Research and development of acacia hybrids for commercial planting in Vietnam

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Abstract:

"Acacia hybrids" refers to the inter-specific hybrids of *A. mangium* and *A. auriculiformis*, including natural, artificial and polyploid ones. The superiorities of selected acacia hybrid are fast growth, straight stem form, small branches, high productivity, and high ratio of wood utilisation. Acacia hybrids are recognized as having a higher pulping potential and greater soil improvement ability than that of the parental species, which may be shown to have 2.5-13 times larger numbers of nitrogen - fixing nodules on its roots in nursery stage. Mass propagation technology using both cutting and tissue culture has been successfully developed for acacia hybrid, enabling large-scale clonal forestry to improve plantation productivity and quality. The area of acacia hybrid plantations up to 2016 was estimated to be 500,000 ha, with an annual increase of 30,000-35,000 ha, making it the most widely planted forest tree variety in Vietnam. Acacia hybrids and propagation technologies have also been introduced in Malaysia, Indonesia, Thailand, Laos, and Cambodia. The research and development of acacia hybrid breeding can be considered as a revolution in the forestry sector and has created new and advanced approaches for both research and training in tree breeding in Vietnam.

Keywords: ***Acacia auriculiformis, Acacia hybrid, Acacia mangium, cutting propagation, nodules, tissue culture.***

Classification number: ***3.1***

Introduction

"Acacia hybrid" ("keo lai" in Vietnamese language) is a common name used to refer to the interspecific hybrids between *A. mangium* and *A. auriculiformis*. The name refers to several types of hybrids, including natural, artificial and polyploid ones.

The study of breeding and deployment of acacia hybrid varieties for commercial planting in Vietnam began in the 1990s when the area of land covered by forests had been reduced to 25%, and the yield of plantations was very poor (approx. 5-8 m^3/ha/year). At that time, there was no appropriate forest planting varieties selected, planting was mostly focused on "reforestation", and cutting propagation was being implemented only at an experimental scale, with no mass - production of clonal planting stock. The huge areas of denuded hills and barren land were mostly planted with a land race of *Eucalyptus camaldulensus* derived from the Binh Dinh area of Vietnam having very poor productivity, but using more water per unit volume of wood produced than other species, leading to just a few scattered planting areas; and thusly, this eucalypt variety was not accepted for production forestry in Vietnam.

At that time, *E. camaldulensis* (Petfordp rovenance) gave the highest yield of available planting varieties, but the yield was still less than 15 m^3/ha/year and this variety proved to be susceptible to leaf blight diseases, such as *Cylindrocladium* and *Kirramyces,* which defoliated the canopy of many plantations, resulting in a major loss of wood production.

Natural acacia hybrids have been observed in Malaysia [1, 2], Papua New Guinea [3] and Thailand [4]. Propagation of these acacia hybrids by tissue culture propagation was studied [5, 6]. However there was a propensity to use either seeds or untested clones of acacia hybrids for planting, and as a consequence, acacia hybrids were not developed for commercial planting in those countries.

Natural acacia hybrids were detected in 1993 in *A. mangium* plantations in some regions of Vietnam [7]. Although the acacia hybrid was found later than in other countries, it was quickly selected and developed for forestry production in Vietnam through the application of progresses in genetics and cytology.

With support from the Ministry of Agriculture and Rural Development (MARD), the Ministry of Science and Technology (MOST), and relevant international organizations, as well as the active engagement of forest growers, there are now more than 500,000 ha of acacia hybrid plantations throughout the country.

The superior characteristics of acacia hybrids

Fast growth, straight stem form and small branches

Acacia hybrids have proven to be superior to both *A. mangium* and *A. auriculiformis* for their traits, that provide both high plantation productivity and commercial wood yield, as observed in trials in Vietnam [8]. In morphological characteristics of phyllodes, flowers, pods, and bark, acacia hybrids are intermediate between *A. mangium* and *A. auriculiformis* (Fig. 1).

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Fig. 1. Phyllode (above) and young pod (below) of *A. mangium* (left), acacia hybrid (middle), and *A. auriculiformis* (right).

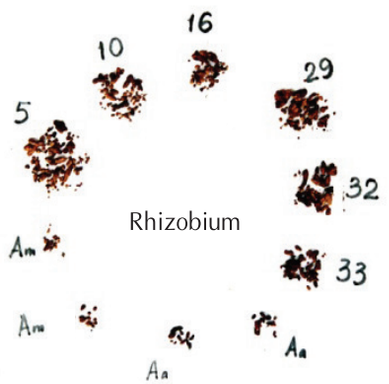

Fig. 2. Nodules on roots of acacia hybrids of its parental species at the nursery stage.
1. 5, 10, 16, 29, 32, 33 are acacia hybrid clones: BV5, BV10, BV16, BV29, BV32, BV33.
2. Am means *A. mangium* cutting; Am means *A. mangium* seedling.
3. Aa means *A. auriculiformis* cutting; Aa means *A. auriculiformis* seedling.

Higher pulping potential

Kraft pulp yield of acacia hybrids was 51.1%, whereas that of both *A. auriculiformis* and *A. mangium* was less than 48%. Paper produced from acacia hybrids has a tensile-strength and folding-strength ranging from 7,700-8,420 m and 2,000-3,000 times, respectively. These values are higher than the corresponding values of 5,460 m and 1,200 times for *A. mangium* and 6,270-6,300 m and 1,700-2,000 times for *A. Auriculiformis* [9].

Better nitrogen fixing potential

At the nursery stage, the number of nitrogen - fixing nodules on acacia hybrid roots range from 39.9-80.3 nodules per sapling, 2-13 times greater than the values for the parental species (Fig. 2) and equal to 0.39-0.47 g per sapling in weight, which is 2.6, 70 times greater than the parental species (0.075-0.15 g per sapling). The total number of bacteria *(Rhizobium*) in one gram of soil from under an acacia hybrid is 1,760 million, 5-17 times higher than that of the parental species (101-386 million), and 96 times higher than the soil samples collected in barren land (18.4 million). These parameters indicated that acacia hybrids have a significantly higher potential for soil improvement than both *A. mangium* and *A. auriculiformis* [10].

Research on acacia hybrids and plantation expansion over time

Research on breeding and development of acacia hybrid varieties for commercial planting in Vietnam can be described as to occur during two major periods:

The period of 1993-2000

Natural acacia hybrids in *A. mangium* trial areas was discovered in Vietnam.

Biological, morphological characteristics, and variations in growth, pulping potential, wood properties, and soil improvement abilities of natural acacia hybrid were determined.

The segregation and regression of second generation (F_2) acacia hybrids that demonstrated the need for vegetative propagation of selected clones was studied.

Research and the development of techniques for cutting and tissue culture propagation were performed.

A clonal test of acacia hybrids at large scales in different ecological regions throughout the country was established.

Research on artificial hybridization, and evaluating the differences among acacia hybrid varieties by molecular markers was performed.

The period of 2000-2015

Protocols for cutting-tissue propagation for acacia hybrids were completed, installed, and widely applied in many forest tree enterprises, as well as the development of acacia hybrid germplasms in Vietnam.

Research on artificial hybridization was continued, breeding new acacia varieties using new strategies, such as generating acacia triploids that are expected to be sterile and fast growing (Fig. 3), complete with early selection and testing trials.

The transfer of germplasm and propagation technology for some forest research and production units in the country was implemented; for instance, the Nguyen Hanh Company in Binh Dinh conducted the WB3 Project in the five provinces of Central Vietnam, and other South East Asian countries, including Indonesia, Thailand, Cambodia, and Laos.

Fig. 3. Segregation of F_2 acacia hybrid seedlings exhibits the morphology of *A. mangium, A. auriculiformis,* and others.

Major research activities for acacia hybrids in Vietnam

After discovering and completing basic research, acacia hybrids were propagated via cuttings. Clonal tests were established in many regions in Vietnam, meanwhile, other research was being carried out, including studies of tissue culture propagation, fertilizer application, drought tolerance assessment, and genetic fingerprinting of clones using molecular markers.

Clonal tests

Acacia hybrid clonal tests were established from 2000 to 2015 in many provinces of Vietnam, including in Yen The (Bac Giang), Ba Vi (Ha Noi), Yen Thanh (Nghe An), Binh Dien and Phu Loc (Thua Thien - Hue), Quy Nhon (Binh Dinh), Long Thanh (Dong Nai), and Bau Bang (Binh Duong). All of these tests verified the superior productivity of these acacia hybrid clones, with mean annual incremental growth of 2-3 times that of the best provinces of *A. mangium* and 3-10 times the best provenances of *A. auriculiformis* [11-16] (Table 1).

Fingerprinting of acacia hybrid clones by molecular makers

At the end of the 1990s, with support provided by Australian molecular scientists [17], a set of molecular markers was used to recognize the identity of acacia hybrid clones selected and field - tested in North Vietnam (BV5, BV10, BV16, BV23, BV27, BV32, and BV33). Two microsatellite markers, namely Am030 and Am435, proved to be suitable to identify the differences among the seven tested acacia hybrid clones. At later stages, in addition to these two markers, another eight markers: Am136, Am164, Am387, Am396, Am460, Am484, Am502, and Am770, also proved suitable to recognize the differences and identity of all (both previous, and newly selected and field-tested) acacia hybrid clones [18].

Research on artificial hybridization between A. Mangium and A. auriculiformis

Methods from recent research of artificial hybridization was implemented aiming to generate cross-combinations between either *A. mangium* and *A.*

Table 1. Growth of acacia hybrids in some clonal tests in the period of 2000-2015.

No.	Germplasm	Growth traits			Mean annual increment (m^3/ha/year) (75% survival)
		D_{BH} (cm)	H (m)	V (dm^3)	
A	**Natural acacia hybrid (Nah) clones**				
1	*Ba Vi (Ha Noi) (2000-2009)*				
	7 best Nah clones	16.5-19.2	16.5-16.8	178.3-249.7	24.7-34.5
	A. mangium (Pongaki)	11.9	11.8	76.8	10.6
	A. auriculiformis (Coen R.)	6.3	7.9	14.6	2.0
2	*Yen Thanh (Nghe An) (2000-2008)*				
	7 best Nah clones	15.2-17.6	18.8-20.7	194.4-260.4	30.3-40.5
	A. mangium (Pongaki)	12.0	15.0	100.7	15.7
	A. auriculiformis (Coen R.)	7.4	8.2	19.1	3.0
3	*Bau Bang (Binh Duong) (1999-2004)*				
	7 best Nah clones	13.7-14.3	17.8-21.1	144.0-164.4	33.5-41.1(1)
	A. mangium (Pongaki)	122.4	16.0	120.0	14.5(1)
	A. auriculiformis (Coen R.)	9.4	12.2	106.9	4.1(1)
4	*Long Thanh (Dong Nai) (2005-2010)*				
	5 best Nah clones	14.4-14.7	-	452.4-500.9	42.2-43.3
5	*Quy Nhon (Binh Dinh) (2008-2015)*				
	6 best Nah clones	14.6-16.0	18.6-20.1	175.3-208.4	30.3-38.5
	A. mangium (Pongaki)	11.6	15.6	103.2	10.3
	A. auriculiformis (Coen R.)	9.3	13.8	56.6	4.8
B	**New natural acacia hybrid (NNah) clones**				
6	*Phu Loc (Thua Thien - Hue) (3/2011-9/2014)(2)*				
	3 best NNah clones	13.2-13.5	11.9-12.6	83.3-89.0	29.5-31.7
	BV10	13.2	12.5	87.3	31.0
7	*Ba Vi (Ha Noi) (2011-2014)*				
	4 best NNah clones	11.3-12.2	10.1-11.0	61.3-73.6	25.4-30.5
	BV32, BV33, and BV73	11.0-11.1	9.8-10.4	47.3- 55.4	19.6-23.0
8	*Yen The (Bac Giang) (2012-2015)*				
	5 best NNah clones	10.5-11.5	13.1-13.3	57.3-68.4	23.9-28.4
	BV16, BV33, and BV73	9.7-10.1	12.8-13.7	48.6-52.9	20.2-21.9
C	**Artificial acacia hybrid (Aah) clones**				
9	*Ba Vi (Hanoi) (2001-2008) (at Cam Quy)*				
	3 best Aah clones	13.7-14.0	13.0-13.3	97.9-108.8	15.4-16.2(1)
	A. mangium (Pongaki)	10.3	10.8	53.7	8.4(1)
	A. auriculiformis (Coen R.)	7.8	9.0	25.1	3.9(1)
10	*Binh Dien (Thua Thien - Hue) (2003-2008)*				
	3 best Aah clones	12.0-12.5	12.7-13.3	78.1-81.0	27.8-28.8
	BV16	12.1	13.3	80.8	28.7
D	**Triploid acacia hybrid (Tah)**				
11	*Song May (Dong Nai) (8/2014-11/2015)*				
	TahX101	7.51	7.53	16.87	-
	BV10	6.66	6.75	12.44	-
	BV16	6.21	7.27	11.18	

Note: (1) Productivity was calculated based on survival; (2) New acacia hybrid clones recently selected.

auriculiformis, or reciprocal backcrosses to the parent species. In a period from 1997-2015, many cross - combinations were produced and tested in the field. Some outstanding individual clones were selected in comparison with the best provenances of the parental species (Table 1) [11, 19].

Initial research on breeding acacia hybrid triploids

Within the framework of research cooperation between Vietnam's Institute of Forest Tree Improvement and Biotechnology (IFTIB) and Australia's University of Tasmania (UTAS) and Commonwealth Scientific and Industrial Research Organization (CSIRO), under sponsorship of the Australian Centre for International Agriculture Research (ACIAR), research on breeding of acacia triploids commenced in 2003.

Acacia triploids were created by hybridization between 4n *A. mangium* which are quite slow-growing [20] and the fast-growing *2*n *A. auriculiformis* in the hybrid orchard at Bau Bang (Binh Duong province). Preliminary results of field tests at Song May (Dong Nai province) showed that at the age of 15 months after planting, triploid hybrid clone X101 is growing faster than (diploid) acacia hybrids BV10 and BV16, whereas at Dong Ha (Quang Tri province) at the age of one year X101 was growing faster than acacia hybrid BV10, but slightly slower than BV16 [21] (Fig. 4).

Fertilizer application and drought tolerance of acacia hybrid clones

Three different fertilizer treatments that were applied before planting consisted of 2 kg of cattle manure + 100 g superphosphate; 2 kg of cattle manure + 300 g NPK (5:10:3), and 6 kg of cattle manure that indicated that in Ba Vi, acacia hybrid stem volume increased by 63-119% compared with a control sample (no fertilizer) at a three year-old plantation. Treatment of 2 kg of cattle manure + 200-300 g superphosphate increased volume by only 20% over the control [8]. Although fertilizers, such as NPK and superphosphate, that incorporate phosphorus increased growth rate of acacia hybrids in the first one to three years after planting, and the addition of a large dose of P does not greatly increase wood yield of acacia hybrids over a full crop rotation, as shown by the results of more recent experiments in Binh Phuoc [22] and Quang Tri.

Fig. 4. Acacia hybrid triploid and BV16 (15 months) at Song May commune (picture from Nghiem Quynh Chi, 2015).

Identification of drought tolerance through some cytological indices, e.g. transpiration intensity, ostomic pressure of the leaf, wilting rate…, determined that the most drought-tolerant clone at the nursery stage was BV32.

Cutting and tissue culture propagation

Regression and segregation of acacia hybrid in the second generation (F_2):

In terms of growth, tree height and diameter at breast level over bark (D_{BH}) of F_1 acacia hybrid cuttings at 22 months, reached 5.8 m and 6.1 cm, respectively, at Ba Vi, North Vietnam. By comparison, F_2 acacia hybrid seedlings and pure species seedlings ranged from 3.8-4.3 m in height and 3.7-4.5 cm in diameter (60-70% of the values of the F_1). Regarding phyllode morphology, the segregationof F_2 acacia hybrid seedlings yielded 16.4% similar to *A. mangium*, 50.1% intermediate between *A. angium* and *A. auriculiformis*; 27.3% similar to *A. auriculiformis*; and 6.2% were misshapen [8]. It was concluded that F_2 seedlings collected from acacia hybrid trees should never be used for plantation forestry because of the strong regression and segregation (Fig. 4).

Acacia hybrid vegetative propagation by cuttings and tissue culture:

Tissue culture in acacia hybrids reported by Darus using basic Murashige and Skooge (MS) medium supplemented with 6-Benzylaminopyrine (BAP) 0.5 mg/l for shoot multiplication and river sand for rooting, obtained a 70% rooting rate [5, 6]. In Vietnam, tissue culture propagation was first studied by Nguyen Ngoc Tan, *et al*. [23], and studies were continued by Doan Thi Mai, Ngo Minh Duyen, Le Son, and others (Fig. 5).

Fig. 5. Acacia hybrid tissue culture plantlets (left) and cuttings (right)
Note: Tissue culture plantlets have bipinates, pimates and phyllodes whereas the cuttings just have phyllodes (picture from Doan Thi Mai).

Another effective propagation method is by rooting stem cuttings. This was first implemented by Le Dinh Kha and others to propagate the first acacia hyrid clones in Vietnam. In late 1999, Le Dinh Kha *et al.* used tissue culure plantlets of seven acacia hybrid clones to root directly on sterile river sand in Malaysia and obtained a rooting rate of 97.8-100% after one month [11]. Plants that are re-captured into tissue culture from clonal ramets grown in the field and propagated by tissue cultures display rejuvenation, in comparion with plants produced by repeated serial rooting of cuttings. The technology combining tissue culture and cutting (*tissue culture - cutting propagation technology*) was therefore recommended as the most effective propagation method to introduce acacia hybrids into mass-production, and also to maintain the physiological vigour of acacia hybrid clones.

Outstanding achievements in acacia hybrid research and development

Application of genetic principles and cytological technologies on forest tree breeding has led to the key successes of acacia hybrid research and development Vietnam, getting its start from the discovery until deployment and utilization of hybrid vigor together with clonal forestry for plantations. This success contributed to a new approach in forest tree improvement of other species.

Acacia hybrid research and development programs have utilized natural variations, which are characteristics of long - lived tree species, as well as actively generating new sources of variation through artificial hybridization, tetraploid induction and infertile triploid production, early selection and molecular genetic application. Some triploid clones now under field testing are of great interest to national and international forest tree breeding organizations.

In general, selected acacia hybrid varieties have demonstrated higher yield, better stem quality, higher pulp yield, and potential for soil improvement than the parental species (in spite of their being developed 12-15 years later than in other countries).

At present, the package of acacia hybrid germplasms and propagating technologies have been transferred to many forest tree production units, leading to a mass movement of acacia hybrid planting in Vietnam that contributed remarkably to increase deplantation productivity, enhanced awareness of the importance of tree breeding to plantation forestry, decrease deforestation, and increase forest cover as well as protecting environmental values in Vietnam.

Fig. 6. Cuttings area of acacia hybrids with mist sprinklers in Binh Dinh.

Development of acacia hybrids in Vietnam and other regional countries

Procedure for acacia hybrid propagation and clonal plantation

Acacia hybrids have rapidly developed into an operational scale after being successfully mass - propagated by cutting and tissue culture technology. The practical procedure for acacia hybrid propagation and clonal plantation was written by the Research Centre of Forest Tree Improvement (RCFTI) and issued by Ministry of Agriculture and Rural Development (MARD) under Decission No. 3092 QD/BNN-KNCN dated 22/10/2006. Then, a series of training courses on cutting-tissue culture technology and germplasm transfer for a number of relevant organizations in Vietnam was organized through collaboration between RCFTI and the Department of Agriculture and Forestry Extension of MARD (Fig. 6).

Germplasm and propagating technology transfer

The period of 1996-2000:

Acacia hybrid varieties and propagation technology were transferred to the Japanese company, Oiji Pulp and Paper Corporation, located on Quy Nhon (Binh Dinh), Ho Chi Minh City Seeds Joint Stock Enterprise, Yen Lap (Quang Ninh), Quy Nhon (Binh Dinh), and Luong Son Agro-Forestry Companies (Hoa Binh).

The period of 2000-2015:

The implementation of transfer courses to numerous forest tree research and production centers in the whole country continue on a scale from two to ten million saplings per year.

The technical courses, together with a semi-automatic sprinkler irrigation system, were transferred to many Forestry Farms and even households, particularly in Binh Dinh (Fig. 6). 152 million acacia hybrid plantlets were also produced in 2014, but that still did not meet the demand for varieties for plantation forestry within the province and other Central Highland provinces.

Protocols for rejuvenation of some major acacia hybrid planting clones such as BV10, BV16, and BV32 were completed; following these protocols, they have retained their superiority in growth rate and other stem quality traits over 20 years.

At present, the Institute of Forest Tree Improvement and Biotechnology (IFTIB) has played consultative role in acacia hybrid breeding and development for Vietnam Paper Corporation, Tan Mai Paper Corporation, An Hoa Paper Company, and Vietnam Forest Corporation.

Development of acacia hybrids for plantation forestry in provinces of Vietnam

In 1997, the area of acacia hybrid plantations was 1,300 ha, however by 2001,

Table 2. Estimates of current areas and ratio of acacia hybrids in the period of 2010-2014 in some provinces of central Vietnam [24].

Province	2010		2011		2012		2013		2014		Mean ratio (%)
	Area (ha)	*Ratio (%)*	*Area (ha)*	*Ratio (%)*	*Area (ha)*	*Ratio (%)*	*Area (ha)*	*Ratio (%)*	*Area (ha)*	*Ratio (%)*	
Quang Binh	1,938	40.5	2,911	55.5	3,167	64.0	2,100	48.8	4,080	58.4	53.4
Quang Tri	959	20.5	-	-	1,670	26.5	2,000	34.8	3,000	50.1	33.0
Th.Thien - Hue	3,800	87.8	4,220	84.6	3,543	84.3	3,510	88.1	2,807	69.3	82.8
Da Nang	275	29.5	196	65.2	605	62.1	350	70.0	150	21.4	49.6
Quang Nam	5,106	16.4	-	-	295	18.0	-	-	1,179	64.9	33.1
Quang Ngai	6,400	76.2	4,707	73.0	3,930	70.5	5,000	71.4	-	-	72.8
Binh Dinh	8,665	89.1	-	-	9,296	96.4	9,164	96.1	9,103	93.3	93.7
Phu Yen	7,719	93.0	1,506	47.1	2,469	61.3	-	-	4,749	77.4	69.7
Khanh Hoa	550	43.7	478	74.9	1,450	73.2	1,050	53.1	1,300	76.2	64.2
Binh Thuan	2,483	59.1	1,863	62.8	2,573	80.8	-	-	2,500	78,.1	70.2
Total area	**37,895**		**15,881**		**28,998**		**23,174**		**28,868**		**62.3**

it had increased to 10,200 ha. According to Vietnam Forestry Administration's statistical data in 20 provinces, the total area of acacia hybrid plantations reached 179,890 ha in the period 2010-2014 [24].

Another report by the Australia International Economy Centre (funded by ACIAR) estimated that total area of acacia hybrid up to 2004 was 127,000 ha with an annual increase of 37,000-46,000 ha occupying 24% of total forest plantation area in Vietnam.

Following the data issued by Forestry Departments of 20 provinces, it was 25,000-45,000 ha, occupying 30-40% of total forest areas in country. In only 10 provinces located from North Central to Coastal South Central Vietnam such as Quang Ngai, Thua Thien - Hue and Binh Dinh, where the harbors were suitable for wood chip export, and having active Forestry Projects of WB3 funded by World Bank, acacia hybrid planting areas increased to 70-90% of total annual planting area (Table 2).

Transferring acacia hybrid clones and propagation technology to foreign counterparts

Many regional forestry organizations noted the results of research and development of acacia hybrids in Vietnam.

Since 1996 acacia hybrid varieties have been introduced for testing and planting through multinational companies such as the Oiji Pulp and Paper Corporation of Japan located in Quy Nhon (Binh Dinh), and the Ta Ann Sarawak Plywood Production Corporation of Malaysia (1999), Indonesia (2002), and Cambodia (2003).

Subsequently, acacia hybrid varieties were transferred or exchanged to Thailand Tree Breeding Research Centre (Royal Forestry Department), Forestry Research Institute of Malaysia (FRIM), Guangzhou Tropical Forestry Research Institute (China) via a collaboration of RCFTI, and Salwood Ltd. Company (Australia).

Recently, technology transfer courses for Kasetsart University of Thailand and Forestry University of Laos as well as Stora Enso (Sweden - Finland) and Birla (India) corporations in Laos have been implemented.

Fig. 7. ACIAR's research program managers at a pruning trial in Long Dai Forestry Company in Quang Binh 2003. Dr. C. Hardner (left) and former manager Dr. J. Fryer (center).

Benefits from acacia hybrid research

Scientific and technological benefits

Research of acacia hybrids has created a new approach to forest tree breeding, which leads to numerous studies of plant physiology, biotechnology, silviculture, and wood processing. As a result, there have been a series of national and international projects implemented in Vietnam, and many scientific papers published, as well as MSc & PhD candidates trained (Fig. 7 and Table 3).

Table 3. Publications related to acacia hybrid.

	Type of publication	Number
A	*Author group*	
1	Monograph books	7
2	Papers published on national journals	28
3	Papers published on international journals	11
4	MSc theses	4
5	PhD theses	1
B	*Other authors*	
1	Books	1
2	Papers published on national journals	88
3	Papers published on international journals	17
4	MSc theses	62
5	PhD theses	5

Socio - economic and other benefits

Economic benefits:

The productivity levels of highest quality acacia hybrid clones is 20-40 m^3/ha/year, higher than that of *A. mangium* at 12-18 m^3/ha/year (Table 1).

Local timber markets reported that mean productivity of acacia hybrids was 25 m^3/ha/year while *A. mangium* was only 15 m^3/ha/year.

Given the current economic conditions, acacia hybrid plantations could benefit by 280 billion VND per year compared with *A. Mangium,* because annual total areas of acacia hybrid plantation harvested in Vietnam is 35,000 ha with stable price of 800,000 VND/m^3 (35,000 ha x 10 m^3/ha/year x 800,000 VND/m^3 = 280,000,000,000 VND).

Social and environmental benefits:

Apart from faster growth rates, higher productivity, a high measure of wood utilization, and greater paper strength,

acacia hybrids carry more nitrogen - fixing nodules than *A. mangium* and *A. auriculiformis* resulting in better soil quality and adaptation. In addition, acacia hybrids are easy to propagate via cuttings; making selected clones readily available; therefore, it has been adopted well by growers for planting over the country generating a national planting movement.

Planting acacia hybrids is not only for reforestation and short - term harvest, but also for increasing local people's income, especially people living in remote areas. It has also contributed significantly to hunger and poverty alleviation and environmental improvement.

It can be said that development and use of acacia hybrids has created a movement in forestry research and training in Vietnam.

Conclusion

"Acacia hybrid" is a common name to refer to the interspecific hybrids of *A. mangium* and *A. auriculiformis*, and can be separated into natural, artificial and polyploid hybrids.

The superiority of acacia hybrids over the parent species is present in its fast growth, straight stem form, small branches, high productivity, and high recovery of commercial wood.

Acacia hybrids have been recognized as having a higher pulping potential and greater capacity for soil improvement.

Mass propagation through cutting and tissue culture technologies has been successfully developed for acacia hybrids, generating uniform planting material of selected clones to improve plantation productivity and quality.

Up to 2016 year, the area of acacia hybrid plantations are estimated to be about 500,000 ha and this is expanding at about 30,000-35,000 ha per year, making it the most widely planted forest tree variety in Vietnam. Its propagation technology has also been introduced into other ASEAN countries.

The research and development of acacia hybrid breeding can be considered as a revolution in the forestry sector and has created new and advanced approaches for both research and training in tree breeding in Vietnam.

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