Central Mindanao University
Journal of Science
ISSN Print: 0116-7847 ISSN Online: 2704-3703

Gall Rust Disease Incidence and Severity in a Falcata (Falcataria moluccana (Miq.) Barneby & J.W.Grimes) Plantation Grown from Select Mother Trees in Mindanao, Philippines

Adrian M. Tulod[1], Jupiter V. Casas[2], Mark Jun A. Rojo[3] Lowell G. Aribal[1], Uzzi Kobe Yitzhak F. Libayao[1], and Brian Rey L. Monteroso[1]*

Forest Biological Sciences Department[1]
Forest Resources Management Department[2]
Wood Science and Technology Department[3]
College of Forestry and Environmental Science, Central Mindanao University,
Musuan, Maramag, Bukidnon, 8714 Philippines

ABSTRACT

It remains unknown whether there are available gall rust resistant seed sources of Falcata (Falcataria moluccana (Miq.) Barneby & J.W.Grimes) in the country or elsewhere. This study was conducted to obtain baseline data for future progeny selection of gall rust resistant clones of Falcata in the region. The objectives were to determine whether there are available seed sources or mother trees in the region that are resistant to gall rust, and whether gall rust infection has negative effects on the growth of Falcata. The trial (with 130 mother trees as treatments and four replications) was assessed in November 2020- or five-years following establishment in 2015. Mean percent incidence (15.0 ± 5.0% to 80.0 ± 14.1%) and severity (3.75 ± 1.25%) to 35.0 ± 16.95%) of gall rust varied significantly among treatments indicative of genetic diversity among mother trees. The incidence ranged from 'occasional' to 'widespread' while severity ranged from 'low' to 'high' with mother trees 99 (Mutia, Zamboanga del Norte) and 106 (Magsaysay, Baliangao, Misamis Occidental) emerged as the most resistant of all. Height and diameter were positively related to gall rust incidence and treatments only, although none of the mother trees with resistant traits had superior growth. There was however indication of growth and disease tolerance tradeoff where trees with higher gall rust incidence tend to grow bigger perhaps to compensate for any negative impacts from gall rust infection.

Keywords: Falcataria moluccana, gall rust, incidence, severity, seed sources

INTRODUCTION

Commercial tree plantations, commonly referred to as Industrial Tree Plantations (ITPs), are important sources of wood and income for wood industries and tree farmers in the Asian region beside other important functions for the environment such as carbon sequestration and soil protection. However, the monoculture-type of planting of commercial tree plantations often expose them to disease infestation or outbreak especially from disease-causing parasites that are usually restricted to parasitizing a few or single host family, genus, or species. Falcata (Falcataria moluccana (Miq.) Barneby & J.W.Grimes), for instance, is the only known host plant to falcataria gall rust fungus (Uromycladium falcatarium sp. nov. Doungsa-ard, McTaggart & Shivas) (Doungsa-ard et al., 2015). This fungus is identified as closely related to acacia gall rust fungus (U. tepperianum (Sacc.) McAlpine), which has over 100 known host plants although mostly from Mimosoideae clade (Morris, 1987). Uromycladium falcatarium is distinguished from other Uromycladium species by the presence of three one-celled fertile teliospores on the pedicel (McAlpine, 1905 as cited by Doungsa-ard et al., 2015). The germination percentage of U. falcatarium spores was observed to reach up to 100% just within three hours from infection (Rahayu et al., 2020). The typical symptoms of rust fungus include a "rust-coloured" (often orange or yellow) pustule on plant shoots or leaf, petiole and rachis deformation, die-back of seedlings, stunting of affected trees or death in more extreme cases (e.g. massive defoliation of tree crowns) (McKenzie, 1998; McTaggart et al., 2015; Rahayu et al., 2018). The devastating impact of U. falcatarium infestation in Falcata plantations has been reported in Malaysia and Indonesia (Rahayu et al., 2010), and Timor-Leste (Old & Dos Santos Cristovao, 2003). The disease was first detected in the Philippines in 1988 and since then the control measures are limited to removal of infected trees or cessation of planting of Falcata in high elevation areas (i.e., >250 m above sea level) (Anino, 1994; Braza, 1997) as incidence/severity of the disease is known to increase with elevation.

Like other countries in the south-east Asia, the Philippines is heavily dependent on commercial tree plantations for wood, which means that the impact of disease infestation on wood production has wide-

Corresponding author:
Adrian M. Tulod
Email Address: amtulod@gmail.com
Received: Aug. 10, 2021; Accepted: Jan. 4, 2022

ranging effects both for the economy and livelihood of small-holder tree plantation farmers. About 82% of wood production in the country are coming from commercial tree plantations especially Falcata as part of the Philippine government's management effort to reduce pressure on remaining natural forests. Falcata is a valuable multi-purpose tree species, and with the moratorium on the cutting and harvesting of timber in natural and secondary forests in the Philippines (cf. Executive Orde No. 23), most wood industries especially in Mindanao have been utilizing wood mainly from Falcata tree plantations to produce lumber, veneer, and plywood (PCAARRD, 2010). In terms of exports, Falcata lumber comprises the bulk or 72% of the country's forest-based exports (PCAARRD, 2010).

Most tree plantations in the country even overseas (cf. Baird, 2014; Lugo, 1997; Semwal et al., 2013) are established in degraded lands to facilitate forest successions or where cultivation of agricultural crops is not anymore suitable and profitable to farmers. Such practice along with the vulnerability of monocultures to disease infestation is likely responsible for the country's poor wood production rate from tree plantations that is below the national and global standards. Wood production rate in the country is only about 632,574 m^3 or 0.006 m^3 per capita (Forest Management Bureau-DENR, 2019), which is about twice lower than the world's average production rate of 0.5 m3 per capita (Bruinsma, 2002).

It remains unknown whether there is available gall rust resistant Falcata population or seed sources in the country. Such resistant population or seed sources is critical for long-term breeding program and in reducing gall rust impacts in Falcata plantations. Moreover, current knowledge is also not clear whether gall rust infestation in Falcata plantations has negative impact on growth to warrant a massive effort especially in breeding for resistance. Previous experience with other rust diseases of major plantation species in Australia and India indicates that without selection for resistant traits, breeding programs could result in highly susceptible population of trees (Old et al., 2000).

This study was conducted to assess the incidence and severity of gall rust disease in a Falcata plantation established from a select number of mother trees or a total of 130 seed sources in Mindanao. Specifically, the objectives of the study were to determine: 1) whether there are available seed sources or mother trees in the region that are resistant to gall rust, and 2) whether gall rust infection has negative effects on the growth of Falcata. The results of this study will provide a benchmark for future selection of resistant clones and to achieve maximum productivity.

METHODOLOGY

Study Site

This study was conducted in November 2020 in an existing Falcata progeny trial established in 2015 within Central Mindanao University landholding in Musuan, Bukidnon, Philippnes (07° 52′ 51′′ North and 125° 03′ 48″ East) (Figure 1). The study site which is about three hectares has an elevation of around 600 m above sea level. The area had an average annual rainfall of 6.18 mm based on the four-year climate data (2017-2020) from the nearest weather station. The mean annual temperature ranged from 19.89°C to 33.80°C, while relative humidity ranged from 90.86% to 92.85%.

Sampling design

The Falcata progeny trial was established in a randomized complete block design (RCBD) (Appendix Figure 1) with progenies of 130 different mother trees (as treatments) from 36 different locations in Mindanao (Table 1). Mother trees from the same origin were treated as different treatments in this study as they were kilometers away (at least 2 kilometers away) from each other. The treatments were replicated four times with each treatment or mother tree consisted of five trees. A total of 2,600 Falcata trees were assessed in the study excluding three rows of buffer trees around the trial. The plantation has a 2 m x 3 m spacing and because of this proximity, each replication was divided into 13 plots to facilitate the measurement of incidence and severity of gall rust disease on a per plot basis. Each plot had a dimension of 10 m x 30 m and covered a total of 50 Falcata trees with a random

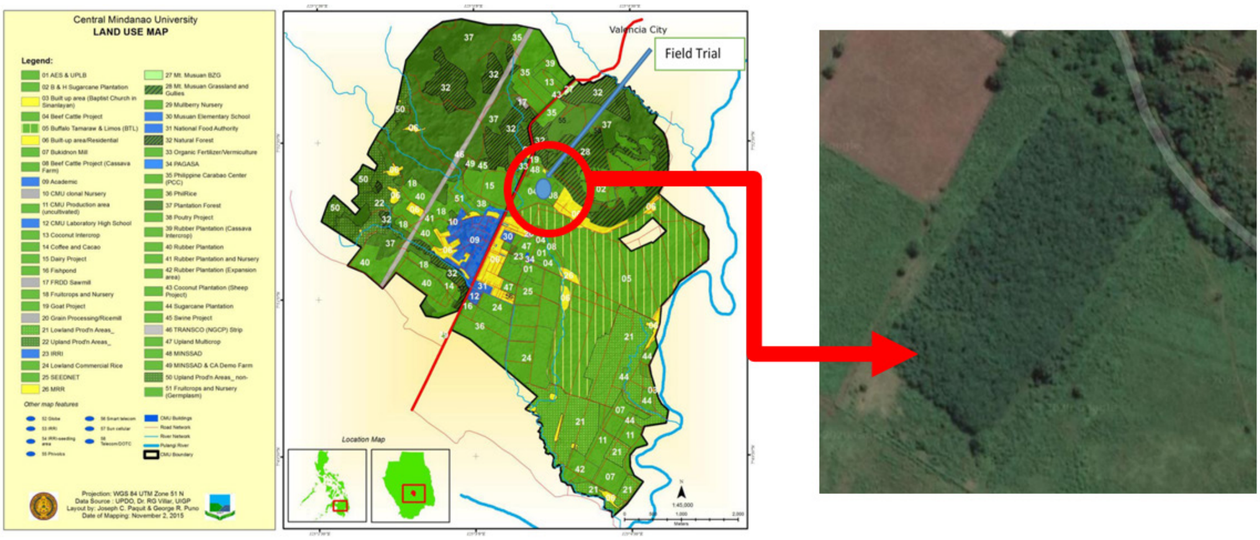

Figure 1. Location of the Falcata field trial in Musuan, Maramag, Bukidnon.

Table 1. Place of origin of the different mother trees in the Falcata progeny trial in CMU, Musuan, Bukidnon. The number in the first column represent the number code of each mother tree in the trial. Note that mother trees from the same origin were treated as different treatments in this study as they were kilometers (at least 2 kilometers) away from each other.

Mother Tree	Origin
1	Brgy. Rawari Kitaotao Bukidnon
2	Brgy. Rawari Kitaotao Bukidnon
3	Brgy. Rawari Kitaotao Bukidnon
4	Brgy. Rawari Kitaotao Bukidnon
5	Dalirig, Manolo Fortich, Bukidnon
6	Dalirig, Manolo Fortich, Bukidnon
7	Dalirig, Manolo Fortich, Bukidnon
8	Miaray, Dancagan, Bukidnon
9	Dalirig, Manolo Fortich, Bukidnon
10	Dalirig, Manolo Fortich, Bukidnon
11	Dalirig, Manolo Fortich, Bukidnon
12	Dalirig, Manolo Fortich, Bukidnon
13	Miaray, Dancagan, Bukidnon
14	Miaray, Dancagan, Bukidnon
15	Dalirig, Manolo Fortich, Bukidnon
16	Dalirig, Manolo Fortich, Bukidnon
17	Himaya Colambugon, Maramag, Bukidnon
18	Himaya Colambugon, Maramag, Bukidnon
19	Himaya Colambugon, Maramag, Bukidnon
20	Himaya Colambugon, Maramag, Bukidnon
21	Guinoyoran, Valencia City Bukidnon
22	Miaray, Dancagan, Bukidnon
23	Guinoyoran, Valencia City Bukidnon
24	Guinoyoran, Valencia City Bukidnon
25	Minsapinit, Gingoog City Misamis Oriental
26	Minsapinit, Gingoog City Misamis Oriental
27	Guinoyoran, Valencia City Bukidnon
28	Guinoyoran, Valencia City Bukidnon
29	Guinoyoran, Valencia City Bukidnon
30	Guinoyoran, Valencia City Bukidnon
31	Guinoyoran, Valencia City Bukidnon
32	Guinoyoran, Valencia City Bukidnon
33	Guinoyoran, Valencia City Bukidnon
34	Maribucao, Gingoog City Misamis Oriental
35	Tagpako, Gingoog City Misamis Oriental
36	Minsapinit, Gingoog City Misamis Oriental
37	Minsapinit, Gingoog City Misamis Oriental
38	Minsapinit, Gingoog City Misamis Oriental
39	Kabulakan, Balingoan Misamis Oriental
40	Kabulakan, Balingoan Misamis Oriental
41	Kabulakan, Balingoan Misamis Oriental
42	Mapua, Talisayan Misamis Oriental
43	Mapua, Talisayan Misamis Oriental
44	Mapua, Talisayan Misamis Oriental
45	Mimbunga, Gingoog city Misamis Oriental
46	Bangbang, Medina Misamis Oriental
47	Hubang, San Francisco Agusan del Sur
48	Hubang, San Francisco Agusan del Sur
49	Hubang, San Francisco Agusan del Sur
50	Sukailang, Surigao del Norte
51	Sukailang, Surigao del Norte
52	Sukailang, Surigao del Norte
53	Sukailang, Surigao del Norte
54	San Jose, Prosperidad, Agusan del Sur
55	San Jose, Prosperidad, Agusan del Sur

Mother Tree	Origin
56	Hubang, San Francisco Agusan del Sur
57	Hubang, San Francisco Agusan del Sur
58	Hubang, San Francisco Agusan del Sur
59	Poblacion, Prosperidad Agusan del Sur
60	Poblacion, Prosperidad Agusan del Sur
61	Poblacion, Prosperidad Agusan del Sur
62	Poblacion, Prosperidad Agusan del Sur
63	San Vicente, Bislig City Surigao del Sur
64	San Vicente, Bislig City Surigao del Sur
65	San Vicente, Bislig City Surigao del Sur
66	San Vicente, Bislig City Surigao del Sur
67	San Vicente, Bislig City Surigao del Sur
68	Maharlika, Bislig City Surigao del Sur
69	New Bataan, Compostela Valley
70	New Bataan, Compostela Valley
71	Mawab Compostela valley
72	San Isidro Davao Oriental
73	San Isidro Davao Oriental
74	San Isidro Davao Oriental
75	San Isidro Davao Oriental
76	San Isidro Davao Oriental
77	San Isidro Davao Oriental
78	San Isidro Davao Oriental
79	San Isidro Davao Oriental
80	San Isidro Davao Oriental
81	San Isidro Davao Oriental
82	San Isidro Davao Oriental
83	San Isidro Davao Oriental
84	San Isidro Davao Oriental
85	San Isidro Davao Oriental
86	Tubac, Mutia Zamboanga del Norte
87	Tubac, Mutia Zamboanga del Norte
88	Tubac, Mutia Zamboanga del Norte
89	Tubac, Mutia Zamboanga del Norte
90	Tubac, Mutia Zamboanga del Norte
91	Mutia, Zamboanga del Norte
92	Mutia, Zamboanga del Norte
93	Sibula, Lopez Jaena Mis. Occ.
94	Sibula, Lopez Jaena Mis. Occ.
95	Sibula, Lopez Jaena Mis. Occ.
96	Sibula, Lopez Jaena Mis. Occ.
97	Sibula, Lopez Jaena Mis. Occ.
98	Sibula, Lopez Jaena Mis. Occ.
99	Poblacion, Mutia Zamboanga del Norte
100	Mahayahay Lopez Jaena, Mis. Occ.
101	Mahayahay Lopez Jaena, Mis. Occ.
102	Dampalan Lopez Jaena Mis. Occ.
103	Tuyabang Alto, Oroqueta City
104	Pulanco, Zamboanga del Norte
105	Pulanco, Zamboanga del Norte
106	Magsaysay, Baliangao Mis. Occ.
107	Magsaysay, Baliangao Mis. Occ.
108	Magsaysay, Baliangao Mis. Occ.
109	Misom, Baliangao Mis. Occ.
110	Misom, Baliangao Mis. Occ.
111	Misom, Baliangao Mis. Occ.
112	Masubong, Sapang Dalaga, Mis. Occ.
113	Masubong, Sapang Dalaga, Mis. Occ.
114	Masubong, Sapang Dalaga, Mis. Occ.
115	Masubong, Sapang Dalaga, Mis. Occ.

Mother Tree	Origin
116	Masubong, Sapang Dalaga, Mis. Occ.
117	Masubong, Sapang Dalaga, Mis. Occ.
118	Masubong, Sapang Dalaga, Mis. Occ.
119	Masubong, Sapang Dalaga, Mis. Occ.
120	Dapacan Calamba Misamis Occidental
121	Dapacan Calamba Misamis Occidental
122	Dapacan Calamba Misamis Occidental
123	Dalirig, Manolo Fortich, Bukidnon
124	Dalirig, Manolo Fortich, Bukidnon
125	Minsapinit, Gingoog City Misamis Oriental
126	Liloy, Zamboanga Sibugay
127	Liloy, Zamboanga Sibugay
128	Liloy, Zamboanga Sibugay
129	Liloy, Zamboanga Sibugay
130	Bunawan, Agusan del Sur

mix of different mother trees.

Gall rust incidence and severity assessment

All trees in each plot in the four blocks were assessed and inspected for the presence of gall rust fungus in the main stem, branches, and shoots. The percent incidence of gall rust disease was then computed for each plot by counting the total number of infected trees, divided by the total number of trees per plot and multiplied by 100. The incidence status was determined using the rating scale used by Palma et al. (2020) (Table 2).

Table 2. Rating scale for gall rust disease incidence per plot.

Percent Incidence	Status
<10	Rare
10 - <25	Occasional
25 - <50	Common
50 - <75	Very common
>75	Widespread

The severity of gall rust disease or the percent area of the whole tree infected by the disease was estimated using a scoring and rating system (Table 3) previously used by Lacandula et al. (2017) and Łakomy and Iwańczuk (2010).

Percent severity index of the disease was computed using the following equation:

$$Severity\ index = \frac{sum\ of\ all\ the\ disease\ rating}{total\ number\ of\ ratings\ X\ max.disease\ grade}\ x\ 100$$

Table 3. Rating scale of gall rust severity per tree.

Rating	Percentage of crown with galls	Qualitative Rating
0	No symptoms	Nil
1	< 10%	Low
2	ll-25 %	Moderate
3	26-60%	High
4	> 60%	Critical

The assessment of gall rust incidence and severity in taller trees was conducted with the aid of binoculars (Figure 2).

Growth parameters measurement

Figure 2. Gall rust assessment in the Falcata field trial in Musuan, Maramag, Bukidnon. Inset (top right) is a photo of globose and elongated galls that formed on infected branches.

Total height (m) and diameter at breast height (dbh, cm) of all trees in each plot were measured using a clinometer and diameter tape, respectively. The volume of each tree expressed in cubic meters was then computed using the following equation:

Tree volume (m^3) = 0.7854 x [dbh (m)]^2 x total height (m)

Growth parameters measurement

Total height (m) and diameter at breast height (dbh, cm) of all trees in each plot were measured using a clinometer and diameter tape, respectively. The volume of each tree expressed in cubic meters was then computed using the following equation:
Tree volume (m3) = 0.7854 x [dbh (m)]2 x total height (m)

Data analysis

Differences in the percentages of gall rust disease incidence and severity due to the effect of mother trees (treatments) were assessed using generalized linear mixed-effects model (GLMM) with a binomial distribution and default logit link function, applying the glmmTMB function in glmmTMB package (Brooks et al., 2017). The number of blocks or replicates were included as random effects in the GLMM models. To test the significance of the parameter in each model, a Wald Chi-squared test in car package (applying the Anova function) was carried out. Post hoc tests were conducted using the emmeans package (Lenth, 2018). All statistical analyses were performed in R software (R Core Development Team, 2018).

Differences in growth parameters (i.e., dbh, total height, and volume) of trees due to mother trees, gall rust disease incidence and severity were modelled using linear mixed effect models (LMMs), applying the lmer function in lme4 package, with plots nested in replications as random effects. Volume data were log transformed prior to analysis to improve the residual fit of the model. Significance of the parameters in the LMM models was assessed using a Wald Chi-squared test and post hoc tests were conducted using the emmeans package.

RESULTS & DISCUSSION

Gall rust disease incidence

Mean percent incidence of gall rust disease varied among treatments (W2[129] = 191.53, $P<0.001$) and ranged from 15.0 ± 5.0% to 80.0 ± 14.1% or from an occasional to widespread incidence among treatments (Figure 3). Most trees or about 94% (i.e., 122 out 130 mother trees) had common to very common incidence. The occasional incidence of gall rust in the study was observed in trees from mother trees number 48 (15.0 ± 9.57%), 99 (15.0 ± 5.0%), and 106 (15.0 ± 9.57%). On the other hand, the widespread incidence of gall rust disease was recorded in trees from mother trees number 30 (80.0 ± 8.2%), 74 (80.0 ± 8.2%), and 108 (80.0 ± 14.1%). The minimum incidence recorded in this study (i.e. 15.0 ± 5.0%) was lower than the minimum incidence reported by Palma et al. (2020) for Falcata plantations in Misamis Oriental (Philippines) and by Lestari et al. (2013) for Falcata stands in Indonesia, which had mean incidence of 47% and 20.99 to 47.22% among trees examined, respectively.

Although the study site is located in an elevation (600 m asl) considered as prone to gall rust incidence (Lacandula et al., 2017; Paquit & Rojo, 2018), some trees still showed resistance to gall rust disease. Post hoc test revealed

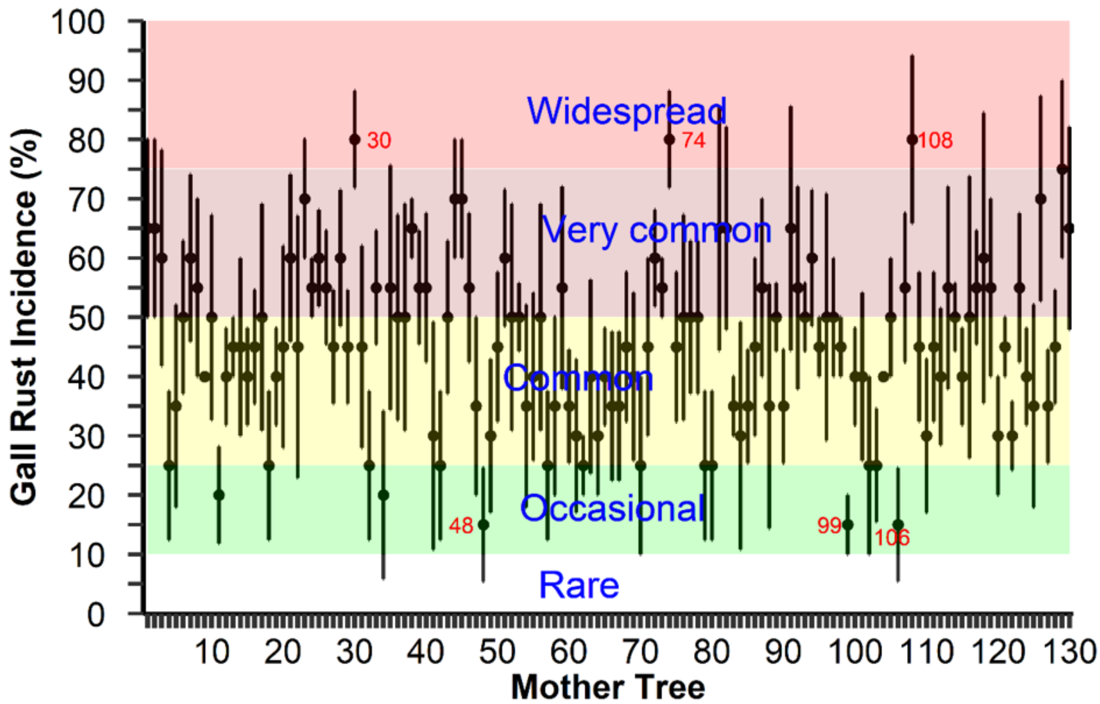

Figure 3. Mean gall rust disease incidence (%) in the Falcata progeny trial in Musuan, Bukidnon as influenced by mother trees. Numbers in red color represent the mother trees with the widespread (30, 74, and 108) and occasional (48, 99, 106) incidence level. Error bars represent ± SE.

significant differences between trees with occasional and widespread incidence (Appendix Table 1), which may indicate resistance to gall rust infection particularly among trees with occasional incidence. These mother trees can be exploited for future breeding of resistant clones of Falcata in Mindanao, although it is possible that different mother trees from different sources or origins may vary in their susceptibility even if they are not completely resistant (Baskorowati et al., 2012). However, even partial resistance to the disease is critical to reduce the infections by the pathogen, increase the latency period, reduce the lesion expansion or sporulation, or any combination of these processes (Gullino et al., 2020).

Gall rust disease severity

Mean percent gall rust severity among treatments in the study ranged from low (3.75 ± 1.25%) to high severity (35.0 ± 16.95%) with most of the trees or more than 72% (i.e., 94 out of 130 mother trees) had moderate severity. Similar to incidence data, the severity of gall rust varied significantly among treatments ($W2[129] = 1512.76$, $P < 0.001$) (Figure 4), which also highlights the important influence of mother trees against gall rust infestation. Such variation is probably due to differences in the susceptibility of different mother trees in the trial – a likely indication of high genetic diversity among treatments. Low genetic diversity usually lead to a very 'high' or 'critical' gall rust disease infestation of all trees as observed in Falcata plantations elsewhere (cf. Rahayu et al., 2009).

In the present study, the lowest mean percent severity was observed in trees from mother trees number 34 (5.00 ± 3.54%), 99 (3.75 ± 1.25%), and 106 (3.75 ± 2.39%). While the trees with high mean gall rust severity were observed from mother trees number 3 (35.0 ± 16.95%), 74 (35.0 ± 16.71%), and 81 (35.0 ± 12.25%). Interestingly, the severity observed in the study had not reached the critical level and was even lower than the severity reported by Rahayu et al. (2018) for Falcata plantations in Malaysia (10 to 80%). The result was comparable to the severity level (10.29 to 20.99%) of gall rust in Falcata-based agroforestry systems in Indonesia reported by Lestari et al. (2013) perhaps due to diversity of species planted which reduced the infection by the pathogen.

Aside from host and pathogen, environmental factors both aerial and edaphic have traditionally been considered to have the major impact on disease development (Keane & Kerr, 1997). Factors including topography, fog, age, altitude, humidity, and wind speed greatly influence the incidence and severity of gall rust (Rahayu et al., 2018). However, in this study, environmental factors may be similar since all samples were taken in one site. The variation in the severity of gall rust per mother tree can therefore be attributed to susceptibility or resistance of mother trees to the gall rust causing pathogen.

The most consistent mother trees in the present study in terms of low incidence and severity of gall rust infection were tree number 99 and 106, suggesting the more superior resistant traits of these mother trees against gall rust disease infection. These mother trees can be exploited in the long-term breeding for resistant clones of Falcata. Experience in other countries (e.g. Australia and India) with gall rust diseases in major plantation species suggests that without selection for resistant traits, breeding programs could result in highly susceptible population of

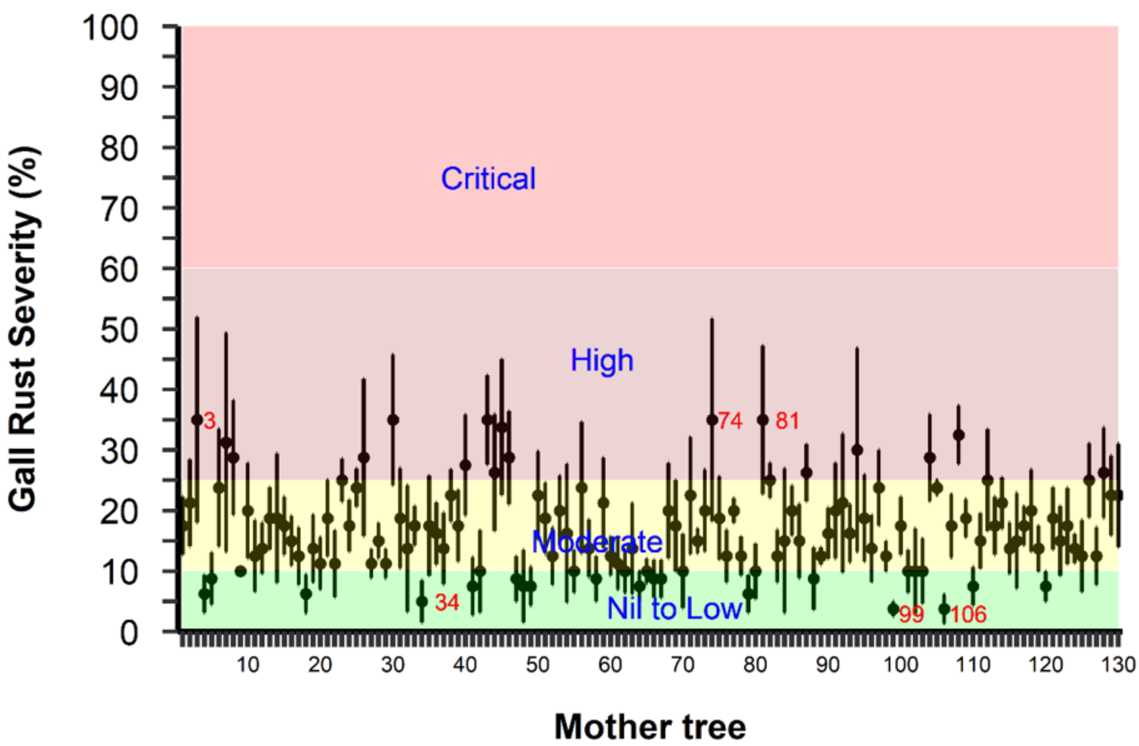

Figure 4. Mean gall rust disease severity (%) in the Falcata progeny trial in Musuan, Bukidnon as influenced by mother trees. Numbers in red color represent the mother trees with high (3, 74, and 81) and low (34, 99, 106) severity level. Error bars represent ± SE.

trees (Old et al., 2000).

Influence of gall rust disease incidence, severity, and mother trees on growth

Total log(volume) (in cubic meters) of individual trees in the trial differed significantly but was due to the influence of gall rust incidence only ($W^2[1]$ = 16.56, P<0.001). There were no significant variations in tree log(volume) associated with treatments ($W^2[1]$ = 141.33, P= 0.216) or gall rust severity ($W^2[1]$ = 3.71, P=0.054). Data on tree height and absolute diameter varied significantly due to treatments ($W^2[129]$ = 177.26, P=0.003) and gall rust incidence ($W^2[1]$ = 16.51, P<0.001). The severity of gall rust had also no significant effect on tree height ($W^2[129]$ = 2.90, P=0.089) and absolute diameter ($W^2[129]$ = 3.24, P=0.072).

Surprisingly, none of the mother trees that indicated resistant traits against gall rust infection had superior growth. Among the treatments, mother trees number 24 (Guinoyoran, Valencia City, Bukidnon), 35 (Tagpako, Gingoog City, Misamis Oriental), and 93 (Sibula, Lopez Jaena, Mis. Occ.) had the more superior height growth (Figure 5a), while mother tree number 35 had the more superior diameter growth of all (Figure 5b). All these mother trees however had 'very common' incidence of gall rust infection that ranged between 50 ± 5.8% and 55 ± 20.6% suggesting that gall rust infection is not a concern for growth of mature Falcata trees. This result is supported by the relationship between growth parameters (volume, height and dbh) and incidence data, which indicated positive or better growth even at higher incidence of gall rust disease (Figure 6). While the influence of genetic diversity or variation in the present study still need to be verified, the result is consistent with the study of Baskorowati et al. (2012) that found strong positive relationship between growth (including diameter) and gall rust incidence in Falcata plantations in Indonesia. Baskorowati et al. (2012) explained that the positive relationship between growth and gall rust incidence in their study was likely due to the observed genetic variations among trees that included 80 families or mother trees. On the other hand, it is also likely that such positive relationship is indicative of the presence of growth and disease tolerance tradeoff i.e., trees need to grow bigger or better to compensate for any negative impacts from gall rust infection. However, this aspect needs to be assessed further via long-term observations of growth against the effect of gall rust disease as results in other studies (e.g. Lacandula et al.,

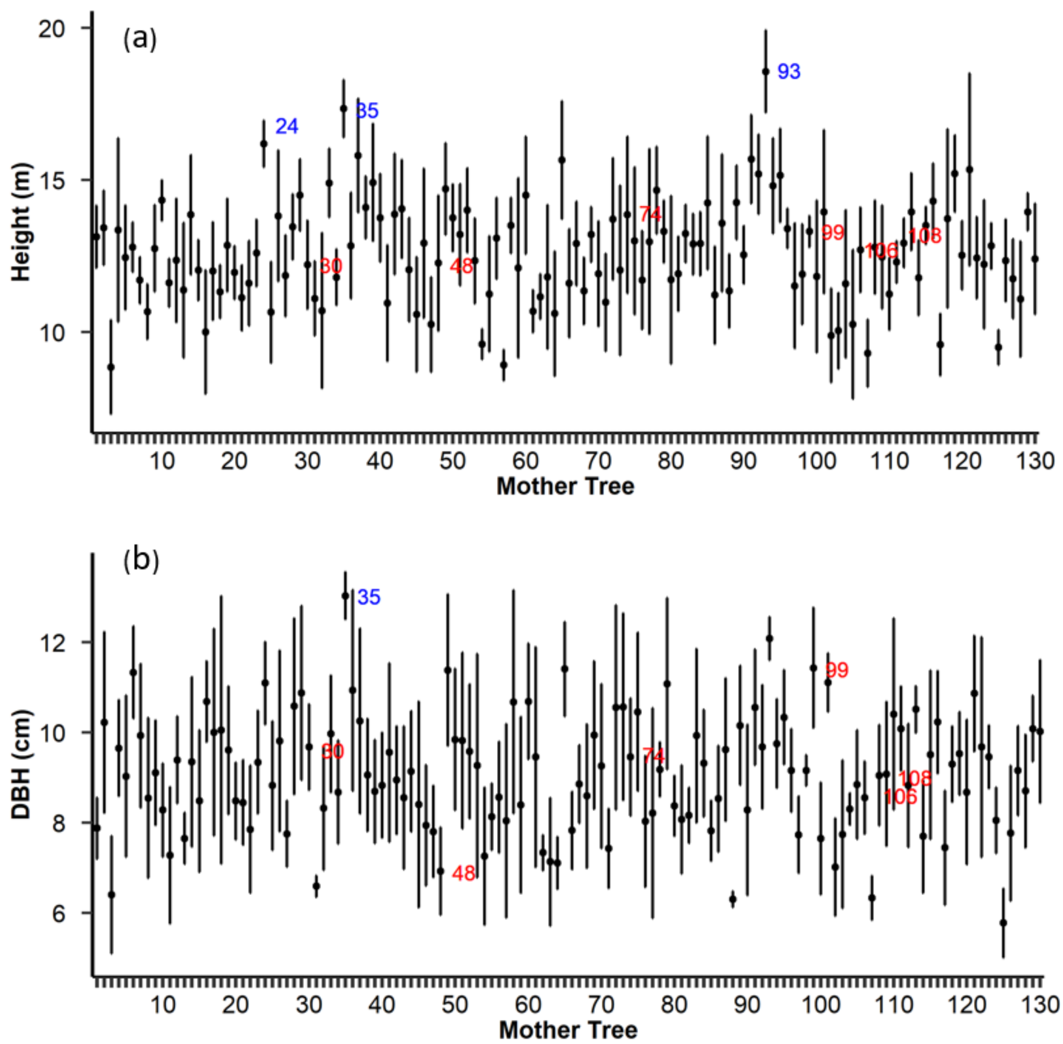

Figure 5. a) Mean total height (m) and b) mean diameter at breast height (cm) of Falcata trees from different mother trees. Also indicated are the mother trees with superior growth (blue number) and mother trees with low and high gall rust incidence (red number). Error bars represent ± SE.

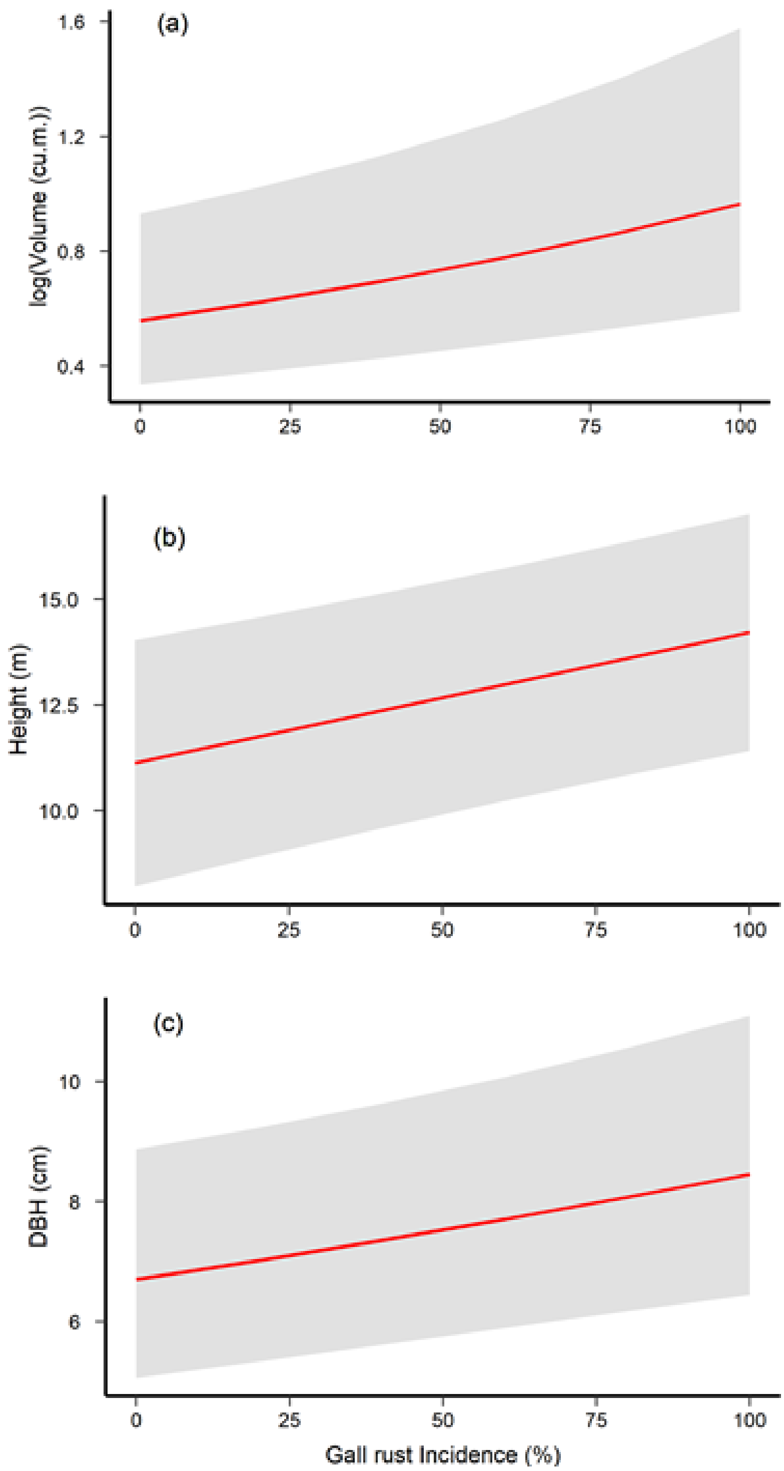

Figure 6. Fitted absolute growth of trees in the Falcata progeny trial in CMU as influenced by gall rust incidence (%): a) volume (m3), b) height (m), and c) diameter at breast height (cm). The area shaded with gray represents 1 ± SD.

2017; Rahayu et al., 2018) indicated negative relationship between incidence and diameter growth, although such differences are likely due to variations in age or density of planting. Previous studies observed gall rust disease to be host density dependent i.e., where the host is densely planted, incidence of mature trees could be up to 100% with severity increasing exponentially with increasing tree size (Wood, 2012). Nonetheless, the results of the study suggest that height or diameter at breast height may be used as criteria for selection of mother trees or provenances that are resistant against gall rust infection.

CONCLUSIONS AND RECOMMENDATION

The study demonstrated significant variations in incidence and severity of gall rust disease among the mother trees including the presence of gall rust resistant traits in trees with low incidence and severity of gall rust infection. Such variation was an indication of genetic diversity among mother trees in the study. Trees from mother trees number 99 (Poblacion Mutia, Zamboanga del Norte) and 106 (Brgy. Magsaysay in Baliangao, Misamis Occidental) emerged as the most resistant of all trees in the trial and can be exploited for future breeding of resistant clones. Apart from these trees, a few more mother trees viz., mother trees number 48 (Hubang, San Francisco Agusan del Sur) and 34 (Maribucao, Gingoog City Misamis Oriental) also showed superior resistance to gall rust disease infection.

Growth performance (particularly height and diameter) was positively related to the independent influence of gall rust incidence and treatments (or mother trees), although none of the mother trees with resistant traits had superior growth. Among the treatments, mother trees number 24 (Guinoyoran, Valencia City Bukidnon), 35 (Tagpako, Gingoog City Misamis Oriental), and 93 (Sibula, Lopez Jaena Mis. Occ.) had the more superior height growth, while mother tree number 35 had the more superior diameter growth of all. All these mother trees had 'very common' incidence of gall rust infection suggesting that gall rust incidence is not a concern for the growth of Falcata trees in the study. The result provided an indication of the presence of growth and disease tolerance tradeoff where trees with higher gall rust incidence tend to grow bigger perhaps to compensate for any negative impacts from gall rust infection. However, this aspect needs to be assessed further via long-term observations (e.g., 10 years or one rotation period) as results in other similar studies indicated negative relationship between incidence and growth parameters, although such differences are likely due to variations in age or density of planting.

LITERATURE CITED

Anino, E. (1994). Commercial plantation establishment, management, and wood utilization of Paraserianthes falcataria by PICOP Resources, Inc. Proceedings of a workshop on Albizia and Paraserianthes species, Bislig, Surigao del Sur, Philippines, Nov. 13-19, 1994,

Baird, I. G. (2014). Degraded forest, degraded land and the development of industrial tree plantations in L aos. Singapore journal of tropical geography, 35(3), 328-344.

Baskorowati, L., Susanto, M., & Charomaini, M. (2012). Genetic variability in resistance of Falcataria moluccana (Miq.) Barneby & JW Grimes to gall rust disease. Indonesian Journal of Forestry Research, 9(1), 1-9.

Braza, R. (1997). Gall rust disease of Paraserianthes falcataria in the Philippines. For Farm Commun Tree Res Rep, 2, 61-62.

Brooks, M. E., Kristensen, K., van Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., Skaug, H. J., Machler, M., & Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R journal, 9(2), 378-400.

Bruinsma, J. (2002). World Agriculture: towards 2015/2030: Summary Report. Food and Agriculture Organization of the United Nations (FAO).

Doungsa-ard, C., McTaggart, A. R., Geering, A. D., Dalisay, T. U., Ray, J., & Shivas, R. G. (2015). Uromycladium falcatarium sp. nov., the cause of gall rust on Paraserianthes falcataria in south-east Asia. Australasian Plant Pathology, 44(1), 25-30.

Forest Management Bureau-DENR. (2019). Philippine Forestry Statistics. https://forestry.denr.gov.ph/index.php/statistics/philippines-forestry-statistics

Gullino, M. L., Albajes, R., & Nicot, P. C. (2020). Integrated pest and disease management in greenhouse crops (Vol. 9). Springer Nature.

Keane, P., & Kerr, A. (1997). Factors affecting disease development. Plant pathogens and plant diseases, 287-298.

Lacandula, L., Rojo, M. J., Casas, J., & Puno, G. R. (2017). Geospatial analysis on the influence of biophysical factors on the gall rust prevalence in falcata (Paraserianthes falcataria L. Nielsen) plantation in Gingoog city, Philippines.

Łakomy, P., & Iwańczuk, M. (2010). Phaeocryptopus gaeumannii in douglas-fir stands in smolarz forest district. Phytopathologia, 58, 43-52.

Lenth, R. (2018). Emmeans: Estimated marginal means, aka least-squares means. R Package Version 1.

Lestari, P., Rahayu, S., & Widiyatno, W. (2013). Dynamics of gall rust disease on sengon (Falcataria moluccana) in various agroforestry patterns. Procedia Environmental Sciences, 17, 167-171.

Lugo, A. E. (1997). The apparent paradox of reestablishing species richness on degraded lands with tree monocultures. Forest Ecology and Management, 99(1-2), 9-19.

McAlpine, D. (1905). A new genus of Uredineae Uromycladium. A. Hopfer.

McKenzie, E. (1998). Rust fungi of New Zealand—an introduction, and list of recorded species. New Zealand Journal of Botany, 36(2), 233-271.

McTaggart, A. R., Doungsa-ard, C., Wingfield, M. J., & Roux, J. (2015). Uromycladium acaciae, the cause of a sudden, severe disease epidemic on Acacia mearnsii in South Africa. Australasian Plant Pathology, 44(6), 637-645.

Morris, M. (1987). Biology of the Acacia gall rust, Uromycladium tepperianum. Plant Pathology, 36(1), 100-106.

Old, K., & Dos Santos Cristovao, C. (2003). A rust epidemic of the coffee shade tree (Paraserianthes falcataria) in East Timor. ACIAR PROCEEDINGS,

Old, K. M., See, L. S., Sharma, J. K., & Yuan, Z. Q. (2000). A manual of diseases of tropical acacias in Australia, South-East Asia and India. CIFOR.

Palma, R., Tiongco, L., Canencia, O., Boniao, R., Florida, E., & Dagonio, J. (2020). Gall rust disease incidence of Falcata

(Paraserianthes falcataria (L.) Nielsen) in Falcata based agroforestry systems in Misamis Oriental, Philippines. E&ES, 449(1), 012035.

Paquit, J., & Rojo, M. J. (2018). Assessing suitable sites for falcata (Paraserianthes falcataria Nielsen) plantation in Bukidnon, Philippines using GIS. International Journal of Biosciences, IJB.

PCAARRD. (2010). Challenges and Recommendations in the Industrial Tree Plantations. Policy Brief.

R Core Development Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing. In https://www.R-project.org/

Rahayu, S., Lee, S. S., & Shukor, N. A. A. (2010). Uromycladium tepperianum, the gall rust fungus from Falcataria moluccana in Malaysia and Indonesia. Mycoscience, 51(2), 149-153.

Rahayu, S., See, L., Shukor, N., & Saleh, G. (2018). Environmental factors related to gall rust disease development on falcataria moluccana (miq.) barneby & jw grimes at brumas estate, Tawau, Sabah, Malaysia. Applied Ecology and Environmental Research, 16(6), 7485-7499.

Rahayu, S., Shukor, N. A. A., See, L. S., & Saleh, G. (2009). Responses of Falcataria moluccana seedlings of different seed sources to inoculation with Uromycladium tepperianum. Silvae Genetica, 58(1-2), 62-68.

Rahayu, S., Widiyatno, W., & Adriyanti, D. T. (2020). Pathogenesis of gall-rust disease on Falcataria moluccana in areas affected by Mount Merapi eruption in Indonesia. Biodiversitas Journal of Biological Diversity, 21(4).

Semwal, R., Nautiyal, S., Maikhuri, R., Rao, K., & Saxena, K. (2013). Growth and carbon stocks of multipurpose tree species plantations in degraded lands in Central Himalaya, India. Forest Ecology and Management, 310, 450-459.

Wood, A. R. (2012). Uromycladium tepperianum (a gall-forming rust fungus) causes a sustained epidemic on the weed Acacia saligna in South Africa. Australasian Plant Pathology, 41(3), 255-261.

ACKNOWLEDGEMENT

The authors would like to acknowledge the funding support (R-0240) of Central Mindanao University (CMU) in the conduct of this assessment and the Department of Science and Technology, Philippines - Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) for the research grant in the establishment of Falcata provenance trial in CMU.