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Effects of Indigenous and Non-Indigenous Arbuscular Mycorrhizal Fungi on Growth and Plant Nutrient Uptake by *Terung Asam* (*Solanum lasiocarpum* Dunal)

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ABSTRACT

Terung asam (*Solanum lasiocarpum* Dunal) is a native fruit vegetable that is gaining interest as a commercial crop in Sarawak and Malaysia. Malaysia is covered by soils that are highly weathered, acidic, and low in fertility and depend on chemical fertilisers to promote good plant growth. Alternative means to reduce dependency on chemical fertiliser, for example arbuscular mycorrhiza fungi (AMF), must be sourced. Very few research on *terung asam* has been documented particularly on nutrients uptake. The objectives of this research were to investigate the effect of indigenous and non-indigenous AMF on nutrient uptake by *terung asam*. A greenhouse experiment was conducted consisting of three treatments namely control (T1), indigenous AMF (T2), non-indigenous AMF (T3). The treatments were arranged in a complete randomised design with four subsamples and four replicates. Thirty-day-old seedlings were transplanted and measured for their heights and stem diameters for 90 days. Fresh and dry shoot and root weights were taken during harvesting. Plant nutrient analyses were conducted using Kjeldahl method for total N, single ashing for P and single ashing and double acid for K, Ca and Mg. The results revealed the addition of AMF spores at 200 spores per pot, increased plant height by 13 to 33% and stem diameter by 5 to 25% and more leaves were retained by T3 plants at harvesting. T3 recorded higher fresh shoot (11.27%) and dry shoot (14.98%) as well as fresh root (23.67%) and dry root (22.77%) weights than T1 plants. Addition of AMF in treatments T2 and T3 promoted better nutrient uptake by aboveground and belowground biomasses particularly for K, Ca and Mg. T3 was superior in terms of the nutrient uptake for most nutrients. AMF used in T3 showed better results as the AMF spores were proven effective in promoting plant growth while AMF used in T2 were obtained from the field and untested. The findings of this study showed the potential of indigenous and non-indigenous AMF in promoting growth and nutrient uptake by *terung asam* plants.

Keywords: Arbuscular mycorrhizal fungi, biomass, growth, nutrient uptake, *terung asam*

INTRODUCTION

Solanum lasiocarpum Dunal or locally known as *terung asam* is a golden yellow sour eggplant of the Solanaceae family that is native to Sarawak (Sman, 2017). *Terung asam* is also known as *terung dayak*, *terung iban*, *terung berui* and *terung bulu* in Sarawak (Lim, 2013). *Terung asam* is known as *terung pasai* in Brunei, *cung bulu* in Indonesia, *khua kon* in Laos, *tabanburo* in the Philippines, *sinkade* in Myammar, *yongkuidi* in Vietnam and *muuk* in Thailand (Razili *et al*., 2015). *Terung asam* can be found planted across the tropical region including India, Bangladesh, southern China, Indochina, Indonesia, Malaysia, New Guinea, Solomon Islands, Thailand, and the Philippines (Heiser 1987; Mohanan & George 2004).

Terung asam is commonly planted together with hill paddy as an intercrop plant by local farmers (Shariah, 2013) or grown on the edges of villages as weeds (Samuels, 2012). *Terung asam* is traditionally planted by seed, which normally germinates within seven days of sowing. Seeds can be directly planted in the field or germinated in polybags or seedling trays in a nursery for a period of 3 to 4 weeks before transplanting (Shariah *et al*., 2013). *Terung asam* prefers temperatures between 25 and 32 °C with an annual rainfall of 1,500 mm

to 2,000 mm and relative humidity of 80% and 50-75% shade for growth. Shariah *et al*. (2013) documented that the best soil for planting *terung asam* will be mineral or loamy soil with proper drainage and pH ranging from 5.5 to 6.8. *Terung asam* prefers soil with high content of organic matter and is known for its water-loving characteristics especially during fruiting.

Agronomically, *terung asam* forms flowers around 120 days after transplanting while fruits can be harvested after 132 to 141 days of transplanting (Shariah *et al*., 2013). *Terung asam* production can reach between 16 and 20 tonnes per hectare. In 2017, the price of the fruit was recorded between RM6 and RM10 per kg depending on the size and quality. Based on this price range, a net profit of RM134,313 to RM 204,323 can be generated from a production of 16,000 to 23,000 fruits from each harvest cycle sold at RM10 per kg (Sman, 2017).

Malaysia is covered by Ultisols and Oxisols soils that are highly weathered, acidic, and low in fertility for crop production. These soil groups are commonly found in the tropics and contain low amounts of organic matter thus making them insufficient in promoting plant growth (Shamshuddin & Anda, 2012). The compost is normally applied to alleviate the infertility issue (Anda *et al*., 2010). Another approach is by applying mineral fertilisers, but this has increased the cost of crop production. Furthermore, the application of fertilisers more than the recommended limits is known to cause undesirable effects such as decreasing soil pH, soil pollution, reduction in beneficial microbial activity, and even soil compaction. Therefore, alternative means must be sourced to reduce total dependency on mineral fertilisers to improve growth.

Arbuscular mycorrhizal fungi (AMF) are one of the many organisms that abundantly found in the environment, colonising almost all land communities including 80% of all vascular plants (Smith & Read, 2010). These fungal symbionts are integral components of plant communities in both natural and agricultural ecosystems. Various authors have documented that associations between plant species and AMF are likely to increase the efficiency of fertiliser uptake and significantly enhance plant growth (height, leaf area, root volume, shoot, and root dry biomass) over uninoculated plants. Increased growth has been reported in various short-term and perennial crops inoculated with AMF. Some studies conclude that indigenous consortia are more effective at promoting plant growth in different species (Trejo *et al*., 2011; Carreón-Abud *et al*., 2015). Jansa *et al*. (2009) explained that the contrasting results that determined the final plant performance could be related to the dominant effect of one or more isolates of the complex AMF community. Meanwhile, Reyes-Tena *et al*. (2015) highlighted that the differences in the ability of indigenous AMF in promoting growth probably relied on the origin and diversity of AMF species that make up the inoculum.

To our knowledge, no studies have been conducted or reported on the roles of AMF in promoting growth and nutrient uptake by *terung asam*. Therefore, the objective of this study was to investigate the growth performance and nutrient uptake by *terung asam* plants inoculated with indigenous and non-indigenous AMF.

MATERIALS & METHODS

Seed Preparation

Terung asam were purchased from a local wet market (Pasar Utama Bintulu), and the seeds were cleaned and dried using paper towels before sowing. Seeds were sowed in potting trays filled with potting media and were allowed to germinate in a greenhouse. The seedlings were considered ready for transplanting when two fully developed leaves had been produced. Only seedlings with similar heights and sizes were selected for the experiment to reduce biases.

AMF Inocula and Soil

The soil samples used in the isolation of indigenous AMF spores were sourced from the rhizospheres of trees growing in the disturbed man-made forest or known as the analogue forest (N 03°12’33.4”, E 113°04’58.2”). The site was selected based on the abundance of AMF found during the preliminary research conducted on the site. In the preliminary research, three AMF genera were found namely *Glomus* spp., *Acaulospora* spp., and *Gigaspora* spp. Soil samples were taken from three random spots at a depth of 5 cm to 20 cm for AMF spore isolation. This depth was selected as most of the root matrix of tropical trees are available at this depth and the root matrix is related to the sporulation of AMF. The soil samples were taken to the laboratory and air-dried. As for the non-indigenous AMF, the source (RHIZAgold) was

Table 1. Concentration of nutrients in potting media prior to experiment

Nutrient Element	Concentration
Total N (%)	0.17 ± 0.01
Total P (mg/kg)	1,614.75 ± 5.64
Available P (mg/kg)	74.59 ± 3.34
Total K (mg/kg)	747.50 ± 6.29
Exchangeable K (mg/kg)	16.95 ± 0.87
Total Ca (mg/kg)	905.00 ± 6.45
Exchangeable Ca (mg/kg)	36.70 ± 5.05
Total Mg (mg/kg)	880.00 ± 4.08
Exchangeable Mg (mg/kg)	17.92 ± 0.69

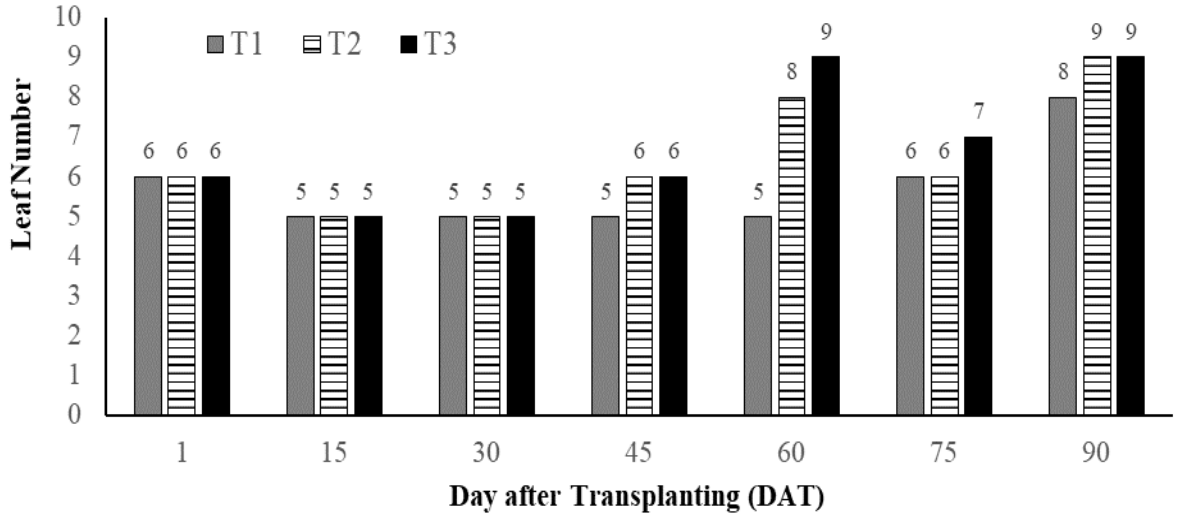

Figure 1. Leaf number of *Terung asam* plants recorded for a period of 90 days

purchased from a local agricultural product supplier shop in Bintulu, Sarawak. RHIZAgold is documented to contain a selected cocktail mixture of at least 12 AMF species in its preparation with an effective concentration of 250-300 spores per 10 g of product.

Seedlings were ready for transplanting 30-days after germination. Approximately 200 AMF spores were added to each planting hole right before the seedling was planted to ensure that the AMF spores were in contact with the seedling root. Each pot (27 cm x 22 cm) was filled with soil of the Bekenu series (Table 1) obtained from an intensive agricultural site in the campus and adjusted to three-part subsoil and one-part sand before being planted with a single *terung asam* seedling. The first day for growth measurement was conducted on the first day after transplanting (DAT).

Plant Monitoring and Growth Parameters

Watering is a critical factor that influences the plant growth. Each plant was provided with approximately 500 mL of water each day to maintain pot medium humidity at the optimum level to promote plant growth. Weeding activity was done routinely to get rid of weeds from growing inside the pot and minimise competition. Strict observation on plant growth, pest, and pathogen, as well as weed control, was conducted. Mechanical pest control method was adopted to avoid the usage of pesticide, weedicide, or

herbicide that may harm the growth and development of *terung asam* plant and AMF.

Plant data including total leaf number per plant and plant height were recorded and measured every three days while plant diameter and chlorophyll content were measured every 15 days. Leaf number was counted manually while the plant height was measured using a measuring tape. The plant height is considered as the vertical measurement made from the leaf tip to the ground under natural conditions while plant diameter was measured using a digital calliper meter (Mitutoyo 500) and made at the widest part of the internode above the cotyledons (Wang *et al*, 2015). Meanwhile, a chlorophyll meter (Minolta SPAD 502) was used to determine the chlorophyll content.

Plant Biomass

Harvesting was conducted on 90 DAT. Plant biomass was separated into aboveground (plant parts above the cotyledon collar including leaves, stem, branches) and belowground biomass (all root parts below the cotyledon collar). Harvested roots were washed thoroughly using tap water to ensure that they were free from any soil debris. Each aboveground and belowground biomass sample was labeled and kept separately in a clear plastic bag and stored in a polystyrene box to retain moisture. Samples were brought to the laboratory and further cleaned then dried using tissue paper before being weighed to obtain the fresh weight using a benchtop balance (A&D EK6100i). The aboveground and belowground biomass were separately inserted into paper envelopes (33 cm x 24 cm) and dried continuously in an oven (Memmert UFB500) at 70 °C until a constant weight was achieved.

Plant Nutrient Content

Plant nutrient analyses were conducted to determine the content of N, P, K, Ca, and Mg of aboveground and belowground biomass. The dried sample was shredded into smaller sizes before the extraction. The Kjeldahl method (Bremner, 1965; Tan, 2005) was used to determine the total N content while the single dry ashing method (Cottenie, 1980) was adopted to extract total P, K, Ca, and Mg. Total P was determined using the UV-Vis spectrophotometer (Perkin Elmer Lambda 25) at 882 nm wavelength (Murphy & Riley, 1962) while total K, Ca and Mg were determined using the Atomic Absorption Spectrophotometer (AAS, Perkin Elmer AAnalyst 800). The nutrient uptake was determined for the two biomasses by multiplying the plant nutrient concentrations with the respective dry weights (Thangasamy & Chavan, 2017).

Experimental Design and Statistical Analysis

The study consisted of three treatments (control, indigenous AMF, and non-indigenous AMF) and each treatment consisted of four subsamples which were replicated four times. Analysis of variance (ANOVA) was used to test the treatment effects. The means were compared using the Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$. The statistical analysis was conducted using the Statistical Analysis Software (SAS) Version 9.3. The correlation analysis was also included to see the relationship between plant roots and height growth.

RESULTS

Height Growth

Table 2 shows that for the first five measurements conducted, no significant difference was observed for *terung asam* supplied with additional AMF (T2, T3) or the control (T1). Significant differences in height growth began to show after 15 DAT. From 15 to 27 DAT, height growth of plants inoculated with non-indigenous AMF (T3) was found to be significantly different from the control (T1) and those added with indigenous AMF from the disturbed man-made forest (T2). From 30 to 45 DAT, T2 and T3 further showed their dominance over T1. This pattern was continuously observed in the following three measurements (48 to 54 DAT) where T1 were found to be significantly inferior to T2 and T3 which among themselves were not significantly different in terms of height growth. As measurements continued from 57 to 81 DAT, T3 further showed their superiority in height growth by being significantly taller than T1 and T2. T1 gave the lowest height growth among the three treatments. For the last three days of height measurement, T3 showed dominance in height growth over T1. *Terung asam* plants provided with additional indigenous and non-indigenous AMF exhibited 13% to 33% higher height growth than the control plants.

Table 2. Mean heights of *terung asam* plants as affected by treatments measured at three days interval for a period of 90 days

DAT	Height growth (cm) by treatment		
	T1	T2	T4
1	$1.99^{a} \pm 0.07$	$2.09^{a} \pm 0.07$	$1.99^{a} \pm 0.12$
3	$2.41^{a} \pm 0.09$	$2.56^{a} \pm 0.06$	$2.38^{a} \pm 0.08$
6	$2.73^{a} \pm 0.09$	$2.89^{a} \pm 0.07$	$2.70^{a} \pm 0.14$
9	$3.19^{a} \pm 0.07$	$3.31^{a} \pm 0.11$	$3.29^{a} \pm 0.18$
12	$4.01^{a} \pm 0.16$	$4.01^{a} \pm 0.15$	$4.45^{a} \pm 0.16$
15	$4.48^{b} \pm 0.16$	$4.36^{b} \pm 0.14$	$5.04^{a} \pm 0.15$
18	$5.03^{b} \pm 0.17$	$4.82^{b} \pm 0.16$	$5.83^{a} \pm 0.14$
21	$5.85^{c} \pm 0.18$	$5.76^{bc} \pm 0.21$	$6.94^{a} \pm 0.23$
24	$6.84^{b} \pm 0.20$	$7.01^{b} \pm 0.29$	$8.23^{a} \pm 0.51$
27	$7.91^{b} \pm 0.26$	$8.19^{b} \pm 0.39$	$9.46^{a} \pm 0.69$
30	$9.46^{b} \pm 0.38$	$10.38^{ab} \pm 0.59$	$11.38^{a} \pm 0.85$
33	$11.36^{a} \pm 0.49$	$12.29^{a} \pm 0.64$	$13.33^{a} \pm 0.85$
36	$13.19^{b} \pm 0.56$	$14.34^{ab} \pm 0.81$	$16.00^{a} \pm 1.17$
39	$15.09^{c} \pm 0.62$	$17.22^{bc} \pm 0.78$	$19.85^{a} \pm 0.93$
42	$16.83^{b} \pm 0.75$	$19.29^{ab} \pm 0.99$	$21.88^{a} \pm 1.08$
45	$18.78^{b} \pm 0.85$	$21.61^{ab} \pm 1.06$	$24.41^{a} \pm 1.35$
48	$20.65^{b} \pm 1.04$	$24.38^{a} \pm 1.21$	$27.38^{a} \pm 1.43$
51	$22.41^{b} \pm 1.05$	$26.94^{a} \pm 1.18$	$29.56^{a} \pm 1.85$
54	$24.24^{b} \pm 1.26$	$29.29^{a} \pm 1.26$	$31.73^{a} \pm 2.04$
57	$25.38^{c} \pm 1.26$	$31.13^{b} \pm 1.41$	$35.63^{a} \pm 1.82$
60	$27.00^{c} \pm 1.32$	$33.63^{b} \pm 1.67$	$39.75^{a} \pm 1.73$
63	$28.88^{c} \pm 1.35$	$35.44^{b} \pm 1.73$	$41.00^{a} \pm 1.54$
66	$30.47^{c} \pm 1.38$	$37.31^{b} \pm 1.88$	$43.75^{a} \pm 1.69$
72	$32.14^{c} \pm 1.58$	$39.19^{b} \pm 1.93$	$46.00^{a} \pm 1.81$
75	$34.56^{c} \pm 1.74$	$41.19^{b} \pm 1.93$	$48.25^{a} \pm 1.88$
78	$36.81^{c} \pm 1.81$	$42.94^{b} \pm 1.95$	$49.25^{a} \pm 1.71$
81	$38.31^{c} \pm 1.69$	$44.50^{b} \pm 1.91$	$50.88^{a} \pm 1.78$
84	$42.88^{b} \pm 1.98$	$48.13^{ab} \pm 1.90$	$53.43^{a} \pm 2.49$
87	$43.62^{b} \pm 2.13$	$50.69^{ab} \pm 2.43$	$54.33^{a} \pm 3.14$
90	$47.31^{b} \pm 2.07$	$51.60^{ab} \pm 2.21$	$56.00^{a} \pm 3.02$

Note: Different letters within a row indicate a significant difference between means ± standard error using DMRT at $p \leq 0.05$

Table 3. Diameter of *terung asam* plants as affected by treatments measured at an interval of 15 days for a period of 90 days

DAT	Diameter growth (mm) by treatment		
	T1	T3	T4
1	$3.32^{a} \pm 0.08$	$3.40^{a} \pm 0.15$	$3.69^{a} \pm 0.05$
15	$4.79^{b} \pm 0.03$	$4.91^{a} \pm 0.14$	$5.56^{a} \pm 0.06$
30	$6.57^{b} \pm 0.12$	$6.32^{b} \pm 0.11$	$7.16^{a} \pm 0.14$
45	$7.67^{b} \pm 0.22$	$7.74^{b} \pm 0.17$	$8.91^{a} \pm 0.23$
60	$8.44^{b} \pm 0.15$	$8.91^{b} \pm 0.27$	$10.20^{a} \pm 0.28$
75	$9.00^{c} \pm 0.09$	$9.84^{b} \pm 0.22$	$11.55^{a} \pm 0.35$
90	$9.55^{d} \pm 0.08$	$10.62^{b} \pm 0.13$	$12.75^{a} \pm 0.16$

Note: Different letters within a row indicate a significant difference between means ± standard error using DMRT at $p \leq 0.05$

Table 4. Fresh shoot and root weights and flowering phase affected by AMF as observed in *terung asam* plants

Parameter	Treatment		
	T1	T2	T3
Fresh shoot (g)	$83.32^{c} \pm 0.33$	$92.40^{b} \pm 0.15$	$93.90^{a} \pm 0.42$
Dry shoot (g)	$10.95^{b} \pm 0.22$	$12.47^{a} \pm 0.19$	$12.88^{a} \pm 0.17$
Fresh root (g)	$45.80^{b} \pm 0.44$	$59.58^{a} \pm 0.18$	$60.00^{a} \pm 0.26$
Dry root (g)	$10.24^{b} \pm 0.16$	$13.42^{a} \pm 0.23$	$13.26^{a} \pm 0.25$
Flowering	Yes	Yes	Yes

Note: Different letters within a row indicate a significant difference between means ± standard error using DMRT at $p \leq 0.05$

Table 5. Nutrient uptake by aboveground biomass recorded at the end of the experiment

Element	Nutrient uptake by aboveground biomass		
	T1	T2	T3
N (mg/plant)	$48.50^{a} \pm 0.61$	$57.96^{a} \pm 4.55$	$48.00^{a} \pm 3.51$
P (mg/plant)	$23.06^{a} \pm 4.90$	$19.64^{a} \pm 1.08$	$25.09^{a} \pm 0.18$
K (mg/plant)	$3.59^{b} \pm 3.65$	$8.27^{a} \pm 0.27$	$8.80^{a} \pm 0.29$
Ca (mg/plant)	$6.61^{c} \pm 0.33$	$16.81^{b} \pm 0.90$	$21.13^{a} \pm 0.91$
Mg (mg/plant)	$4.08^{b} \pm 0.25$	$6.31^{a} \pm 0.11$	$6.67^{a} \pm 0.20$

Note: Different letters within a row indicate significant difference between means ± standard error using DMRT at $p \leq 0.05$

Table 6. Nutrient uptake by belowground biomass recorded at the end of the experiment

Element	Nutrient uptake by below ground biomass		
	T1	T2	T3
N (mg/plant)	$2.72^{b} \pm 0.28$	$7.59^{a} \pm 1.02$	$5.50^{a} \pm 0.65$
P (mg/plant)	$11.65^{a} \pm 0.72$	$15.30^{a} \pm 0.40$	$16.88^{a} \pm 2.70$
K (mg/plant)	$3.50^{c} \pm 0.37$	$9.16^{b} \pm 0.21$	$10.41^{a} \pm 0.55$
Ca (mg/plant)	$6.26^{c} \pm 0.46$	$17.17^{b} \pm 0.99$	$22.24^{a} \pm 0.59$
Mg (mg/plant)	$3.84^{c} \pm 0.27$	$6.86^{b} \pm 0.09$	$7.37^{a} \pm 0.16$

Note: Different letters within a row indicate significant difference between means ± standard error using DMRT at $p \leq 0.05$

Diameter growth

Table 3 shows the growth of stem diameter for 90 days. *Terung asam* plants added with non-indigenous AMF (T3) showed better diameter growth than the control plants (T1) as early as 15 DAT. All plants with added AMF (T2 and T3) were not significantly different from one another during this period. *Terung asam* in T1 showed lower diameter growth than plants supplied with indigenous and non-indigenous AMF. T3 showed higher diameter growth than the other two treatments after 30 DAT and this pattern continued until the end of the experiment. T3 continuously showed dominance over T1 and T2, with T1 always showing inferiority in terms of diameter growth. All diameter growth became significantly different at 75 DAT whereby plants inoculated with AMF became more prominent than the control plants. Plants inoculated with indigenous or non-indigenous AMF showed better diameter growth by 5% up to 25% than the control plants.

Plant biomass and leaf number

Table 4 displays the mean fresh root weight, mean fresh shoot weight and the ability of the plant under each treatment to reach the flowering stage. The fresh weights for the treatments varied from 83.32 g to 93.90 g for the shoots and 45.80 g to 60.00 g for the roots. Meanwhile, the dry weights of plants for the treatments ranged from 10.95 g to 12.88 g for the shoots and 10.24 g to 13.26 g for the roots. Generally, higher fresh and dry shoot and root weights were observed for plants with indigenous and non-indigenous AMF than the control plants (T1). A difference of up to 11.27% for fresh shoot weight and 14.98% for dry shoot weight were observed between plants with non-indigenous AMF (T3) and the control plants (T1). Plants inoculated with additional AMF (T2 and T3) recorded heavier shoot and root weights than the control plants (T1). Similarly, plants with non-indigenous AMF (T3) recorded higher fresh root weight with a difference of 23.67% than T1 while 22.77% was documented for dry root weight for the same treatment. All plants began to flower at 90 DAT.

Leaf numbers in all treatments began to show some significant differences after 45 DAT (Figure 1). *Terung asam* plants treated with indigenous AMF (T2) and with non-indigenous AMF (T3) were found to have more leaves (nine leaves) compared to plants without additional AMF (T1). *Terung asam* plants provided with additional non-indigenous AMF (T3) were found better in retaining their leaves than other treatments.

Plant nutrient uptake

The nutrient uptake by the plant based on the aboveground biomass for the treatments was significantly different for all treatments except for total N and P (Table 5). T2 and T3 treated plants showed significantly higher nutrient values compared to T1 for total K, Ca, and Mg. The total K uptake was 3.59 mg/plant, 8.27 mg/plant in T1 and 8.80 mg/plant in T3, respectively. As for total Ca, all treatments showed significant differences for nutrient uptake with T3 plants showing the highest uptake (21.13 mg/plant) followed by T2 (16.0 mg/plant) and T1 with the lowest (6.61 mg/plant) uptake value. Meanwhile, total Mg values were recorded between 4.08 mg/pot in T1 and 6.67 mg/plant in T3 with values recorded

for T2 and T3 not significantly different.

As for nutrient uptake by belowground biomass (Table 6), T2 recorded significantly higher uptake (7.59 mg/plant) for total N than the rest of the treatments with values ranging from 2.72 mg/plant in T1 to 7.59 mg/plant in T3. Only T2 plants (23.52 mg/plant) showed better uptake than T1 plants (11.65%) for total P. As for total K, Ca and Mg uptakes, all treatments were superior to T1 which exhibited lower uptakes for all three elements. The values for nutrient uptake ranged from 3.50 mg/plant (T1) to 10.41 mg/plant (T3) for total K, 6.26 mg/plant (T1) to 22.24 mg/plant (T3) for total Ca, and 3.84 mg/plant (T1) to 7.37 mg/plant (T3) for total Mg.

The addition of AMF spores in treatments T2 and T3 promoted better nutrient uptake in both aboveground and belowground plant biomass especially for nutrients such as K, Ca, and Mg than T1. As for aboveground biomass, treatment T3 was found to be superior to other treatments in terms of nutrient uptake for most nutrient elements. Nutrient uptakes by T3 aboveground biomass as compared to other treatments were greater by 28.29% to 59.20% for K, 20.44% to 68.71% for Ca, and 10.49% to 38.83% for Mg. On the other hand, comparison with other treatments observed that nutrients uptake by T3 for belowground biomass were higher by 12.00% to 66.38% for K, 22.62% to 71.31% for Ca, and 6.92% to 47.90% for Mg.

DISCUSSION

Significant differences were observed in the physical growth (height and stem diameter) of *terung asam*. Generally, *terung asam* plants with additional AMF showed better height growth than the control. *Terung asam* treated with the indigenous and non-indigenous AMF grew 13% to 33% higher than plants without any additional AMF provided. Meanwhile, plants inoculated with indigenous and non-indigenous AMF showed better diameter growth by 5% up to 25% than plants without any addition of AMF. Song (2017) noted the importance of strong root growth in ensuring proper growth and development of the shoot as the root system connects the soil and plant shoot with regards to material exchange between the two. *Terung asam* plants treated with non-indigenous AMF showed superior diameter growth as well as the overall aboveground biomass. Sun *et al*. (2019) documented that stem diameter is responsible to supply developing leaves with resources for growth besides its role in dictating the flow of photosynthates from the mature leaves to other parts of the plants. It is believed that the higher aboveground biomass shown by *terung asam* plants in T3 may be closely related to the better stem diameter growth of the plant as predicted by Paul *et al*. (2016).

The findings of this research agree with the report by Eo & Eom (2009) on some vegetable plants and Lu & Wu (2017) on white clover (*Trifolium repens*) where plants inoculated with AMF showed higher biomass increment. Hoeksema *et al*. (2010) reported that plants colonised by AMF grew larger than those without AMF. A similar conclusion was documented by Ortas (2010) where cucumber plants inoculated with AMF resulted in better plant growth. Better growth observed in AMF plants may be an indication that AMF inoculated plants, through the development of extraradical hyphae, can absorb more water and nutrients from the soil (Chen *et al*., 2016). Cagras *et al*. (2000) also reported that mycorrhizal inoculation significantly increased the fresh and dry weight of leaf and shoot, and root biomass of cucumber plants.

In the present study, the nutrient analysis conducted on the potting media (Table 1) before the experiment concluded that the soil was nutrient deficient with low available P, very low exchangeable K and exchangeable Ca, and low exchangeable Mg, which are characteristics of the Bekenu Series. Teste *et al*. (2016) noted deficiency in soil P can cause plants to have low biomass increment of extraradical hyphae in the acquisition of P despite a high AMF root colonisation thus affecting the overall plant growth in *Lycopersicon esculentum* (tomato).

Therefore, it was suggested that AMF inoculation and fertilisation are necessary to achieve sufficient growth in areas where nutrient availability is limited. Schreiner (2007) noted that grapevines, which are highly dependent on AMF to acquire P and other nutrients when planted in P-deficient soils, become less dependent when grown in fertile soils. Subhashini (2016) on the other hand reported a significant increase in plant biomass of *Nicotiana tabacum* L. when NPK fertilisers and AMF were added to plants planted in a soil with poor nutrients availability.

The symbiotic relationship between host plants and AMF is complex. The taxa of the AMF used in the present study were not of the same origin but a mixture of different AMF species. In the present study, although the indigenous mycorrhiza applied in T2 was sourced from a disturbed forest, the diversity of mycorrhiza may still be kept intact and high as the site was planted with perennial tree species with no further disturbance after the establishment until present. *Terung asam* plants inoculated with non-indigenous AMF were found to show better growth than plants inoculated with indigenous AMF for both height and diameter growth. AMF inoculation has been reported to promote plant growth, but it is not always the case. Some isolates of AMF have been reported to decrease the biomass of host plants (Smith & Read, 2010). AMF symbiosis could have been found to differ according to the genotypes involved, the host plants as well as the combination of AMF (Munkvold *et al*., 2004).

There have been various reports regarding the effectiveness of indigenous and non-indigenous AMF in promoting the growth of host plants. Pellegrino *et al*. (2011) noted that indigenous AMF inoculum was more effective than exotic fungal isolate in improving growth and nutrient absorption by *Trifolium alexandrinum*. Ziane *et al*. (2017) reported that indigenous fungal isolates and commercial AMF inoculum failed to give any significant difference in stimulating the growth of tomatoes. Similarly, Ortas & Ustuner (2014) documented that inoculation with an indigenous and commercial inoculum of AMF gave the same effect on *Citrus aurantium* with native spores having the same effect as a commercial inoculum. Meanwhile, Schreiner (2007) concluded that indigenous AMF is not necessarily better in promoting growth and nutrient absorption which is aligned with the findings of this research.

According to Meyer (2004), AMF may significantly improve the growth of host plants during the early stage of plant establishment but van der Heijden *et al.* (2002) highlighted the influence of host plants and environmental conditions in controlling the efficiency of AMF. Environmental factors that can influence AMF colonisation include soil conditions such as the nutritional (Nouri *et al*., 2014) and physical characteristics of soil (Posada *et al*., 2008). Goss *et al*. (2017) highlighted the impact of past cultural or management practices in influencing mycorrhizal colonisation. Thus, the source of indigenous AMF applied may have influenced the effectiveness of AMF in promoting the growth of T2 plants.

Liu *et al*. (2002) documented the ability of AMF in increasing K, Ca, and Mg uptake in soil when the concentration of soil P is low. Similarly, Cruz *et al*. (2017) noted that AMF inoculation will increase the uptake of K, Ca, and Mg besides P and N content. According to Liu *et al*. (2002), lower K, Ca and Mg may be due to the improvement in the exploitation of soil by the AMF either through the increment of the absorption area by the hyphae or shortening of the travel distance required by nutrients to reach the roots. Kothari *et al*. (1990) reported that AMF relationships could increase K, Ca, and Mg uptake by increasing water uptake by speeding up the mass flow of nutrients in the soil to reach the root system.

It was also noted that the effects of AMF on plants can be influenced by factors such as soil conditions and AMF inoculum. The amount of P in the potting medium used in the study was not controlled as the soil was collected from an agricultural field. The source of AMF inoculum added to T2 was from a disturbed forest thus the possibilities that environmental conditions, such as variation in soil P, may have influenced the diversity of AMF taxa causing differences in response by the host plants (Eo & Eom, 2009). Goss *et al*. (2017) also highlighted the impact of past cultural practices that can influence mycorrhizal colonisation.

CONCLUSION

Terung asam plants treated with indigenous (T2) and non-indigenous (T3) AMF spores showed better growth performance than the control plants (T1). Incorporation of AMF in modern agricultural practice is important especially in practicing good and healthy farming. It should be encouraged and exploited to reduce further dependency on chemical fertilisers that can cause detrimental effects on the environment besides the annual rise in fertiliser prices. Search for local sources or indigenous AMF inoculum especially those with host specificity is of high importance as it can further help in reducing crop production costs. Exploration and testing of indigenous AMF inoculum such as the one used in T2 are very much recommended. Future research should explore more indigenous AMF and study the contribution of other microorganisms that complement AMF in enhancing nutrient availability in soil and uptake.

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