Integrated disease management to control gall rust disease on the seedling and sapling of *Falcataria moluccana*

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**Abstract.** Several control methods have been developed to control the disease caused by *Uromycladium falcatariae*. However, it is still used a single approach that may not receive satisfactory results. This study applied integrated disease management that consisted of physical, chemical, and biological approaches to reduce gall rust disease incidence. In the nursery, the control methods used were selecting nursery location, applying the biological agent *Trichoderma* sp., and regular spraying with fungicides. Meanwhile, after planting, the control methods used were regularly spraying with fungicides, pruning the infected tissues, and fertilizer application. Three active ingredients were used for fungicide application: tebuconazole, a mixture of azoxystrobin and difenoconazole, and tribasic copper sulfate. The result showed no gall rust disease incidence in the seedling until it was ready for planting (4 months old). In addition, the application also gave positive results on seedling growth performance compared to the control. After planting, the incidence of gall rust disease can be reduced between 16.5-32.5% when the saplings were three months old and 14.3-26.3% when the saplings were ten months old. Fungicide with the active ingredient, a mixture of azoxystrobin and difenoconazole, showed more effective protection against gall rust disease infection compared to other active ingredients.

1. **Introduction**

Pest and disease management is one of the crucial things for the sustainability of forest crop production. Various pests and diseases have been reported to cause significant yield losses in various forest crops in Indonesia. Two diseases on acacia, stem wilt-cancer caused by *Ceratocystis* and root rot caused by *Ganoderma* have forced some industrial plantations to change their Acacia to Eucalyptus [1]. An outbreak of sup sucker *Tingis beesoni* caused severe defoliation, dieback, and tree death on thousands of hectares of *Gmelina arborea* plantation in Java [2, 3]. The pests and diseases also cause significant yield losses in *sengon* (*Falcataria moluccana*). The bagworm pests, cerambycid borer *Xystrocera festiva*, and gall rust disease caused by *Uromycladium falcatariae* are the major pests and diseases in *sengon* causing significant yield losses [4, 5].

The epidemic of gall rust disease has occurred in almost all *sengon* plantations in Java since 2006 [5, 6]. Reduction of wood yield due to this disease can reach more than 60% [7]. *Sengon* is the most dominant plant in community forests, with a population of nearly 50% [8]. Meanwhile, based on national wood production data, overall, *sengon* wood production in Indonesia is the third-largest after acacia and eucalyptus [9]. As the most dominant tree in small-scale forest plantations [8], reducing *sengon* wood...
production due to pests and diseases may affect the wood supply for community forest-based wood industries.

Several control methods developed to control the gall rust disease still used a single chemical approach, such as applying lime sulfur [10] and copper-based fungicide [11]. Several cultivation approaches such as fertilizers, pruning, and mixed planting were reported to correlate with the gall rust disease incidence [12]. Therefore, integrated disease management consist of both physical, chemical, and biological approaches that need to be applied to reduce gall rust disease incidence. In this study, various approaches such as selecting nursery locations, using biological agents, organic and chemical fertilization, eradication, and chemical control were applied from the seedling to planting scale to control gall rust disease.

2. Materials and Methods

2.1. Location

The nursery for seedling production was in Resort Pemangkuan Hutan (RPH) Jatirejo, Bagian Kesatuan Pemangkuan Hutan (BKPH) Pare, Kesatuan Pemangkuan Hutan (KPH) Kediri. This location was chosen due to it is far from the source of the gall rust pathogen inoculum. In addition, the climatic conditions at this location are less favorable for disease development.

The location for planting the tree was in compartment 105, RPH Pandantoyo, BKPH Pare, KPH Kediri. RPH Pandantoyo was chosen because it is a gall rust disease-endemics area. Previously, the disease incidence was extremely high and the yield losses due to this disease could be more than 60% [7]. Therefore, compartment 105 was chosen due to the preliminary survey's highest gall rust disease incidence compared to the other compartment. The altitude of this location is about 400 m asl (above sea level). According to Schmidt and Fergusson climate classification, the type of climate in the area is a C type with an average rainfall of 2000–2200 mm year\(^{-1}\). The minimum temperature in this area is 20\(^\circ\)C, and the maximum temperature is 32\(^\circ\)C, with humidity levels ranging from 56-82.5%.

| Table 1. Treatments for Falcataria moluccana seedling. |
| Code | Seeding treatments | Frequencies |
|------|--------------------|-------------|
| A    | Application of tebuconazole (430 g L\(^{-1}\)) with dose of 0.2 ml L\(^{-1}\) water | every month |
|      | - Bioagent *Trichoderma* sp. with dose 2 g per polybag | once |
| B    | Application of a mixture of azoxystrobin (200 g L\(^{-1}\)) and difenoconazole (125 g L\(^{-1}\)) with dose 0.2 ml L\(^{-1}\) water | every month |
|      | - Bioagent *Trichoderma* sp. with dose 2 g per polybag | once |
| C    | Application of tribasic copper sulfate 92.6% with dose 0.5 g L\(^{-1}\) water | every month |
|      | - Bioagent *Trichoderma* sp. with dose 2 g per polybag | once |
| D    | Combination of application of fungicide A, B, and C | every month |
|      | - Bioagent *Trichoderma* sp. with dose 2 g per polybag | once |
| E    | Application of foliar fertilizer (N 11%) with dose 2 ml L\(^{-1}\) water | every month |
|      | - Bioagent *Trichoderma* sp. with dose 2 g per polybag | once |
| K    | No treatments | - |

2.2. Seedling treatments

Before sowing, the seeds were soaked in a fungicide solution containing the active ingredient tebuconazole 0.2 ml L\(^{-1}\) for 30 minutes. After that, the seeds were rinsed with water to remove the fungicide residue. The seeds are then soaked in hot water (temperature ± 80\(^\circ\)C) and allowed to cool. The drained seeds were then sown in wet sacks and tightly closed to speed up germination. After the closure
was carried out for three days, the seeds were directly planted in polybags. The seedling medium used was soil + compost with a ratio of 3:1. The polybags were then covered with a shading net until the seeds germinated. Finally, the seedlings were maintained until it was ready for planting.

A trial of seedlings' protection from gall rust infection consists of five treatments and one control is carried out as presented in Table 1. It was the combination of applications of the biological agent *Trichoderma* sp. and regular spraying with fungicides. *Trichoderma* sp. was applied once before planting the seeds in polybags with a dose of 2 g per polybag. Fungicide used in this study were tebuconazole (430 g L\(^{-1}\)), a mixture of azoxystrobin (200 g L\(^{-1}\)) and difenoconazole (125 g L\(^{-1}\)), and tribasic copper sulfate 92.6%. We used a completely randomized design with each treatment used 400 seedlings and three replications.

Table 2. Treatments for *Falcataria moluccana* after planting.

| Code | Planting treatments | Frequencies |
|------|---------------------|-------------|
| A    | Application of tebuconazole (430 g L\(^{-1}\)) with dose of 0.2 ml L\(^{-1}\) water | every two months |
|      | Organic fertilizer  | once         |
|      | Dolomite fertilizer | once         |
|      | Pruning             | every two months |
| B    | Application of a mixture of azoxystrobin (200 g L\(^{-1}\)) and difenoconazole (125 g L\(^{-1}\)) with dose 0.2 ml L\(^{-1}\) water | every two months |
|      | Organic fertilizer  | once         |
|      | Dolomite fertilizer | once         |
|      | Pruning             | every two months |
| C    | Application of tribasic copper sulfate 92.6% with dose 0.5 g L\(^{-1}\) water | every two months |
|      | Organic fertilizer  | once         |
|      | Dolomite fertilizer | once         |
|      | Pruning             | every two months |
| D    | Combination of application of fungicide A, B, and C | every two months |
|      | Organic fertilizer  | once         |
|      | Dolomite fertilizer | once         |
|      | Pruning             | every two months |
| E    | Application of foliar fertilizer (N 11%) with dose 2 ml L\(^{-1}\) water | every two months |
|      | Organic fertilizer  | once         |
|      | Dolomite fertilizer | once         |
|      | Pruning             | every two months |
| K    | No treatments       |              |

2.3. Planting treatments
Four months old seedlings were planted in compartment 105, RPH Pandantoyo. A trial of integrated disease management to reduce gall rust disease incidence consisted of five treatments on a five hectares area (one hectare for each treatment), as presented in Table 2. It was a combination of the application of organic and chemical fertilization, disease eradication, and regular spraying with fungicides. Organic fertilization was applied once at the time of planting. Chemical fertilization was applied once at three months after planting.
2.4. Measurement of growth performance and disease incidence

Plant height measurement was carried out for the seedlings when the seedling was 2 and 4-months old. The disease incidence was measured by census routinely every month. Meanwhile, for the saplings, the disease incidence was measured at 3 and 10-months old trees. The disease incidence (DI) was measured with formula as follow:

\[
DI = \frac{\text{Numbers of plant infected}}{\text{Numbers of plant observed}} \times 100\%
\]

3. Results and Discussion

3.1. Gall rust disease management in the seedling level

Some approaches applied to sengon seedling include selecting nursery locations, using biological agents, and regular spraying with fungicides. The results showed that there was no gall rust disease infection while the seedlings were in the nursery. The treatments also did not have a negative effect on the seedling. Otherwise, it had a positive effect on seedling growth performance. As presented in Figure 1, the average plant height in the treatment was higher than the control both in the second month and the fourth month of observation. For two months old seedlings, the highest average plant height was shown by treatment B, which was 22.9 cm, and followed by treatments A, C, E, and D, which were 21.8, 20.8, 20.2, and 19.8, respectively. The same result was also shown for four-month-old seedlings, with treatment B showing the highest average plant height.

![Figure 1](image-url)  
**Figure 1.** Growth performance of 2- and 4-months old seedling. A-E = Treatments, K = Control.

The nursery is located at an altitude of 140 m above sea level. Around the nursery, there were no gall rust diseases were recorded. Therefore, this location was ideal for a sengon nursery because it is far from the source of the inoculum and the climatic conditions did not support disease development. According to the National Academy of Sciences [13], the principle of this disease control was disease avoidance. With this approach, we can eliminate the initial inoculum of the disease and reduce the infection rate. This approach may be the most dominant factor in why there is no gall rust infection on sengon seedlings. This hypothesis was based on the absence of gall rust infection in control.

The growth performance of sengon seedlings in the treatment was higher compared to the control. It is presumably due to the role of the biological agent *Trichoderma* sp. In previous studies, this fungus
was also reported to increase the growth of *sengon* seedlings [14]. *Trichoderma* spp has been widely used as a biological agent against various plant pathogens. For example, the fungus directly suppresses soil pathogens and can induce systemic plant defense against foliar pathogens [15, 16]. Trichoderma has also been known to play a role in plant growth by several mechanisms, including increased nutrient uptake and fertilizer utilization [17, 18].

![Figure 2](image)

**Figure 2.** Gall rust disease incidence of 3- and 10-months old sapling. A-E = Treatments, K = Control.

![Figure 3](image)

**Figure 3.** Reduction of disease incidence 3- and 10-months old sapling. A-E = Treatments.
3.2. Gall rust disease management in the sapling level

The results for 3-month-old saplings showed that the gall rust disease incidence was varied for each treatment (Figure 2). The minor disease incidence was shown in treatment B, which was 7.5%. The further subsequence of disease incidence from the smallest was treatment A, D, C, and E, 15.7, 16.5, 20.5, and 23.5%, respectively. The disease incidence in all treatments was smaller than that of the control, which was 40%. It means that the treatments can reduce gall rust disease incidence significantly. The reduction was varied, ranged from 16.5 to 32.5% (Figure 3).

Meanwhile, when the sapling was 10-month-old, the minor disease incidence was shown in treatment D (Figure 2). Treatment B, which had the most negligible incidence when it was three months old, became the second smallest with a value of 20%. The reduction of gall rust disease incidence after 10-month-old was still significant. However, the reduction was smaller compared to disease incidence when it was 3-month-old. The reduction of gall rust disease incidence at 10-month-old was ranged from 14.3 to 26.3% (Figure 3).

The study site was chosen because it indicated the highest gall rust disease incidence compared to the other compartment. In addition, the surrounding of this location was mature trees with high severe gall rust disease infection; thus, the source of gall rust pathogen inoculum was very abundant. Therefore, when the trial at this location can reduce gall rust disease incidence, it may also be applicable in other locations.

The use of chemical fungicides seemed to play an essential role in reducing infection and disease progression. Fungicide with the active ingredient a mixture of azoxystrobin and difenoconazole showed more effectiveness in protecting the tree from gall rust disease infection than other active ingredients. However, combination treatment with tebuconazole and copper sulfate seemed to increase its effectiveness against gall rust disease. Azoxystrobin is a group of Strobilurins. It has a broad spectrum against all major fungal from Oomycota, Ascomycota, and Basidiomycota Division [19]. Azoxystrobin was reported effectively against some rust diseases, such as bean rust caused by *Uromyces appendiculatus* [20] and coffee leaf rust caused by *Hemileia vastatrix* [21]. The mode of action of Azoxystrobin is to prevent the synthesis of ATP and thus interfere with fungal respiration. Meanwhile, Tebuconazole is a 14α-Demethylase inhibitor fungicide. It is a new azole, and in addition to 14α-Demethylase, it has a site of action on sterol biosynthesis [22]. Tebuconazole was reported to significantly reduce yellow rust (*Puccinia striiformis*) and brown rust (*Puccinia triticina*) attack in wheat [23].

Another approach, application of organic fertilizers, dolomite, and pruning, may also reduce gall rust infection. Pruning can reduce the source of the inoculum so that reinfection of the pathogen can be reduced. In addition, dolomite contains calcium and magnesium. These two compounds play a role in cell wall synthesis; thus, their deficiency may lead to susceptibility to the pathogen [24, 25].

4. Conclusion

There was no gall rust disease infection at the seedling level. Selection of nursery locations, the use of biological agents, and regular spraying with fungicides effectively prevented the seedling from the gall rust disease infection. Further treatment using organic and chemical fertilization, pruning, and chemical fungicide application at the sapling level could reduce gall rust disease infestation. Thus, the integration of various physical, chemical, and biological control methods seems to be promising in reducing gall rust disease infestation.

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Author's contribution
All authors contributed equally to this work as the main contributor.