Review: Utilization of interspecific *Acacia* hybrid for pulp/paper industry and increasing of forest biodiversity

S Sunarti and A Nirsatmanto

Center for Forest Biotechnology and Tree Improvement Research and Development Jl. Palagan Tentara Pelajar Km. 15, Purwobinangun, Pakem, Sleman, Yogyakarta, Indonesia

Email: narti_nirsatmanto@yahoo.com; nartinirz@biotifor.or.id

Abstract. Wood-based forestry industries are one of the strategic sectors in the development for providing a good impact in ecological and socio-economic in a country. Such an industry should have high productivity in order to ensure sustainable resources and an efficient manufacturing process. Based on this fact, tree breeding program is one of the good practices which could be done through the hybridization method to increase the uses from forest genetic resources. This paper presents a review on the basis of the utilization of inter-specific *Acacia* hybrids resulted from hybridization between two species of *Acacia mangium* and *Acacia auriculiformis* for supporting the pulp/paper industry and increasing the forest biodiversity in Indonesia. Improving some traits relevant to the industrial requirements is the main target in the development of *Acacia* hybrid. This involves fast growth, good wood properties, and tolerance to pests and diseases. The *Acacia* hybrids could provide some advantages in overcoming the current problems of the forest plantation and industry in which some of them could not be resolved by planting the pure species. In addition, the varies of the *Acacia* hybrid progenies could be used to increase forest biodiversity, which is important as a genetic base for further breeding purposes and challenges.

1. Introduction

Wood-based forestry industries are one of the strategic sectors in the development for providing a good impact in ecological and socio-economic in a country. Facing global competitiveness, such industry should have high productivity in order to ensure the sustainable resources and an efficient manufacturing process. Pulp and paper industries are one of the most important industries in Indonesia among the others five huge commodities which had significantly supported the national foreign exchange [1]. Ministry of Industry Republic Indonesia reported that the Indonesian pulp industry is the sixth biggest in the world, while the paper industry is the tenth biggest [2].

In South East Asia region, Indonesia is one largest pulp and paper manufacturing countries which produce around 11 million tons of pulp and 16 million tons of papers per year [3]. APKI [2] also reported that such industries are projected to grow 5% every year with good global markets opportunities. However, to support the production capacity of the industries, the availability of wood raw materials should be adequate and sustain. This is because wood is the major raw material for the most of pulp paper and industries in Indonesia. Unfortunately, the gaps of supply and demand tend
to increase due to various problems in forest plantation, including the low productivity stand and quality of the wood produced and the threat of pest and disease attacks as well [4].

The high productivity of the pulp and paper industry should be supported by the high stand productivity and good wood quality as raw materials. High stand productivity is commonly obtained from the appropriate species selection, which is eligible in fast growth, short rotation, good quality of wood properties. In the facts, growth and some of the wood properties show an adverse correlation which becomes a problem in improving stand productivity as a whole. In addition, pest and disease attacked and marginal of site conditions could be other serious problems in the plantation [4]. Therefore, finding an alternative species is necessary to find out other potential tree species which is more productive and eligible to industry.

Forest tree breeding through a hybridization program is a good practice to get the appropriate alternative species [5]. Some Acacias species have become major species for plantation to supply the raw materials in pulp and paper industry in Indonesia. Moreover, inter-specific hybridization as a crossing between Acacia mangium and Acacia auriculiformis to produce a new variety of Acacia hybrid has been successfully practiced. Some studies reported that the Acacia hybrid showed a good vigor as a combination of good characteristics from each parent tree species [6,7]. It was suggested that the Acacia hybrid vigour has many advantages to solve some current problems which are facing by the pulp and paper industry in maintaining high quality and sustain a supply of raw materials. In addition, the Acacia hybrid is also expected to increase the forest biodiversity in Indonesia due to the high variety of their phenotypic characters.

This paper presents a review in the utilization of inter-specific Acacia hybrid as a new potential alternative species for pulp/paper industry and increasing of forest biodiversity, particularly referencing with the Indonesia condition. The review would focus on the benefit of Acacia hybrid relating to raw materials suitable for industrial need as compare to the pure parent species which is commonly used in the current forest plantation. In addition, the benefit from a high variation of the Acacia hybrid progenies to increase forest biodiversity is also discussed.

2. Acacia hybrid and forestry industry

2.1. Acacia hybrid

A hybrid plant is an offspring that is resulted from sexual hybridization, or in common, it is also defined as a crossing/matting between two unlike genotypes of parent trees [6,8]. According to Allard [9] and Kha [7], the hybridization between the two different genotypically parents will produce the first generation of hybrids containing the new combination of genes that lies between both parent trees. While Chaudhary [5] stated that hybrid is a heterozygous individual trees resulting from the cross of two unlike parents. For the most foresters, the hybridization is defined as offspring obtained from the crosses between two species or between the two different geographic races within the same species [10]. The hybrids progenies are heterozygous individual which is usually vigorous. This is often referred as hybrid vigor or heterosis [5]. Heterosis usually relates to trait of size or any measurably characteristic such as wood quality, tolerance to pest/disease, and in certain condition it also includes precocity in flowering and yields [4,7,8,11]. In practices, there are many types of hybrid depending on the scheme of crossing [4,7].

There are four types of hybridization based on the parent trees crossed which could produce a various of the hybrid progenies [6]. The first two types are hybridization within the same species including the hybridization between different variant or strain for producing intra-varietal hybrid, and that between different varieties for producing inter-varietal hybrid. Both of them could be then classified as intra-specific hybrid. These two types are commonly practiced on crops improvement program such as rice (Oriza sativa), wheat (Triticum aestivum) and other crop [5], in which the process could be simple or complex depending upon the number of parent trees involved [5,10,12].
The type three of hybridization is inter-specific hybrid or intra-generic hybrid that is referred as hybridization between two species belonging to the same genus. Type four is inter-generic hybrid that is referred to as hybridization between species from two different genera. These two types of inter-specific hybridization are commonly practiced for forest tree species, such as for the genus of *Quercus* (oak), *Juniperus* (juniper), *Picea* (spruce), *Pinus* (pine), *Populus*, *Larix*, *Eucalyptus* (eucalypt), *Acacia* and others [6,8,13].

Figure 1. *Acacia* hybrid breeding strategy [14]
In Acacias species, the term of Acacia hybrid is an inter-specific hybrid which is resulted from a crossing between parental species of Acacia mangium and A. auriculiformis (Figure 1) [6,15]. The Acacia hybrids may be obtained from naturally or artificially hybridization whether A. mangium as female or male parent tree [3,4,13]. The first observation of natural Acacia hybrid was done on 1972 in Sabah and then in UlU Sedili, Johor, Malaysia [7,16]. These observations reported that the hybrids is as vigor as A. mangium and showed a better branching and lighter color bark than A. mangium. Some further studies reported that the Acacia hybrid’s vigor or heterosis exhibited a fast growth, cylindrical and straight stems, better wood quality, more adaptive to marginal lands and more tolerance to pests/diseases attacked than the both of the parental species [11,17,18]. Based on its superiority, Acacia hybrid has been further developed and commercially grown in plantations in Malaysia [6] Vietnam [19] and become a promising species in Thailand [19,20] and Indonesia [14].

In Indonesia, a comprehensive Acacia hybrid breeding program was started on 1999s through establishing a hybrid seedling orchard (HSO) in Wonogiri, Central Java, which is managed under the Centre for Forest Biotechnology and Tree Improvement (CFBTI). The HSO composed of 2000 selected parent trees from two species of A. mangium and A. auriculiformis to produce natural Acacia hybrid seeds (A. mangium and A. auriculiformis). For improvement, the breeding strategy has been further updated in 2009 [14] (Figure 1). The such improvement was taken place including an artificial Acacia hybrid program through establishing a hybrid breeding garden from marcotted superior parent trees of A. mangium and A. auriculiformis. The 44 clones of Acacia hybrids obtained from the such artificial hybridization have been tested in clonal trial. Based on the growth traits improvement, some superior hybrid clones have been selected based on height growth and it has been registered to the Variety Plant Protection. Further selection to find the Acacia hybrids clones related to others traits, such as wood properties and tolerance to pest and disease attacked is still in progressing to support raw material supply for pulp/paper industry.

2.2. Potency of Acacia hybrid for pulp/paper industry
Pulp and paper industries require a good quality raw material to produce a higher quality of pulp/paper. Several big private companies of pulp/paper industry in Indonesia have their own plantation to supply raw material of wood. Two Acacia species of A. mangium and A. crassicarpa are major species of the plantation. The advantages of A. mangium are fast growth, straight stem form and easy on silvicultural system, particularly for the dry-land area. While the A. crassicarpa is recognized as the one available of species for the peat-land area. However, currently A. mangium plantation showed an extremely reducing on productivity due to a serious disease attacked by Ganoderma spp and Ceratocystis sp. Although a clear evidence of resistance is not available, it is suggested that the Acacia hybrid could be used as an alternative species to A. mangium due to a high tolerance rate of the A. auriculiformis as parental trees [4].

The current problems of the stand productivity had caused only around 70% of raw materials for pulp and paper industries could be supplied by domestic industrial forest plantation, while the remained 30% should be imported [3]. Therefore, productivity and quality of industrial plantation forest should be increased. Looking for the alternative new forest plants species which faster growth, better wood quality, shorter rotation, eco-friendly and more tolerance to pest and disease that is eligible the needs of the fiber-based industry, such as Acacia hybrid is crucial to be done.

Acacia hybrid vigor is expected to have some new characteristics which is a combination desirable characters of the their both pure parent species. Many studies reported that Acacia hybrid were more superior than the female and male parents (heterosis) [14,21]. Moreover, some characteristics of Acacia hybrid vigor are faster growth, better stem circularity and lighter branching than A. mangium with the wood properties and its tolerance to pest/disease is as good as on A. auriculiformis [7,20]. In addition, the Acacia hybrid is also adaptive on some adverse environment conditions. Sunartii et al [14,22,23] reported that the Acacia hybrid showed a good growth in Central
Java, Riau and Jambi which had differences on soil type, precipitation and daily temperature. These studies suggested that the *Acacia* hybrid showed a high adaptability on many types of soils, such as vertisol, marine clay, spodosol and ultisol with various climate types.

In case of wood and pulp properties, the wood from *Acacia* hybrid is reported to be high potential for raw materials of pulp/paper due to a good fiber dimension and its derivate properties. Yahya et al. [24] reported that natural *Acacia* hybrid wood was appropriate for pulp and paper manufacturing. Some wood properties showed a longer fiber, higher slenderness ratio, proportion of fibers than *A. mangium* and *A. auriculiformis*. In addition, it also had a lower proportions of vessels, parenchyma cells and extractives. The hybrid tended to have thinner cell walls, smaller proportion of ray cells, smaller coefficient of rigidity and lignin content, and higher flexibility coefficient and wood density than *A. mangium*. Based on these properties, the *Acacia* hybrid could produce a higher pulp yield and give better paper higher slenderness ratio, higher proportion strength than *A. mangium* and *A. auriculiformis*.

A study from a breeding program using artificial *Acacia* hybrid showed that the fiber dimension and derived properties of superior hybrid clones from full-diallel artificial hybridization between *A. mangium × A. auriculiformis* were suitable for raw materials of pulp and paper industry, even some of them showed an outstanding values [25]. Based on Pulp Requirement Standard Scores [26], the fiber dimension and derived properties of *Acacia* hybrid wood either from natural or artificial showed a higher total scores as compared to those of *A. mangium* wood as one of pure parent trees.

3. *Acacia* hybrid for forest biodiversity

3.1. Characterization of *Acacia* hybrid

Indonesia is one of the major biodiversity country which covers 11 percent of the world’s plant species. Acacias species including *A. mangium* and *A. auriculiformis* are native to eastern part of Indonesia, namely island of Sula, Ceram, Aru, West Papua and Maluku islands [6]. The *Acacia* hybrid, a hybridization between *A. mangium* and *A. auriculiformis*, could produce new combination of genes expressing an inherited characteristics of parent trees species, whether under the desirable or undesirable characteristics [8]. The characteristics of *Acacia* hybrids obtained from natural or artificial hybridization will have different genes combinations which could be reflected on their phenotypes [26] from the seedling in nursery level up to the mature trees.

The phenotypes of *Acacia* hybrid in the nursery level varied, and it is dominated by intermediate characters between their pure parent species [7,26]. The phenotype variation of *Acacia* hybrid seedling is easy to be recognized using leaves, stem node, and stem form patterns, which indicates that the seedlings could be genetically varied. Assessment using at least 12 different morphological characters showed that the *Acacia* hybrid seedling clearly varied (Figure 2). The varies in morphological could be also observed after field planting (Figure 3).

The phenotype of 6 months mature trees of natural *Acacia* hybrid varied, especially on stem form, branch form, leaves shape and leaves size patterns (Figure 3). The stem form was straight to crooked with the light to heavy branching and small to medium leaves. The leaves features were dominated by the intermediate between both parental species, while some others were similar to *A. mangium* or *A. auriculiformis*. The tree phenotypes of variation within the *Acacia* hybrid indicated that the genetic diversity could be high, although further verification using molecular marker is necessary.

The variation of *Acacia* hybrid was also observed in the further growth after field planting [27]. The height growth variation on 1 year of *Acacia* hybrid trees varied ranging from 0.5 m to 4.48 m [14]. The best growth was characterized by straight stem, light branching and good diameter, while the worst was heavy branching to scrubby form. The such growth classes were then categorized into superior, intermediate, and inferior. The intermediate class was the most abundance (50%) than the superior (25%) and inferior (25%). It indicated that the genetic of *Acacia* hybrids are diverse and
tend to be different from the both parent species. It suggested that the genetic diversity on the *Acacia* hybrid could enrich the forest biodiversity in Indonesia.

![Figure 2](image_url)

**Figure 2.** Phenotype variation of natural *Acacia* hybrid seedling (Source: Internal report [28])

![Figure 3](image_url)

**Figure 3.** Phenotype variation of natural *Acacia* hybrid (*A. mangium* × *A. auriculiformis*) at 6 months after planting (Photo: Sri Sunarti [28])

### 3.2. Molecular marker in developing of *Acacia* hybrid

As described in preceding paragraph, the phenotype character of the *Acacia* hybrid is easy to be recognized using morphological marker, such as the development of leaf pattern, stem, barkstem,
branching and other morphological characters. The morphological marker is useful for identification and selection of the Acacia hybrid in the nursery stage (seedling) and on mature trees in the field. Beside the morphological markers, more advanced technology using molecular markers could be used for recognizing of the Acacia hybrid [14].

In term of the molecular marker, a sequence-characterized amplified region (SCAR) marker has been developed for Acacia hybrid using a basis from species specific marker of A. mangium and A. auriculiformis [29]. Binding pattern of Acacia hybrid is marked by presence of 400 bp and 900 bp as a combining of the base pair of A. mangium and A. auriculiformis (Figure 4). The SCAR marker is usually needed for identifying the natural Acacia hybrid when the similarity characteristic to the parent species is high. However, if the natural Acacia hybrid showed a clear characteristic, identification using the molecular marker is not necessary. This is because the accuracy of morphological marker from mature trees could reach 100% [14]. This is similar for the Acacia hybrids resulted from the artificial hybridization which usually produce undoubtedly the hybrid offspring.

Figure 4. Binding pattern resulted from electrophoresis using agarose 1,2% with ethidium bromide staining and primer R01 (Sources: Sunarti et al. [14])

4. Conclusion
Natural and artificial Acacia hybrid showed a high potential as raw material for pulp and paper industry, particularly on the stand productivity and the wood properties of fiber dimension and derivates. Acacia hybrid vigor could show a heterosis as indicated by a better performance than both of parental species in term of stand productivity, wood properties, and tolerance to pest/disease. Such benefits of the Acacia hybrid would be important in overcoming the current serious problem on the declining stand productivity of forest plantation due to the high intense of pest and disease attacked and a lower site adaptability as well. Beside the potential for pulp and paper industry, the varied of Acacia hybrid phenotypes from the nursery level (seedling) up to mature tree could potentially increase the Indonesian forest diversity. This is important to maintaining genetic base for further tree breeding purposes in anticipating future challenges in forestry industry and biodiversity.

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