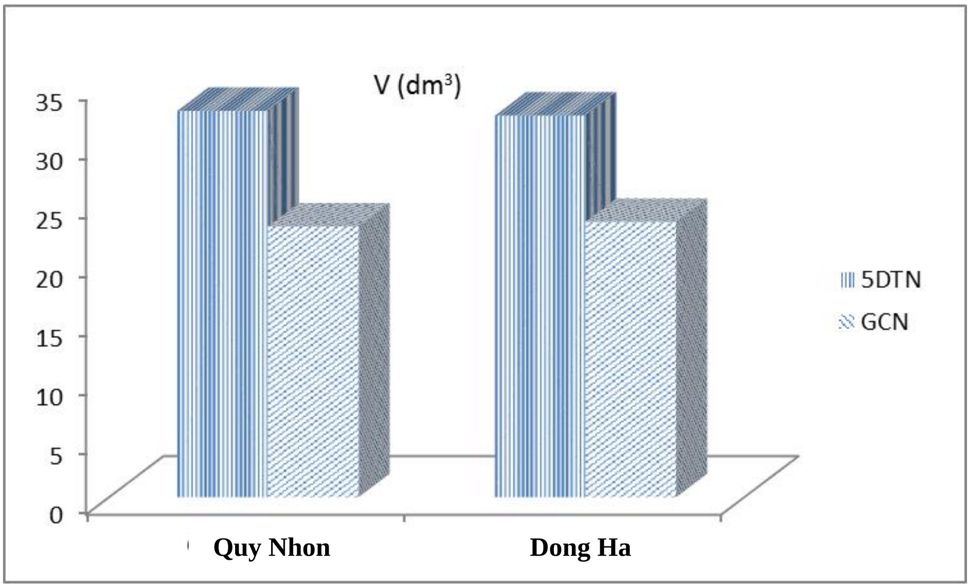

Figure 3.2. Comparison of the volume between the 5 best clones (5DTN) and recognized clones (GCN) in Quy Nhon and Dong Ha

CONCLUSION, SHORTCOMINGS AND IMPLICATION

1. Conclusion

1.1. Level of clonal variation among new selected Acacia hybrid

- At 2-3 years of age, growth and stem quality of the 550 varieties of Acacia hybrid selected from the 4 trials showed great variation and significant differentiation (Fpr < 0.001). In all 4 clonal screening trials, the average growth value and stem quality of the newly selected Acacia hybrid clones were lower than those of recognized Acacia hybrid varieties; however, the variation range was large. All 4 trials had the existence of clones with outstanding growth rate with the frequency of 5-10%, which showed the possibility of selecting new Acacia hybrid clones.

- At the age of 2 - 3, the basic density and modulus of elasticity of the wood of the newly selected Acacia hybrid clones in 3 trials in Ba Vi, Yen The and Bau Bang showed great variation and significant differentiation (Fpr < 0.001).

- In 4 clonal screening trials in Ba Vi, Yen The, Dong Ha and Bau Bang, the study has initially selected 23 potential Acacia hybrid clones with the stem volume of 10-40% higher than which of the recognized Acacia hybrid varieties. Among these clones, 3 clones BB064, BV469 and BV575 were initially identified to have relatively high growth rate, basic density and modulus of elasticity. These are the potential clones that need continuous evaluation for the selection of superior clones for production.

1.2. Effect of mother tree species and family to clone performance

- The mean value of the natural Acacia hybrid clones from the *A. mangium*'s mother trees showed superiority and significant differentiation (Fpr < 0.001) compared to natural Acacia hybrid clones from the *A. auriculiformis*'s mother trees. However, in the clonal screening trial in Ba Vi and especially in the trial in Bau Bang, some natural Acacia hybrid clones from the *A. auriculiformis*'s mother trees had outstanding growth rate compared to the recognized varieties and equivalent to which of the Acacia hybrid clones with the best growth rate from the *A. mangium*'s mother trees. This is important in the selection of Acacia hybrid varieties from different group of mother tree species for the selection for each ecological region.
- The level of differentiation between Acacia hybrid from the mother tree species - *A. mangium* and from the mother tree species - *A. auriculiformis* is insignificant in basic density and modulus of elasticity of wood.
- The effect of family on the expression of the Acacia hybrid clones is nonsignificant and negligiable. Therefore, the selection of Acacia hybrid clones for increased growth should be conducted in large number of families to increase the possibility of the selection of superior clones.

1.3. Applicable to the estimation of genetic parameters, genotype–environment interactions and genetic correlation among traits

- *Broad-sense heritability (H^2) and genotypic coefficient of variation (CV_G)*

- Broad-sense heritability of growth traits ranged from moderate to high (0.16   0.47) depending on location and tended to be stable with age and higher than those of the stem quality (0.07 - 0.20). The genotypic coefficient of variation of growth traits was also moderately high (7.77 19.99% at 2-3 years of age). This shows that it is highly possible to select clones of superior growth trait.

- Broad-sense heritability of wood basic density and modulus of elasticity was moderate to high (0.20 0.49), and tend to be higher than that of growth and stem quality at certain site. The genotypic coefficient of variation of wood basic density and modulus of elasticity were moderately low (5.98 9.49%) except for the value of modulus of elasticity in Bau Bang (19.5%).

- *Genotype–environment interactions*

The genotypic correlations between sites of growth traits were weak to moderate, demonstrating a relatively strong genotype-environment interaction between sites in growth traits. Therefore, the clonal selection should be conducted for each site condition or ecological area to maximize selection gain.

The genotypic correlations between sites of wood basic density was quite high, demonstrating a low genotype-environment interaction in such trait. In contrast, the correlations in the modulus of elasticity among the sites was very low or nonexistent, indicating a strong interaction among the sites in this character.

- *Genetic correlation among traits*

Genotypic correlation coefficient and phenotypic correlation coefficient between growth and wood properties were weak and non-significant. The results showed that the selection of Acacia hybrid clones for increased growth will not significantly affect the wood quality. Therefore, the selection of Acacia hybrid varieties for growth traits can be conducted independently of which for wood properties, but the possibility of selection of Acacia hybrid clones with both high growth rate and good wood properties is low.

1.4. On the selection results of promising clones

The 2 clonal trials found 5 clones BV523, BV585, BV564, BB055, BB026 with high growth rate, the stem size of 28-38% higher than which of recognized varieties and good steam quality. In the coming time there should be further evaluation to recognize the varieties and develop them in production.

2. Shortcomings

The objective conditions in hybrid selection, propagation and trial establishment partly influenced the results of some research contents. Moreover, the wood properties evaluated at the 2-3 years of age stage may not accurately reflect the wood properties at the mature stage.

3. Implication

Continuation of clonal trial evaluation to select clones with good growth traits at higher ages.

Continuation of clonal trial establishment to evaluate the growth, wood properties, pest and disease resistance of promising clones.

Studies of the wood properties were only limited to 2-3 years of age in wood density and modulus of elasticity. The evaluation at higher ages (technological maturity stage) and for some other important wood properties such as shrinkage, modulus of static bending and heart rot are needed for better evaluation of the wood properties of the Acacia hybrid clones to allow the selection of Acacia hybrid varieties with high growth rate and good wood properties for large timber supply.

LIST OF ARTICLES RELATED TO THE THESIS HAVE BEEN PUBLISH

1. **Do Huu Son**, Ha Huy Thinh, Nguyen Duc Kien, Duong Hong Quan, Nguyen Quoc Toan, Trinh Van Hieu (2016), "Genotypic variation on clones of *Acacia hybrid* at Yen The clonal test", *Vietnam Journal of Forest Science*, No. 4 - 2016 (pp. 4593 – 4602).
2. **Do Huu Son**, Ha Huy Thinh, Nguyen Duc Kien, Duong Hong Quan, Duong Thanh Hoa, Ngo Van Chinh (2017), "Performance of clones of *Acacia hybrid (Acacia mangium x A. auriculiformis and A. auriculiformis x A. mangium)* in North centre and South centre of Vietnam", *Sciecne and Technology Jounal of Agriculture & Rural Development*, No. 3 + 4 – 2017 (pp. 222 - 227).