Growth of *Falcataria moluccana* and *Albizia chinensis* seedling under aluminum exposure

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Abstract. *Salim MA, Setyaningsih L, Wahyudi I, Budi SW. 2021. Growth of* Falcataria moluccana *and* Albizia chinensis *seedling under aluminum exposure. Biodiversitas 22: 3694-3702.* Aluminum (Al) is an element found in acid soils and is one of the limiting factors for plant growth. This study aims to examine the growth of *Falcataria moluccana* (Miq.) Barneby & J.W.Grimes and *Albizia chinensis* (Osbeck) Merr seedlings underexposure of aluminum. This study used an one-factor completely randomized design (Al concentration) consisting of 5 levels, namely 0, 2, 4, 6, and 8 mM. Each treatment was repeated 3 times and each replication consisted of 3 plant units. The results showed that the Al exposure treatment gave significant differences in the growth of height, root length, dry weight (root, shoot, and total) of *F. moluccana* and *A. chinensis* seedlings. The 2 mM Al concentration stimulated the growth of height, root length and dry weight (root, shoot, and total) of *A. chinensis* seedlings. The tolerance index for *F. moluccana* and *A. chinensis* seedlings was highest when the Al 2 mM concentration was 147.55% and 115.32%, respectively. 2 mM Al exposure treatment increased the chlorophyll content a, b, total chlorophyll and carotenoids of *F. moluccana* and *A. chinensis* seedlings. Al exposure treatment did not significantly differ from the rate of photosynthesis and MDA content in *F. moluccana* and *A. chinensis* seedlings. The Al content in the roots was higher than in the shoots, and the increase in Al concentration increased the Al content in the roots and shoots of *F. moluccana* and *A. chinensis* seedlings.

Keywords: Aluminum, concentration, increase, seedlings, stimulated

INTRODUCTION

One of the elements found in acid soils is aluminum. Generally, Al toxicity occurs on acid soils when the pH is below 5, Al solubility increases (Al toxicity increases) (Lilienfein et al. 2003; Silva 2012). Aluminum is very soluble at soil pH (<5) and is a limiting factor in plant growth (Panda et al. 2009; Nunes-Nesi et al. 2014; Singh et al. 2017). Al toxicity in acid soils has harmed plant growth and production (Yu et al. 2011; Pattanayak and Pfukrei 2013). Al toxicity can inhibit root growth and development, thus inhibiting the absorption of water and nutrients that impact inhibiting plant growth (Konarska 2008; Böhlenius et al. 2018). In addition, Al toxicity is capable of causing oxidative stress due to the accumulation of reactive oxygen species (ROS), which later affects the physiological processes and metabolism of plants (Inostroza-Blancheteau et al. 2012). Al toxicity is available in Al^{3+} (Liu et al. 2014; Schmitt et al. 2016). When dissolved Al^{3+} levels reach 10-20 mg/kg or more, they can cause a toxic effect on plants (Kochian et al. 2004). Even according to Balsberg et al. (1990) Al concentrations of more than 2-3 ppm at soil pH of 5.5 can poison plants.

Falcataria moluccana (Miq.) Barneby & J.W.Grimes and *Albizia chinensis* (Osbeck) Merr are species belonging to the Fabaceae family. Both species are included in the fast-growing species (Hughes and Uowolo 2006), which have quite high economic value (Yuskianti and Shiraishi 2017). So, they are widely cultivated, especially in Indonesia (Widyastuti et al. 2013). In addition, the *F. moluccana* and *A. chinensis* is quite essential in Southeast Asian countries (Aiso et al. 2016). The species of *F. moluccana* is also a species that is widely used in forest rehabilitation programs including in post mine areas (Prematuri et al. 2020), especially in Indonesia. Species of *F. moluccana* and *A. chinensis* are also commonly planted in agroforestry systems (Uddin et al. 2008; Sarimah et al. 2018). Species of the Fabaceae family can have symbiosis with rhizobium bacteria, so that they can fix nitrogen in the atmosphere (Hughes et al. 2012; Arunakumara et al. 2013). This study aims to examine the growth of *F. moluccana* and *A. chinensis* seedlings against exposure to aluminum, and to examine the resistance of each species of seedling to exposure to Al.

MATERIALS AND METHODS

Germination of seeds. The breaking of the seed dormancy of *F. moluccana* and *A. chinensis* was done by soaking in hot water (80 °C) for 15 minutes and then soaked in water (25-30 °C) for 24 hours (Alghofar et al. 2017). After that, the seeds are sown in a tub of sprouts that

already contain zeolite media. The seeds are maintained for ±14 days until the seeds are ready for weaning.

Media preparation. The media used in this research was water culture. The nutrient solution used refers to the nutrient solution developed by Sopandie (1999), consisting of: 1.5 mM $Ca(NO_3)_2.4H_2O$, 1.0 mM NH_4NO_3, 1.0 mM KCl, 0.4 mM $MgSO_4.7H_20$, 1.0 mM KH_2PO_4, 0.50 ppm $MnSO_4.H_2O$, 0.02 ppm $CuSO_4.5H_2O$, 0.05 ppm $ZnSO_4.7H_2O$, 0.50 ppm H_3BO_3, 0.01 ppm $(NH_4)_6 Mo7O_{24}.4H_2O$. For Al exposure using $AlCl_3$.

Seedling adaptation test and Al exposure treatment experiment. The seedlings ready to be weaned are transferred to the tub that already contains the media. During the adaptation test, the seedlings were kept for 14 days. Each seedling is placed on the serophome that has been perforated. The stems of the seedlings are wrapped in cotton so that the seedlings can stand upright. After the adaptation test, the seedlings were transferred again to a container that already contained media that had been treated with predetermined concentrations of Al (0, 2, 4, 6, and 8 mM). During the adaptation test and treatment experiment, the media was maintained at pH 4. The pH adjustment was carried out by adding 1 N HCl and 1 N KOH. The addition of media was carried out when the media volume had begun to decrease. The media is replaced after 14 days to keep seedling growth optimal. Seedlings are maintained for up to 28 days.

Evaluate parameters. Growth parameters measured included: plant height, root length, root and shoot dry weight. Plant height was measured every week for four weeks, while root length was measured at week 4. The photosynthetic rate was measured using a Licor (Li-6400 XT) portable photosynthesis system in the morning (09.00-11.00). Plants were harvested after 30 days, the roots and shoots were separated and oven for two days at 80 ºC. After that, the plant samples were weighed to obtain the root and shoot dry weight. The seedling tolerance index was calculated using the equation from Liu and Ding (2008), as follows:

$$\text{Tolerance index} = \frac{\text{Total dry weight of plants treated with Fe}}{\text{Total dry weight of plants not treated with Fe (control)}} \times 100\%$$

Analysis of chlorophyll and carotenoid content. Chlorophyll and carotenoid content refer to Sims and Gammon (2002) with modifications. Leaf samples 0.03-0.05 g were crushed using a mortar until smooth by adding 2 ml of acetone (85: 15%, Trs HCl 1%, pH 8) and centrifuged at 10,000 rpm for 5 minutes. Take 1 ml of supernatant and add 3 ml of tris acetone, then shake until homogeneous. The absorbance was measured at wavelengths (λ) 470, 537, 647, and 663 nm and was measured using a UV-VIS spectrophotometer. Chlorophyll and carotenoid values are expressed in mg/g. Chlorophyll and carotenoid content are determined based on the equation Sims and Gamon (2002).

$Anthocyanin = 0.08173*A_{537} - 0.00697*A_{647} - 0.002228*A_{663}$
$Chl_a = 0.01373*A_{663} - 0.000897*A537 - 0.003046*A_{647}$
$Chl_b = 0.02405*A647 - 0.004305*A537 - 0.005507*A663$
$$Carotenoids = \frac{(A470 - (17.1*(Chla+Chlb) - 9.479*Anthocianin))}{119.26}$$

Where, Ax is the absorbance at the measured wavelength.

MDA lipid peroxide analysis. Lipid peroxide analysis refers to Siska et al. (2017) with modifications. Leaf samples of 0.03-0.05 g were crushed with a mortar, then added 5 ml of 0.1% (w / v) trichloroacetic acid (TCA) and centrifuged at 10,000 g for 5 minutes. After that, 1 ml of the supernatant was transferred to a new tube and 4 ml of 0.1% (w / v) thiobarbituric acid (TBA) was added in 20% (w / v) TCA. The solution was incubated at 80 oC in a water bath for 30 minutes, and then cooled to room temperature. The absorbance of the TBA-MDA complex was measured using a spectrometer at a wavelength (λ) of 532 nm, while non-specific absorbance was measured at a wavelength (λ) of 600 nm (Meriga et al. 2010). The MDA content is determined based on the equation from Heath and Packer (1968), as follows:

$$MDA = \frac{\left(\frac{A532 - A600}{\varepsilon}\right) X\ 10^6}{\text{Fresh weight (g)}}$$

MDA: MDA concentration (nmol/g)
ε = MDA extention coefficient value (155 mM^{-1}cm^{-1})

Research design and data analysis. This study used a one-factor completely randomized design (CRD) with 5 levels of Al doses, namely 0, 2, 4, 6, and 8 mM. Each treatment was repeated 3 times and each replication consisted of 3 plant units. Data analysis used the Anova test followed by the Duncan Multiple's Range Test (DMRT) at a 95% confidence level (α = 5).

RESULTS AND DISCUSSION

Plant height

The height growth of the two seedlings gave a significant difference at several Al concentrations (Figure 1). The 2 mM Al concentration provided the highest growth response in the two seedlings compared to other Al concentrations. Meanwhile, the increasing concentration of Al was able to reduce the height growth of the two seedlings. The height growth of *A. chinensis* was higher than that of *F. moluccana*.

Root length

The Al exposure treatment reduced the root length in *F. moluccana* seedlings until the concentration of 6 mM Al. Meanwhile, in *A. chinensis* seedlings, the 2 mM Al concentration was able to increase root length and decrease again with increasing Al concentration (Figure 2). The 0 mM and 2 mM Al concentrations did not show a significant difference, as did the Al 4, 6 and 6 mM concentrations, nor did they significantly differ from the root length of *F. moluccana* seedlings. Meanwhile, in *A. chinensis* seedlings, the 2 mM and 4 mM Al concentrations did not show any significant difference in root length. At these concentrations, it was the highest root length compared to other Al concentrations.

The dry weight

Treatment of 2 mM Al concentration increased root, shoot and total dry weight in both seedlings (Figures 3, 4 and 5). However, the increasing concentration of Al was able to reduce dry weight in both seedlings. Root dry weight of *F. moluccana* and *A. chinensis* seedlings at concentrations of 0, 4, 6, and 8 mM did not show a significant difference (Figure 3). The shoot dry weight of *F. moluccana* seedlings showed no significant difference between the Al 0 and 4

mM concentrations and between the Al 6 and 8 mM concentrations. Meanwhile, while, on the seedlings of *A. chinensis* Al exposure treatment provides significant differences between the concentrations of Al, except between 6 and 8 mM concentration which showed no significant difference (Figure 4). The total dry weight of *A. chinensis* seedlings was higher than that of *F. moluccana* seedlings (Figure 5). It is shown that *A. chinensis* seedlings have higher growth compared to *F. moluccana* seedlings.
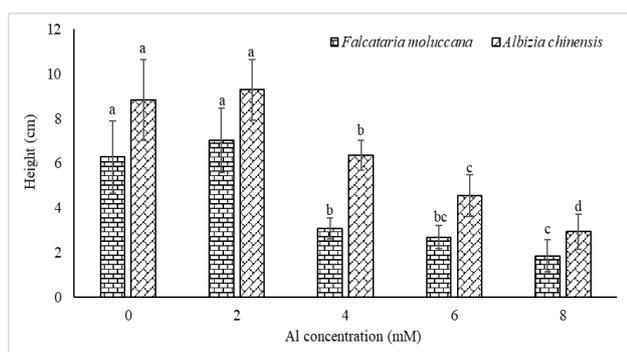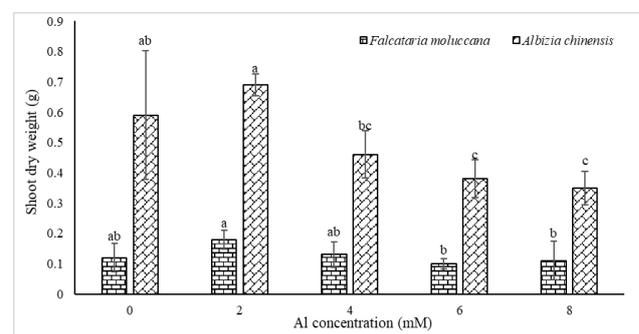

Figure 1. Height growth of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a sifnificant difference in the result of the DMRT test at the 5% level.
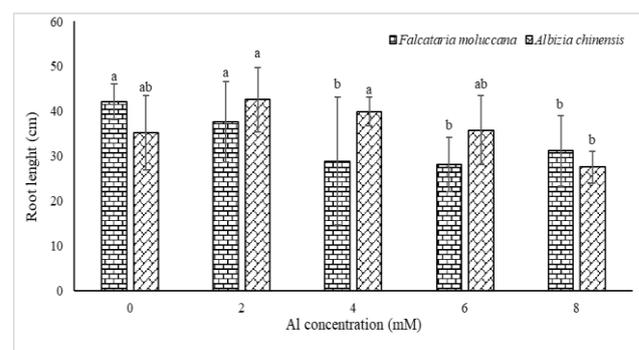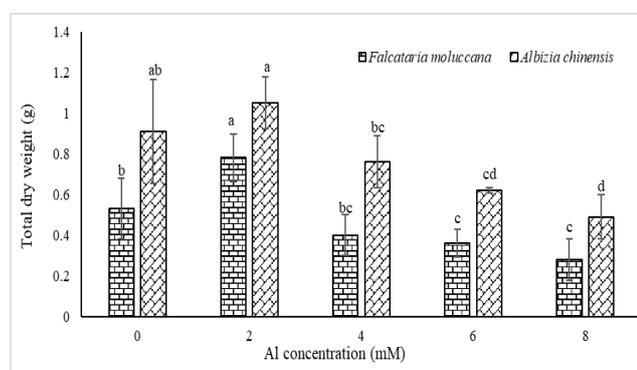

Figure 2. Root lengths of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level.
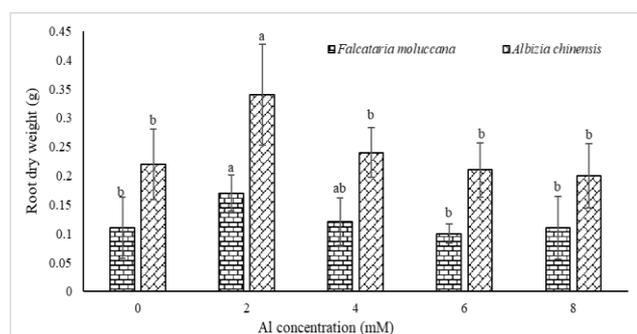
Figure 3. Roots dry weight of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level.

Figure 4. Shoots dry weight of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level.

Figure 5. Total dry weight of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level.

Figure 6. Tolerance index of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level
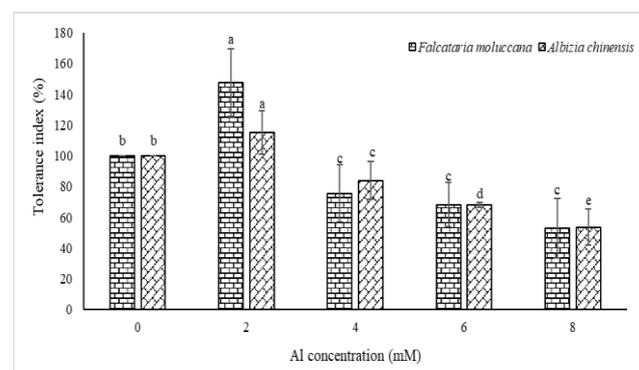
Table 1. Chlorophyll and carotenoid content of *F. moluccana* and *A. chinensis* at various Al concentrations

Species	Al concentration (mM)				
	0	2	4	6	8
Chlorophyll a (mg/g)					
F. moluccana	2.16 ± 0.10 abc	2.29 ± 0.09 a	1.93 ± 0.07 c	2.23 ± 0.26 ab	1.98 ± 0.08 bc
A. chinensis	3.22 ± 0.14 a	3.29 ± 0.36 a	2.52 ± 0.27 b	2.30 ± 0.24 b	1.75 ± 0.26 c
Chlorophyll b (mg/g)					
F. moluccana	1.30 ± 0.05 ab	1.42 ± 0.03 a	1.20 ± 0.03 b	1.40 ± 0.16 a	1.23 ± 0.08 b
A. chinensis	1.98 ± 0.14 a	2.04 ± 0.18 a	1.58 ± 0.16 b	1.40 ± 0.17 b	1.09 ± 0.15 c
Chlorophyll total (mg/g)					
F. moluccana	3.45 ± 0.15 ab	3.71 ± 0.11 a	3.14 ± 0.10 b	3.63 ± 0.42 a	3.20 ± 0.14 b
A. chinensis	5.20 ± 0.29 a	5.33 ± 0.53 a	4.10 ± 0.43 b	3.70 ± 0.41 b	2.83 ± 0.41 c
Carotenoids (mg/g)					
F. moluccana	0.71 ± 0.04 ab	0.78 ± 0.03 a	0.68 ± 0.01 b	0.79 ± 0.08 a	0.71 ± 0.03 ab
A. chinensis	4.15 ± 5.41 a	1.03 ± 0.10 a	0.86 ± 0.07 a	0.80 ± 0.08 a	0.62 ± 0.09 a

Note: mean ± standard deviation, the different letters show a significant difference in the DMRT test results at the 5% level. *: significant effect at the 5% level, ns: not significat at the 5% level

Tolerance index

The Al exposure treatment gave a significant difference in the tolerance index for *F. moluccana* seedlings, while for *A. chinensis* seedlings only up to 4 mM Al concentration which resulted in a significant difference to the tolerance index (Figure 6). The tolerance index for *F. moluccana* and *A. chinensis* seedlings was the highest when the Al 2 mM concentration exceeded the tolerance level of the seedlings under control treatment (0 mM) with values of 147.55% and 115.32%, respectively (Figure 6). However, the increasing concentration of Al (from 4 mM to 8 mM) reduced the tolerance index in *F. moluccana* and *A. chinensis*.

Chlorophyll and carotenoid content

2 mM Al exposure treatment increased the chlorophyll content a, b, total chlorophyll, and carotenoids of *F. moluccana* and *A. chinensis* seedlings (Table 1). The chlorophyll a, b, total chlorophyll, and carotenoid content of *F. moluccana* seedlings fluctuated considerably compared to *A. chinensis* seedlings. Meanwhile, the chlorophyll a, b, and total chlorophyll content of *A. chinensis* seedlings decreased when the Al concentration was 4 to 8 mM. It is shown that the higher Al concentration can reduce the chlorophyll content of *A. Chinensis* seedlings. The carotenoid content of *A. chinensis* seedlings decreased with increasing Al concentration.

Photosynthesis rate

Al exposure treatment did not significantly differ in the rate of photosynthesis in *F. moluccana* and *A. chinensis* seedlings (Figure 7). The photosynthesis rate in the two seedlings was quite fluctuating. The highest photosynthetic rate of *F. moluccana* seedlings was when the Al concentration was 2 mM (18.39 µmol CO2 m-2 s-1), while in *A. chinensis* seedlings, the highest photosynthetic rate was when the Al concentration was 4 mM (15.36 µmol CO2 m-2 s-1). It is indicated that the two seedlings responded quite differently to Al exposure to the rate of photosynthesis.

MDA content

Lipid peroxidation (malondialdehyde) is a response from plants due to exposure to heavy metals. Al exposure did not show a significant difference in the MDA content of the two species of seedlings (Figure 8). The MDA content of both species of seedlings at various concentrations of Al was quite varied, and the MDA content of *F. moluccana* seedlings was higher than that of *A. chinensis* seedlings. The highest MDA content in both seedlings was at a concentration of 4 mM, and this indicates that with an Al concentration of 4 mM, it was able to trigger MDA production.

Al content in seedling tissue

Al content in the tissue (roots and shoots). seedling *F. moluccana* and *A. chinensis* were able to increase when the concentration of Al also increases (Table 2). The Al content in the roots was higher than in the shoots of the two seedlings. It is shown that the Al uptake is more accumulated in the roots than in the shoots.

Table 2. The content of Al *F. moluccana* and *A. chinensis* in roots and shoots at various concentrations of Al

Species	Al concentration (mM)				
	0	2	4	6	8
Al content in roots (ppm)					
F. moluccana	-	12.045	12.423	14.4	14.748
A. chinensis	-	7.675	14.366	15.376	15.751
Al content in shoots (ppm)					
F. moluccana	-	0.408	1.304	1.511	2.18
A. chinensis	-	0.442	0.839	2.292	3.15
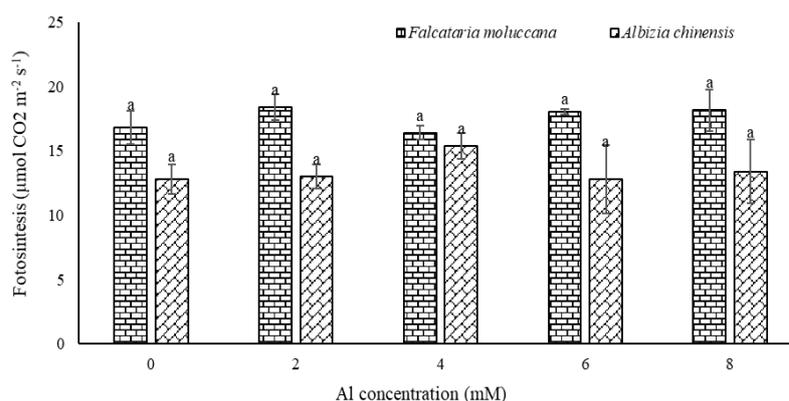
Figure 7. Photosynthetic rate of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level
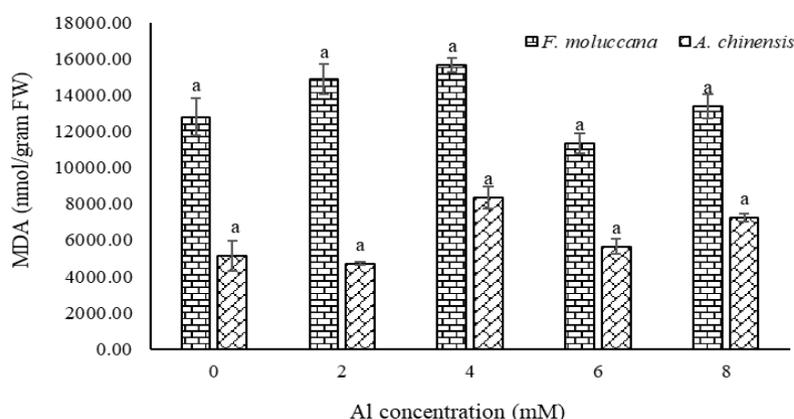
Figure 8. MDA content of *F. moluccana* and *A. chinensis* at various Al concentrations. Vertical bars indicate standard deviations (n = 3). Different letters show a significant difference in the result of the DMRT test at the 5% level.

Discussion

Al is a non-essential metal. Its function is not widely known in plant metabolism (Wang and Kao 2004). Each plant can respond to Al toxicity differently (Arunakumara et al. 2013). Al exposure can reduce growth in several plant species that are sensitive to Al (Böhlenius et al. 2018). However, at specific concentrations, Al can stimulate plant growth (Arunakumara et al. 2013). It was proven that 2-mM Al concentration was able to stimulate the height growth of *F. moluccana* and *A. chinensis* seedlings (Figure 1). However, when the Al concentration increased (4 to 8 mM), it reduced the height growth of the two seedlings. Pidjath et al. (2020) reported that Al concentration of 4 mM was able to inhibit growth and nutrient uptake of four forest seedlings (*C. calothyrsus*, *S. saman*, *O. bicolor*, and *C. inophyllum*). Singh et al. (2011) also reported that Al toxicity was able to reduce the growth of *P. sativam* L. Arkil and Rachana varieties. Böhlenius et al. (2018) reported that 200-300 mg/l Al exposure treatment reduces the relative height growth, root, leaf, and stem biomass relative to four poplar cultivars.

High concentrations of Al can inhibit root growth and development (Motoda et al. 2010; Kopittke et al. 2015). The results of this study also showed that increasing Al concentration was able to reduce the root length of *F. moluccana* and *A. chinensis* seedlings (Figure 2). Tolra et al. (2009) reported that Al toxicity did not improve the root length of the Cateto variety *Zea mays* L. (tolerant). Gunsé et al. (2003) also reported that Al toxicity had little inhibition on root exposure of *P. vulgaris* L. Preto and Carioca varieties (tolerant) and Andean varieties (tolerant). Meanwhile, several studies reported that Al toxicity was able to inhibit root lengthening of soybean varieties Zhechun 2 (tolerant) and Huachun 18 (sensitive) (Cai et al. 2011), *Phaseolus vulgaris* L. Quimbaya varieties (tolerant) and VAX-1 varieties (sensitive) (Rangel et al. 2009). Al in low concentration (2 mM) was able to stimulate the root length of the *F. moluccana* plant. This condition is probably caused by an increase in the apical root meristem activity induced by Al (Arunakumara et al. 2013). Yu et al. (2011) reported that Al of low concentrations (10-30 mg/L) was able to increase root activity, maintain a reasonably

high root respiratory metabolism, and increase the ability to absorb water and nutrients. Restoration of plant root length is highly dependent on the ability to withstand oxidative stress and reduce lignin production (Matsumoto and Matoda 2012). The immobilization of Al-pectin at the root cell border has played an important role in protecting the root apex from exposure to Al (Yu et al. 2009). Inhibition of root length was due to the binding of Al in the root cell walls (Rangel et al. 2009). The root tip or root apex is the most sensitive area to Al toxicity (Huang et al. 2009). Roots affected by Al toxicity have an impact on water and nutrient absorption inhibition (Sun et al. 2010; Abate et al. 2013; Kichigina et al. 2017), thereby reducing plant growth (Wang et al. 2006; Miyasaka et al. 2007). The results of several studies reported that Al toxicity was able to damage the cell ultrastructure of longan (Xiao et al. 2003) and wheat (Li et al. 2006). Al concentrations in several micromolar (5 - >5 micromolar) can inhibit plant root growth quickly (Matsumoto and Motoda 2012; Pattanayak and Pfukrei 2013). Yu et al. (2011) reported that increasing the Al concentration was able to reduce the total root volume of soybean cultivars Z.2 and Z.3.

Biomass and height are among the agronomic parameters that correlate with plant tolerance to Al exposure (Anas and Yoshida 2004). Al toxicity can reduce plant biomass (Abate et al. 2013). However, at certain concentrations, Al can increase plant biomass. This study also showed that 2 mM Al concentration was able to stimulate root, shoot and total dry weight of *F. moluccana* and *A. chinensis* seedlings (Figures 3, 4, 5). Meanwhile, increasing the Al concentration (2 to 4 mM) reduced the dry weight of roots, shoots, and the total in both seedlings. It is because the growth in height and root length of the two seedlings began to decrease when the Al concentration was 2 mM to 8 mM. These conditions have an impact on reducing root, shoot, and total dry weight in both seedlings. Kichigina et al. (2017) reported that Al 80 ml $AlCl_3$ treatment for 10 was able to decrease root and shoot biomass in soybean genotypes.

Increasing the Al concentration (4 to 8 mM) reduced the tolerance index level of the two species of plants (Figure 6). It is shown that Al is capable of being toxic when available in high concentrations (8 mM). Each plant can develop various mechanisms to tolerate Al exposure (Garzon et al. 2011; Pattanayk and Pfukrei 2013). Exclusion and detoxification of Al in roots is a common mechanism for plants to tolerate Al toxicity (Kochian et al. 2004; Abate et al. 2013). In addition, plants also develop an organic acid exudation mechanism to tolerate Al exposure (Singh and Chaucan 2011; Abate et al. 2013; Kichigina et al. 2017). Organic acids can chelate Al so that Al does not become toxic to plants (Ryan et al. 2011). Organic acids such as malic, oxalate, and citric have been positively correlated with plant tolerance to Al toxicity (Mimmo et al. 2013; Vondráčková et al. 2015). The results of several studies reported that exudation of citric, oxalic and malic acids in *P. tremuloides* and *P. trichocarpa* (Naik et al. 2009) and *P. tremula* (Qin et al. 2007).

The content of chlorophyll and carotenoids in *F. moluccana* seedlings was more fluid, while in *A.*

chinensis seedlings the increase in Al concentration reduced the chlorophyll and carotenoid content (Table 1). This condition indicates that *F. moluccana* seedlings can adapt well to several Al concentrations to a certain extent. Al toxicity can reduce chlorophyll content (Abdalla 2008; Mukhopadyay et al. 2012). The decrease in chlorophyll content is related to disruption of Mg uptake and transportation because Mg is an integral part of the chlorophyll molecule (Ali 2008). Al exposure was able to reduce the chlorophyll content and the photosynthetic rate of eucalyptus plants, where the Al 4.4 mM concentration with a pH of 3 significantly reduced these two parameters (Yang et al. 2015). Guo et al. (2012) reported that AL toxicity was able to reduce the chlorophyll content of *Oryza sativa* L. cultivars Xiushui 132 (tolerant) and Yongyou 8 (sensitive).

The rates of photosynthesis in *F. moluccana* and *A. chinensis* seedlings did not show significant difference between Al concentrations (Figure 7). The decrease in the rate of photosynthesis is one of the effects of Al toxicity (Abate et al. 2013). ROS accumulation causes oxidative stress and results in damage to the photosynthetic process equipment (Yang et al. 2015). In addition, the decrease in the rate of photosynthesis is caused by the Al stress can inhibit the process of nutrient absorption and cause plants to become deficient (Ridolfi and Garrec 2000). Martins et al. (2013) reported that aluminum was able to significantly reduce photosynthetic pigments in *Plantago algarbiensi* with soil pH 4.0.

Lipid peroxides exhibit oxidative damage to lipids containing several carbon-carbon double bonds (Jin et al. 2008). Lipid peroxide in plants is caused by toxicity from heavy metal exposure (Washa et al. 2012). The increase in MDA levels indicates that heavy metals cause oxidative stress in plants. The presence of heavy metal treatment can stimulate the production of MDA, which is thought to be the result of the formation of free radicals (Panda et al. 2003). This can be seen in the results of the study, where at some Al concentrations the MDA content of both seedlings increased, although it did not show a significant difference between Al concentrations (Figure 8). The highest MDA content in both seedlings was when the Al concentration was 4 mM. This indicated that the Al concentration of 4 mM was able to cause oxidative stress in both seedlings. However, the MDA content in both seedlings decreased again when the Al concentrations were 6 and 8 mM. This finding is different from results reported by Jin et al. (2008) that the higher concentration of the metal can increase the levels of MDA in plants.

Al toxicity is also capable of causing oxidative stress caused by the increase and accumulation of ROS (Darkó et al. 2004). This condition disrupts plant metabolism (Inostroza-Blancheuteau et al. 2012; Yamamoto et al. 2002), causes damage to DNA (Meriga et al. 2010), cell homeostasis, DNA strand or band damage, protein defragmentation, cell membrane damage, and photosynthetic pigments, and stimulates plant cell damage (Flora 2009; Miller et al. 2010; Rout and Sahoo 2015). Increased production of ROS such as superoxide free radicals ($O2^-$), hydroxyl free radicals (OH^-), singlet oxygen

(O2*), and hydrogen peroxide (H_2O_2) as cytotoxic compounds that can cause disruptive oxidative stress. The balance between pre-oxidants and homeostasis in plant cells (Hossain et al. 2012). The accumulation of ROS can produce lipid peroxides, which in turn can damage the biofunctions of cell members and plant cell metabolism, which will reduce plant growth (Sytar et al. 2013; Mathimaran et al. 2017).

The Al concentration or total Al content in plant tissue is strongly influenced by the treatment given, the plant organs analyzed, and the Al concentration in the soil (Vondráčková et al. 2015). The results showed that the Al content in *F. moluccana* and *A. chinensis* seedlings was higher in the roots than in the shoots in each treatment. The Al content of *F. moluccana* and *A. chinensis* seedling tissue increased when the concentration of Al was available in high concentrations (6-8 mM). The difference in Al distribution between the two seedlings can be presumed due to the different Al detoxification mechanisms in each plant (Vondráčková et al. 2015). Teraoka et al. (2002) reported that Al accumulation was higher in roots of *Triticum aestivum* L. Brevor variety. Al accumulation in eucalyptus roots is strongly influenced by soil pH (Godbold and Brunner 2007). However, several studies have reported that Al tolerance is not correlated with Al content in roots (Bernal and Clark 1997; Kichigina et al. 2017).

Al exposure treatment gave significant differences in the growth of height, root length, dry weight (root, shoot, and total) of *F. moluccana* and *A. chinensis* seedlings. Low Al concentration (2 mM) was able to trigger the growth of *A. chinensis* seedlings. The tolerance index of the two seedlings was highest when the Al concentration was 2 mM, which indicated that both species of seedlings were able to grow well with exposure to Al (2 mM). Al content in seedling tissue of *F. moluccana* and *A. chinensis* increased when Al concentration was high (6-8 mM). These results can be used as the basis that *F. moluccana* and *A. chinensis* species can be used as plants for revegetation activities on lands that have low Al content.

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