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Early field growth performance of ten selected bamboo taxa: The case study of Sabal bamboo pilot project in Sarawak, Malaysia

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Abstract. *Hassan NHM, Abdullah N, Kelana DNA, Perumal M. 2022. Early field growth performance of ten selected bamboo taxa: The case study of Sabal bamboo pilot project in Sarawak, Malaysia. Biodiversitas 23: 2882-2892.* Information on early growth performance and survival rate of bamboos are pivotal for the development of the Sarawak bamboo industry. Thus, a study on the early growth performance of ten bamboo taxa was conducted at the Sarawak Bamboo Pilot Project site in Sabal, Simunjan, Sarawak, Malaysia. Six taxa were originated from Yogyakarta, Indonesia, and the other four bamboo taxa were originated locally from Sarawak. Study sites were established at bamboo plantation areas at different age stands. Two replications of data for each taxon involving 50 readings (25 readings for one replication) were measured and quantified for growth parameters of the number of culms per clump, number of new shoots, culm diameter, and culm height. The findings indicated that *Gigantochloa hasskarliana* (Busi bamboo) had the highest number of culms per clump (43) while *Guadua angustifolia* (Duri bamboo) had the highest number of new bamboo shoots (2.93). Nonetheless, *Dendrocalamus asper* (Green) had the highest culm diameter (3.61 cm) while *Bambusa balcooa* (Bema bamboo) had the highest culm height (8.36 m). The results showed that different bamboo species have different early growth performances, thus further detailed investigation and long-term monitoring period are required to achieve the commercial plantation scale, especially in Sarawak.

Keywords: Bamboo diameter, bamboo height, growth performance, Sarawak bamboo, Yogyakarta bamboo

INTRODUCTION

Bamboos are perennial giant herbaceous and woody grasses that belong to the Poaceae or Gramineae family (Liese and Köhl 2015). They are native and widely distributed in the tropical, subtropical, and temperate regions of all continents except Antarctica and Europe, with approximately 90 genera and over 1500 species (Kaminski et al. 2016; Yigardu et al. 2016). Bamboos grow faster than any other plant in nature, with some species reaching 40 meters in height in just a few months while some others can grow at a rate faster than one meter per day (Getachew et al. 2021). In Malaysia, bamboos are distributed from sea level to 3000 m above and there are about 70 bamboo species in the country with 20 of the world's species found in the country's native forests, including *Gigantochloa levis* (Beting bamboo), *Gigantochloa scortechinii* (Semantan bamboo), and *Gigantochloa ligulata* (Tumpat bamboo) (INBAR 2021). Specifically, there are 50 species of bamboo in Peninsular Malaysia, 30 species in Sabah, and 20 species in Sarawak.

Bamboo is widely recognized as a highly renewable, fast-growing, and cost-effective raw material. It is a commodity utilized by one-third of the world's population as an important material for housebuilding. It was also traditionally used for the making of rafts that serve as an important medium of transportation and used by the communities in agriculture, construction, arts and crafts, and furniture (Setiawati et al. 2017; Irawan et al. 2019). It can be a sustainable source of raw material as it matures quickly within three to four years and can live up to 100 years. Bamboo is widely regarded as an excellent substitute for wood in the form of laminated bamboo boards (Appiah-Kubi et al. 2014). In the Philippines, Pulhin and Ramirez (2016) reported that due to the limited supply and high cost of wood and wood products as a result of unfavorable policies and regulations affecting the wood industries, bamboo is gaining widespread acceptance as the best substitute material. Bamboo is regarded as one of the most important non-timber forest products in terms of total production and export gain in the country (Razal and Palijon 2009). Bamboo was used to produce a variety of household and light construction applications at a low cost, earning it the moniker "poor man's timber". For example, giant bamboo (*Dendrocalamus asper*) is a popular and economically important species of bamboo in Bukidnon Province, the Philippines (Decipulo et al. 2009). On the other hand, in Sarawak, Malaysia, the native species of bamboo are mostly medium-sized and thin-walled and therefore suitable for slivering, mat making, and basketry. These are also suitable for products such as toothpicks, skewers, chopsticks, incense sticks, and handicrafts. Those with a thicker culm wall like *G. scortechinii*, *G. levis*, *Bambusa blumeana*, and exotic species would be suitable for construction, furniture, and industrial manufacture of timber substitutes (Subramony et al. 2016).

In terms of economy, the bamboo industry has come a long way since 2015 when total national export stood at USD 0.18 million, compared to USD 2.09 million in 2019 (INBAR 2021). Based on the available data, INBAR (2021) estimates the global bamboo and rattan sector has a trade value amounting to USD 60 billion, and most of the revenue is contributed by domestic trading. According to the data from UN Comrade Database, international exports of bamboo and rattan products in 2017 were valued at USD 1.7 billion. This included many highly processed bamboo and rattan goods, such as flooring, panels, and cladding, as well as more traditional, homemade products, such as woven items. Most of the exporting countries come from subtropical and tropical regions which grow bamboo. The bamboo-producing countries are mostly concentrated in Asia for instance China. Based on the custom data, China is leading in bamboo trading in 2018 with a trade value amounting to USD 39 billion. However, several non-bamboo-producing areas are also big exporters of bamboo products. For example, the European Union is the world's second-largest exporter of bamboo products. EU sources raw materials and intermediate products of bamboo from Asia, process them, and then exports them to other countries as high value-added finished products (Amir et al. 2020).

Besides benefiting the economy, bamboo is proficient in providing environmental, and employment security to societies. India is considered to be a net importer of bamboo which implies that there are greater opportunities to harness the market potential by increasing its production. However agronomic practices need to be standardized to cultivate bamboo based on agroclimatic conditions on such marginal lands to maximize cost-effective biomass production. Planting densities are an important aspect that requires optimization for enhancing the productivity of biomass through canopy development, retention of soil moisture, and competition with weeds (Patel et al. 2019). The supply of bamboo can be increased by raising intensively managed high-density plantations in degraded forest and non-forest areas. Initiatives of large-scale commercial or industrial plantations may take the lead in bamboo production to fulfill the gap between demands and supply (Hossain et al. 2018).

Sarawak Timber Industry Development Corporation (STIDC) has been appointed by the Sarawak State Government to spearhead the project development area strategically about the development of the bamboo industry in Sarawak. Part of the initiatives was the establishment of a bamboo nursery and bamboo trial plot, and the development of Bambusetum under the Sabal Bamboo Pilot Project that adopted a bamboo plantation model, which is technically and commercially viable. The goal of this bamboo pilot project is to develop better silviculture management, ensure the sustainable supply of quality bamboo, and explore the greater business potential of the bamboo industry for Sarawak in the future. As for the implementation of the Bamboo Pilot Project Plantation, the center provides a large-scale area for the trial experiment. The plantation area is approximately 38 ha (a total of which 25 ha is planted with bamboo) where it is divided into 28 plots for planting different types of bamboo species.

Since research on the early field performance of bamboo taxa in Sarawak has received little attention, there is a need to assess the survival and field growth. Therefore, the objective of this research is to evaluate the bamboo survival rate and early field growth performance of ten selected bamboo taxa, in terms of their number of culms per clump, the number of new shoots, culm diameter, culm height, and mean annual increment of height and diameter.

MATERIALS AND METHODS

Study area

The study was conducted at Block 8406B, Sabal Forest Reserve, Simunjan, Sarawak, Malaysia (00°55' N, 110°43' E) (Figure 1) which is located approximately 51 km Southeast of the Serian town at an altitude of over 20 to 35 m above sea level. The land slopes are between 10° - 20° and the area was previously a mix of dwarf dipterocarp forest or *Kerangas* forest which has been subjected to heavy logging in the past. The soil was derived from non-calcareous sedimentary rocks consisting of fine and whitish sandstone during the mid-Tertiary period. The top layer (0-15 cm) soil texture is sandy clay loam, friable without gravel, and yellowish-brown in color (10YR 5/4). From 15 cm to 50 cm, the soil texture consists of clay to sandy clay and the color was brownish yellow (10YR 6/8) with red mottling. The soil drainage was well-drained and had good permeability (Amir et al. 2020). From 2011 to 2020, the study site received 4,134.7 mm of rain annually. (Meteorological Department 2021). The monthly average air temperature and relative humidity were 26.9°C and 84.1%, respectively, from 2011 to 2020 (Meteorological Department 2021).

Planting materials and propagation methods

We used several types of planting materials, origins, and propagation techniques applied for each planting material. Table 1 shows the origin and propagation methods of the bamboo seedlings planted at the study plots. All the bamboo seedlings that originated from Yogyakarta, Indonesia were from tissue culture. Meanwhile, the local bamboos, were produced from branch cuttings from the mother plant except for *Gigantochloa hasskarliana* (Beti bamboo) which was from rhizomes cutting. These seedlings were sown in the polybag at the nursery before transplanting to the field area. Topsoil and river sand was used as the potting medium in the volumetric ratio of 1:1 for the seedling production in the nursery. After 4 months, the seedlings were transferred into the plantation field.

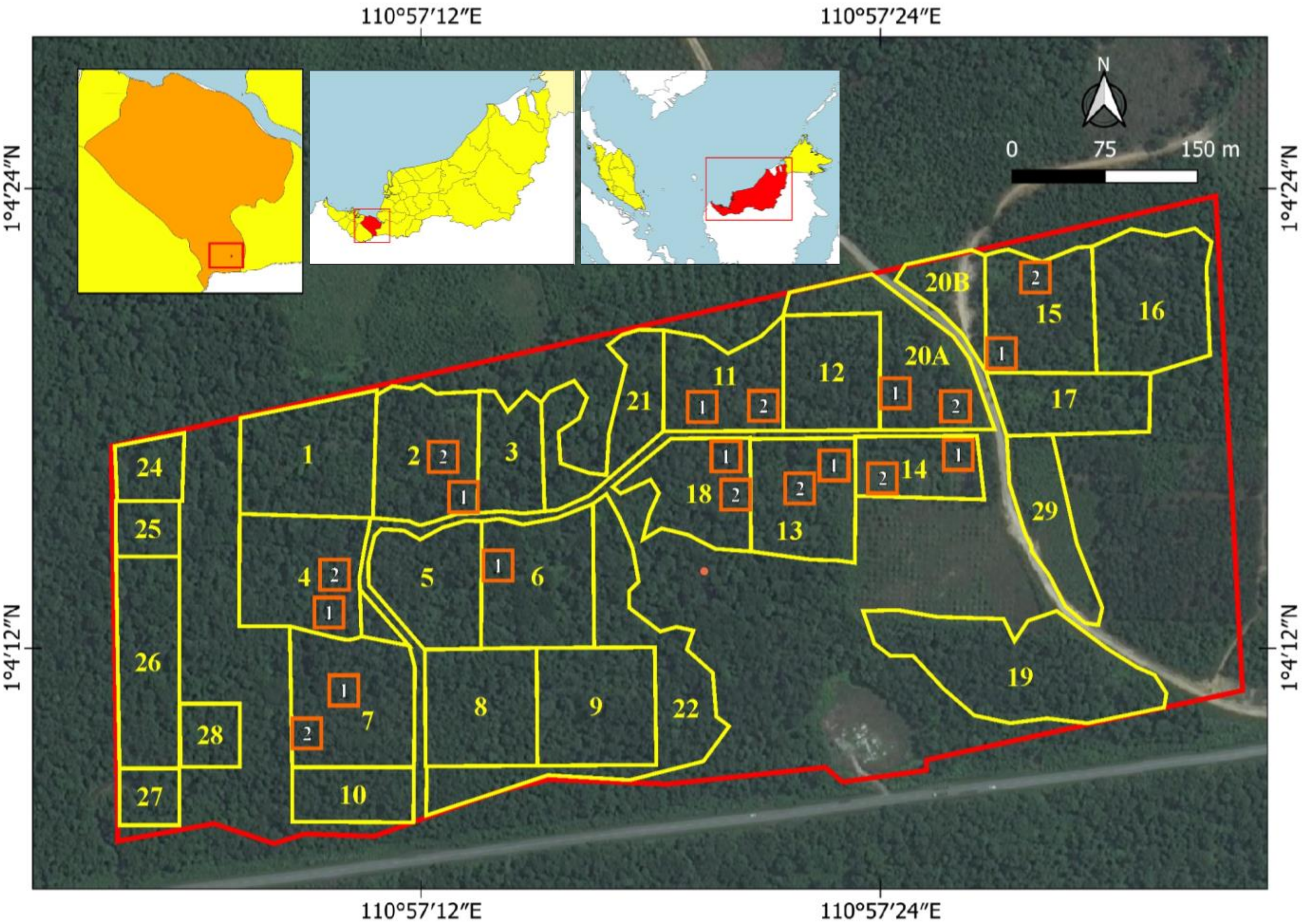

Figure 1. Segregation between different bamboo species at STIDC Bamboo Pilot Project study area in Sabal Forest Reserve, Simunjan, Sarawak, Malaysia

The precipitation was relatively uniform in this region throughout the year when the seedlings were planted. After the planting, the fertilization process was carried out three (3) times per year at each plot. The inorganic fertilizer (NPK) was applied during the early stage of planting. After 3 months, the organic fertilizer (chicken manure) was applied to the planted bamboo until the bamboo reached its age of two years or depending on the bamboo growth condition in the plantation area. During the growth stage, the bamboo species were maintained accordingly. Table 2 shows the five types of silviculture treatments applied in the bamboo plantation area.

The first assessment or data collection on bamboo growth was conducted in November 2019. After 3 months, in February 2020, the second assessment was carried out. The bamboo growth performance assessment was scheduled to be collected quarterly but due to the COVID-19 pandemic and the implementation of the Movement Control Order (MCO) in March 2020, the assessment process had been postponed. The third assessment was conducted in February 2021 after the COVID-19 situation improved and Recovery Movement Control Order (RMCO) was implemented, which was exactly a year after the second assessment.

Experimental procedure

At each bamboo plot with an area of 1 ha, 400 bamboos were planted with a 5 m x 5 m planting distance. For the growth assessment, only 50 bamboos (2 replications with 25 readings for each replication) per plot which comprise 12.5% of the bamboo clumps in each bamboo plot were evaluated. Sample measurements were taken representing a fraction of the entire stand. The numbers are all proportional to the actual stand values (Amir 2019).

These 50 selected bamboo clumps were tagged based on the plot number (P), line number (L), and clump number (C) following the Permanent Sample Plot (PSP) technique. The same selected and tagged bamboo clumps were evaluated for the first, second, third, and subsequent assessments. The PSP boundaries were tagged with the PVC pipes with the exact coordinates in each PVC pipe namely A, B, C and D.

The first assessment parameter was the number of culms per clump. As for the second assessment parameter, the new shoots in each PSP clump were counted and recorded. The third assessment parameter was the measurements of the culm diameter. For each clump, three culms' diameters were measured using the digital caliper, and the culms were sprayed with white paint to ensure that the same culms will be measured for the next assessment.

The culms diameter was recorded in unit cm. As the fourth assessment parameter, the clump heights were measured. The average height of the culms was measured using the height pole and the clumps' height was recorded in unit meter (m). The Mean Annual Increment (MAI) in terms of seedling culm diameter (MAID) and culm height (MAIH) were estimated based on the mean values of the seedling diameter and height of the assessed bamboo seedlings with the stand age of the study plot.

Data analysis

One-way analysis of variance (ANOVA) was used to analyze the data on outplanting performance. Each individual seedling was treated as a replicate of the sampling unit for statistical purposes, and the experimental unit was the mean response from the sampling units for each treatment replication. In each analysis, when ANOVA was significant, Scheffe's multiple comparison tests were used to identify statistically significant differences between means. Statistical Package for the Social Sciences (SPSS) (IBM, version 24.0 for Windows) (Copyright: SPSS Inc., 2016) was used to conduct all statistical analyses.

RESULTS AND DISCUSSION

Results

The bamboo growth measurements were conducted in November 2019, February 2020, and February 2021, which was categorized as the sampling year versus the assessment parameters which were the survival rate of planted bamboo species, number of culms per clump, number of new shoots, culm diameter, culm height, and mean annual increment in terms of culm diameter and height of ten bamboo species in Sabal, Simunjan, Sarawak. The ten species used in this study (with the local name in the bracket) were *Bambusa vulgaris* (Buluh minyak), *Bambusa balcooa* (Buluh bema), *Dendrocalamus asper* (Green) (Buluh betong), *Dendrocalamus asper* (Black) (Buluh betong), *Gigantochloa levis* (Buluh beting), *Gigantochloa hasskarliana* (Buluh busi), *Dendrocalamus asper* (Buluh betong), *Guadua angustifolia* (Bulu duri), *Dendrocalamus hamiltonii* (Buluh Hamilton), and *Gigantochloa atter* (Buluh pring).

Survival rate of planted bamboo species

Figure 2 shows the survival rate of the ten bamboo species in February 2021 planted at the Sabal Forest Reserve, Simunjan. The survival rate was calculated based on the number of survived bamboo plants and divided by the number of bamboo seedlings planted and multiplied by 100 for the survival percentage.

The number of samples involved in the survival rate determination was 25 bamboo clumps multiplied by 2 replications for each bamboo species. Based on Figure 2, *G. atter* had the highest survival rate with 98%, followed by *D. hamiltonii* with 90%. *G. angustifolia*, *D. asper*, *G. levis*, and *D. asper* (Green) have the same survival rate of 88% followed by *B. vulgaris* with 86%, *D. asper* (Black) survived at 76%, *G. hasskarliana* at 70%, and the lowest survival rate was at 64% found in *B. balcooa*.

Table 1. Planting materials, origins, and propagation techniques of bamboos used in this study

Plot no.	Planted species	Local name	Origin	Method of propagation
2	*Bambusa vulgaris*	Buluh minyak	Sarawak, Malaysia	Cuttings (Branch)
4	*Bambusa balcooa*	Buluh bema	Yogyakarta, Indonesia	Tissue Culture
6	*Dendrocalamus asper* (Green)	Buluh betong	Yogyakarta, Indonesia	Tissue Culture
7	*Dendrocalamus asper* (Black)	Buluh betong	Yogyakarta, Indonesia	Tissue Culture
11	*Gigantochloa levis*	Buluh beting	Sarawak, Malaysia	Cuttings (Branch)
13	*Gigantochloa hasskarliana*	Buluh beti	Sarawak, Malaysia	Cuttings (Rhizome)
14	*Dendrocalamus asper*	Buluh betong	Sarawak, Malaysia	Cuttings (Branch)
15	*Guadua angustifolia*	Buluh duri	Yogyakarta, Indonesia	Tissue Culture
18	*Dendrocalamus hamiltonii*	Buluh Hamilton	Yogyakarta, Indonesia	Tissue Culture
20	*Gigantochloa atter*	Buluh pring	Yogyakarta, Indonesia	Tissue Culture

Table 2. Silvicultural treatments applied at the plantation site

Silviculture treatments	Description
Circle weeding	All the grasses were removed using sickle within 60 cm in radius from basal/clump
Slashing	Removal of unwanted weeds/grasses and trees in planting areas or between planting points or at inter-row
Pruning	Unwanted and unhealthy lower branches were pruned every 4 months
Weedicide spraying	Weedicides were sprayed in the planting area (between planting points or at inter-row)
Fertilization	Application of fertilizers (NPK: 200 g/clump, Organic: 2 kg/clump, 2 feet from clumps base)

Mean number of culms per clump

The culm, which is a woody material, is the most important part of bamboo that has good properties and appearance. The culm consists of nodes and cylindrical hollows known as internodes (Zhang et al. 2002). Figure 3 shows the mean number of culms per clump for each bamboo species at different sampling years in November 2019, February 2020, and February 2021. Generally, all the bamboo species showed an increasing pattern as the planting period increased, with the highest mean number of bamboo culms depicted in *G. angustifolia* (19), followed by *G. hasskarliana* (13) and *D. hamiltonii* (11) in November 2019. After 3 months (February 2020), the highest mean number of culms per clump was found in *G. hasskarliana* (18), followed by *G. angustifolia* (16) and *G. atter* (12). One year later (February 2021), two same species showed the highest mean number of culms per clump which were *G. hasskarliana* (43) and *G. angustifolia* (28) and followed by *D. hamiltonii* (21) and closely followed by *G. atter* (20). It showed that these four species produced the highest mean number of culms per clump compared to other species. Nevertheless, all other species also showed the increment of the mean number of culms per clump with the increment of the planting period, as can be seen in *B. vulgaris* (3, 4, 10), *B. balcooa* (6, 7, 14), *D. asper* (Green) (8, 9, 13), *D. asper* (Black) (8, 7, 14), and *G. levis* (3, 4, 11) in November 2019, February 2020, and February 2021, respectively. Two species that had no increment in terms of the mean number of culms per clump were *D. asper* and *D. hamiltonii* which had 5 and 11 culms, respectively in November 2019 and February 2020, and only increased one year after that, to 10 and 20 culms in February 2021.

Mean number of new shoots

Figure 4 shows the mean number of new shoots at different sampling years and species. In terms of sampling year, in November 2019, *G. angustifolia* produced significantly the highest mean number of new shoots followed by *G. hasskarliana* and *G. atter* at 2.93, 0.86, and 0.73 mean new shoots, respectively. Within 3 months, in February 2020, the same species showed the same highest mean number of new shoots at 1.77, 0.83, and 0.61. However, after a period of 1-year, in February 2021, *G. angustifolia* (1.09) still had dominantly the mean number of new shoots, followed by *G. hasskarliana* (0.97) and *B. balcooa* (0.56).

Mean culm diameter

Figure 5 shows the mean culm diameter of ten bamboo species at different sampling years. During the first assessment in November 2019, the highest culm diameter was found in *B. balcooa* with 2.51 cm, followed by *D. asper* (Green) with 1.94 cm and *D. asper* (Black) with 1.67 cm. In the second assessment in February 2020, only 3-month later, the same species which were *B. balcooa, D. asper* (Green), and *D. asper* (Black) showed the highest mean culm diameter at 3.26, 3.18, and 2.99 cm, respectively. The same trend as happened in the mean number of new shoots also happened in the mean of culm diameter, which was during the third assessment in February 2021, *D. asper* (Green), *B. balcooa*, and *B. vulgaris* showed the highest mean of culm diameter with 3.61, 3.59 and 3.42 cm, respectively.

Mean culm height

Figure 6 shows the mean culm height of different bamboo species and sampling year. In November 2019, the highest mean of culm height was found in *D. asper* (Green) at 3.75 m, followed by *D. asper* (Black) at 3.60 m and *D. asper* at 3.15 m.

Mean annual increment of diameter (MAID) and height (MAIH)

Figure 7.A shows the mean annual increment of diameter (MAID) of ten bamboo species in the STIDC Pilot Project in Sabal, Simunjan. The measurement was based on the growth data collected in February 2021 and the diameter increment was divided by the bamboo age. It showed that the five fastest species in terms of their diameter growth were *B. balcooa*, *B. vulgaris*, *D. asper* (Green), *D. asper* (Black), and *G. angustifolia* with the diameter increment of 1.84, 1.77, 1.74, 1.67, and 1.35 cm respectively per year. For the rest of the bamboo species, the diameter increments per year were recorded between 1.01-1.30 cm per year.

On the other hand, Figure 7.B shows the mean annual increment of height (MAIH) of the ten bamboo species planted in Sabal, Simunjan. The measurement was also based on the growth data collected in February 2021, at the bamboo age of 23-26 months old. The bamboo height recorded in February 2021 was divided by each bamboo species' age to come out with MAIH data. The highest height increment recorded were found in *B. balcooa*, *D. asper* (Black), *G. angustifolia*, *B. vulgaris*, and *D. asper* (Green) with the height increment at 4.35, 4.17, 3.77, 3.52, and 3.29 m respectively per year. The rest of the bamboo species showed increments in the range of 2.29-3.07 m per year.

Discussion

Based on Figure 2, the survival rate of ten bamboo species planted in the STIDC Pilot Project in Sabal ranged from 64 to 98%. Many factors contributed to the survival rate of the bamboo planted such as soil properties, the plantation maintenance regime, the temperature, relative humidity, and rainfall. The bamboo plantation area is the area of Forest Reserve and there should be no soil issue for any plant to be planted in this area.

Bamboo locality could be one of the factors affecting the survival rate. As mentioned before, six of the ten total bamboo materials studied were originated from Yogyakarta, namely *B. balcooa* with a survival rate of 64%, *D. asper* (Green) (88%), *D. asper* (Black) (76%), *G. angustifolia* (88%), *D. hamiltonii* (90%) and *G. atter* (98%) and the other four bamboo materials were originated locally from Sarawak which was *B. vulgaris* (86%), *G. levis* (88%), *G. hasskarliana* (70%) and *D. asper* (88%). The highest survival rate for imported bamboo was 98% and the lowest was 64%. Meanwhile, the highest survival rate for local Sarawak bamboo was 88% and the lowest was 70%. On average, the survival rate for imported bamboo was 84% and the average for local bamboo was 83%. It showed that there was no significant difference in terms of locality for bamboo survival rate.

Were et al. (2017) used six bamboo species (*B. blumeana*, *B. bambos*, *B. vulgaris*, *D. asper*, *D. membranaceus*, and *D. birmanicus*) to reduce the risk of chromium (Cr) exposure from a contaminated tannery site in Kenya. Interestingly, all the bamboo species showed a survival rate of 100% under the prevailing conditions of the tannery soils, except for *D. birmanicus*, where two of its twelve samples failed to grow to maturity. The heights and clump diameters varied from 3.8-8.5 m and 77-180 cm for *B. blumeana*, 0.7-2.7 m and 69-280 cm for *B. bambos*, 2.8-6.5 m and 34-109 cm for *B. vulgaris*, 4.4-4.5 m and 46-100 cm for *D. asper*, 1.7-5.2 m and 30-190 cm for *D. membranaceus*, and 0.9-3.8 m and 51-144 cm for *D. birmanicus*, respectively. The heights of *B. bambos* and *D. birmanicus* were significantly shorter than the rest of the species.

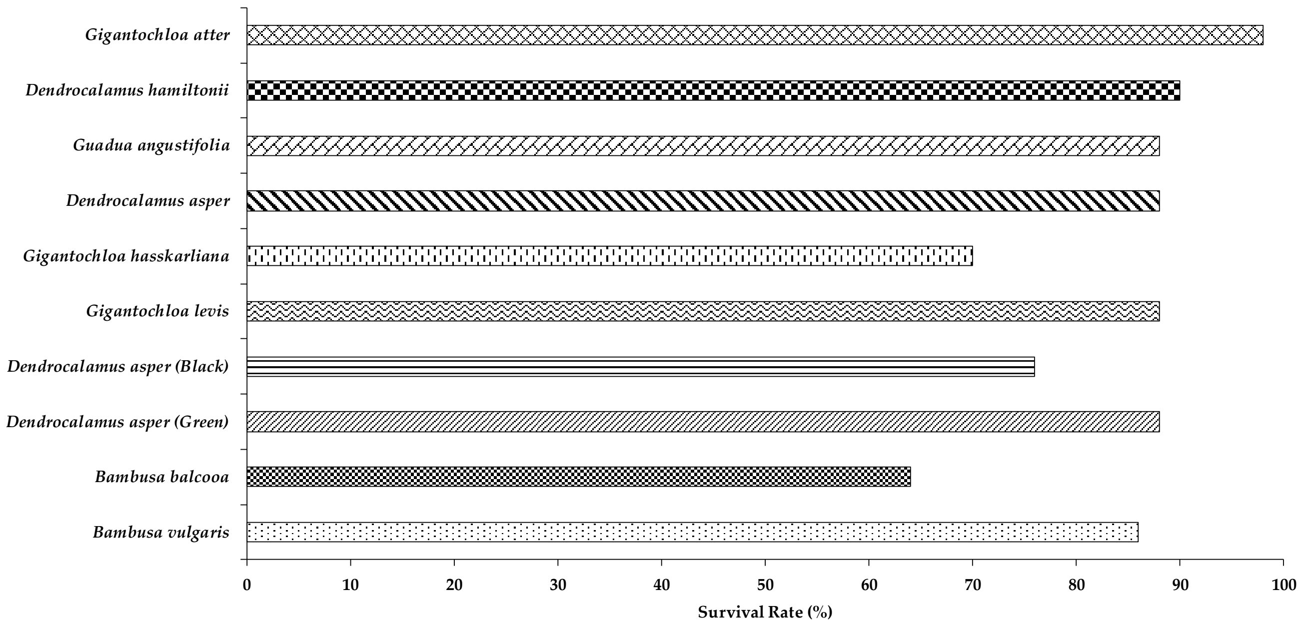

Figure 2. Mean survival rate (%) of planted bamboo species

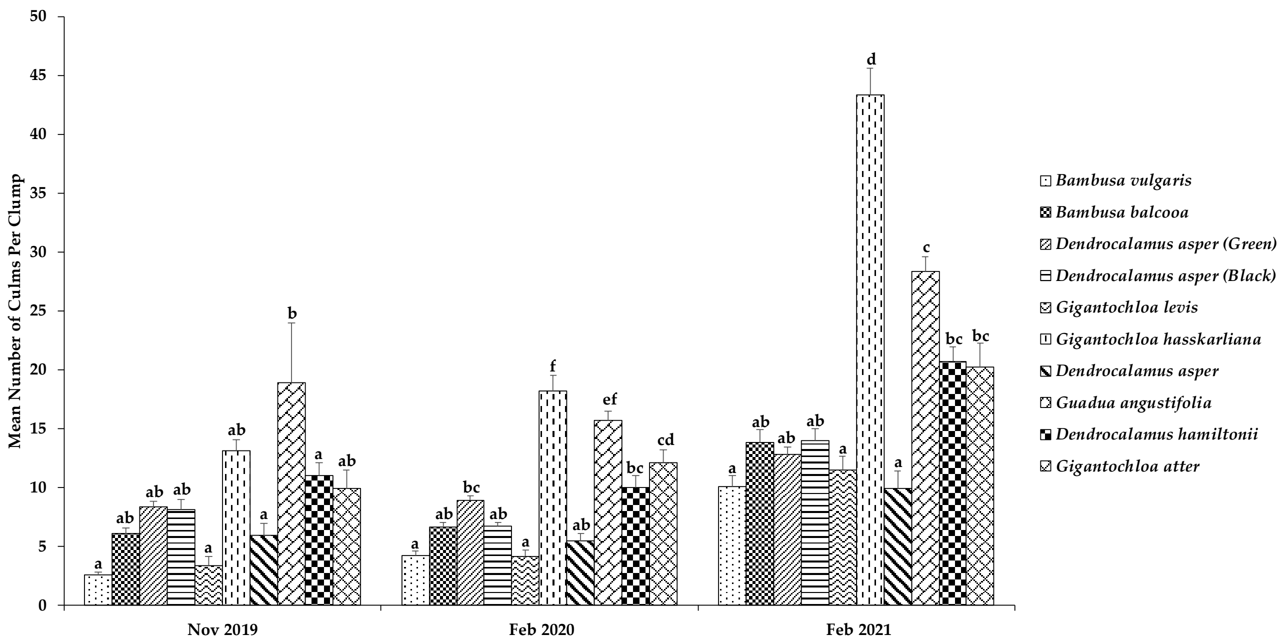

Figure 3. Mean number of culms per clump of planted bamboo species

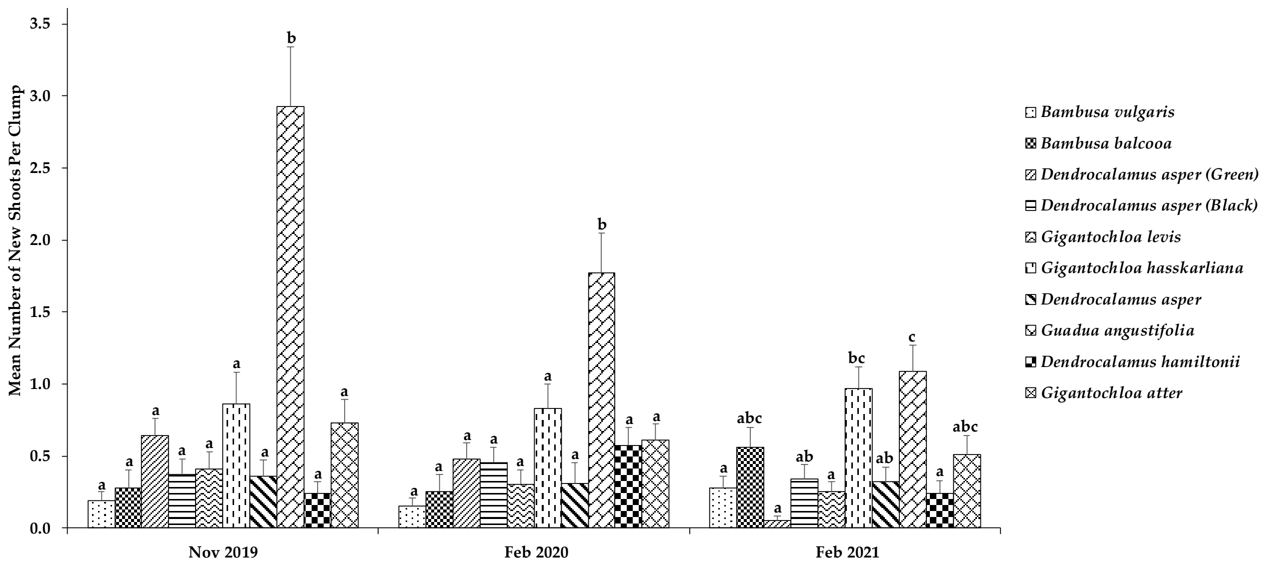

Figure 4. Mean number of new shoots per clump of planted bamboo species

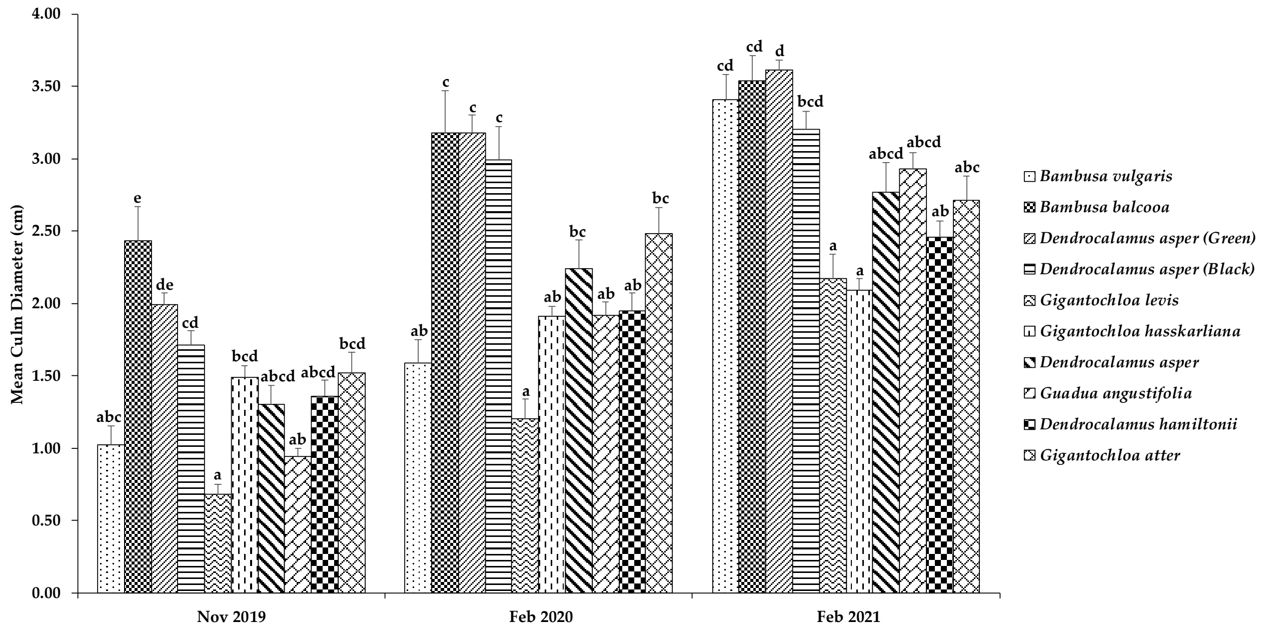

Figure 5. Mean culm diameter of planted bamboo species

Figure 3 shows that the number of culms per clump for all bamboo species increased along with the increase of the planting period. All bamboo species planted in this plantation area are sympodial bamboo species in which the new bamboo culm will grow at the outer layer of the clump. As time goes by, the clump's diameter radius will be bigger and that was the main reason the bamboo seedlings were planted 5 m x 5 m from each other.

There were many internal and external factors contributing to the number of culms per clump. Internal factors included the plant origin, the plant species, and the plant resilient system. External factors were the fertilizer used, the slashing techniques, and other plantation maintenance regimes.

According to previous studies reported by Krishnakumar et al. (2017), *B. balcooa* exhibited its superiority over *B. vulgaris* by producing a maximum number of culms in the first year (6.46), second year (13.00), third year (19.34), fourth year (26.05) and fifth year (32.37). In general, our findings show that the early growth in terms of numbers of culms after one year in February 2021 for *B. balcooa* and *B. vulgaris* were within the range of results.

Figure 4 shows that the number of new shoots fluctuated either by species or by the period of the plantation. The number of new shoots showed how fast the bamboo propagated weekly or monthly. Since the data collection was conducted within 3 months and a year, there was a high ranged (1-7) of new bamboo shoots recorded for each clump in each plot of bamboo. But on average, the ranged was only 1 to 3 for each bamboo species.

Closely monitoring the bamboo shoots production is crucial in understanding the most active bamboo species in terms of bamboo growth. Bamboo new shoots are the earliest bamboo products that can be commercialized for food industries. When the shoots were left unharvested, it will be matured and become bamboo culm and thus will change the usage of bamboo for other industries such as charcoal and furniture. Bamboo has an important role to play in sequestering carbon in the forest ecosystem (INBAR 2014). The demand for bamboo is increasing at a much higher rate than its availability (supply) due to the rapid growth in the human population. In recent years, there has been growing concern over the rapidly declining production of bamboo both in villages and natural forests.

The mean was calculated based on three measurements of bamboo culms for each clump in the 50 sampling stands, for each species of bamboo. Generally, all bamboo species' mean culm diameter increased with the increase of the plantation period (Figure 5). However, looking at column number 7 for each sampling year, the mean culm diameter for *D. asper* (locally known as the giant bamboo) was 1.09 cm in November 2019, 2.23 cm in February 2020, and 2.88 cm in February 2021. By dividing by the growth period, *D. asper* (Buluh betong) has a wide range of growth performance which is 0.05 to 0.38 cm per month.

In terms of species-sampling year comparison, *G. levis* (Buluh beting) had the lowest mean culm diameter of 0.54 cm in November 2019, 0.98 cm in February 2020, and 2.14 cm in February 2021. By dividing the culm diameter by its growth period either 3-month or 1-year, *G. levis* only increased 0.10 to 0.15 cm per month. On the other hand, *B. vulgaris* had, culm diameters of 0.95, 1.43, and 3.42 cm in November 2019, February 2020, and February 2021, respectively. By dividing by the growth period, it showed that *B. vulgaris* had a culm diameter of 0.16 to 0.17 cm per month. This was because the mean culm diameter increased significantly within 3-month from 1.09 to 2.23 cm, but had only a slight increment within 1-year from 2.32 to 2.88 cm. A lot of factors could contribute to these phenomena such as the fertilizer applied, the soil condition, and the weather condition, which should be investigated further for each of the bamboo species.

The bamboo diameter could contribute to the higher strength of bamboo species suitable for structural applications such as housings, bridges, flooring, and even furniture. Based on a previous study reported by Krishnakumar et al. (2017), the diameter registered a significant highest grand general mean of 5.42 cm in *B. balcooa* over five years of the growth period in five agroclimatic regions. However, it was reported that *B. vulgaris* registered at 4.61 cm as a grand general mean in their study.

Figure 6 shows the mean culm height for each bamboo species for each sampling year in November 2019, February 2020, and February 2021. The culm height was recorded based on the average height of the culms per clump for 50 replications for each bamboo species. As the same trend as the mean culm diameter, mean culm height also increased with the increase of the bamboo plantation period. Three bamboo species with the highest height growth rate were *B. balcooa*, *G. angustifolia*, and *D. asper* black in which their height increment from November 2019 to February 2020 and February 2021 were 2.94, 5.82, and 8.36 m for *B. balcooa*, 2.93, 3.93 and 8.23 for *G. angustifolia*, and 3.30, 5.98 and 8.00 m for *D. asper* (Black).

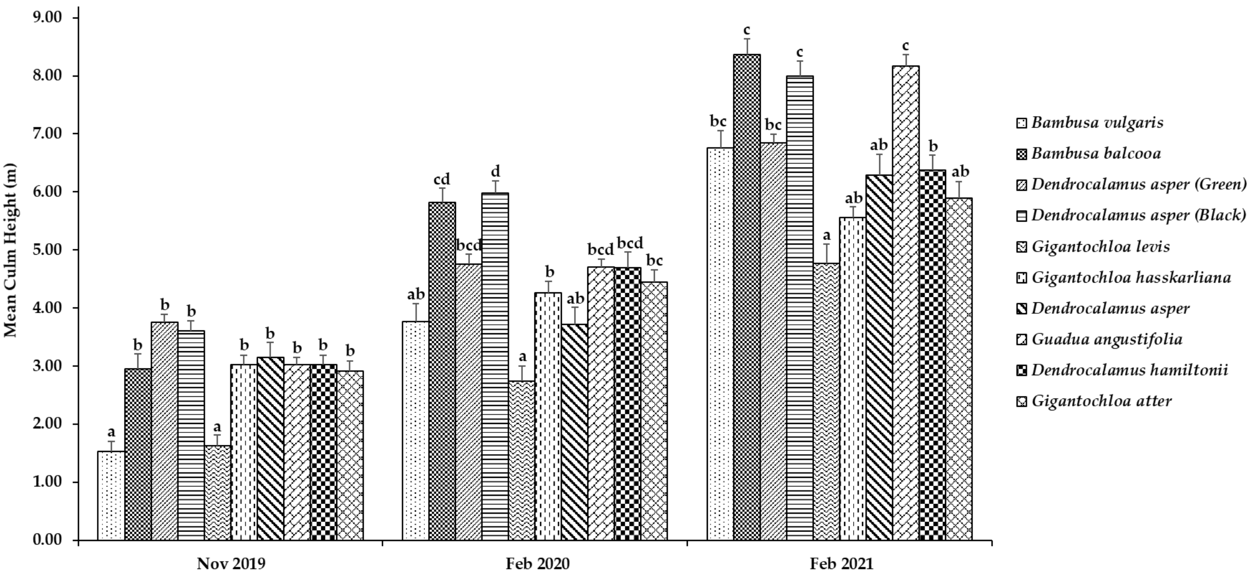

Figure 6. Mean culm height of planted bamboo species

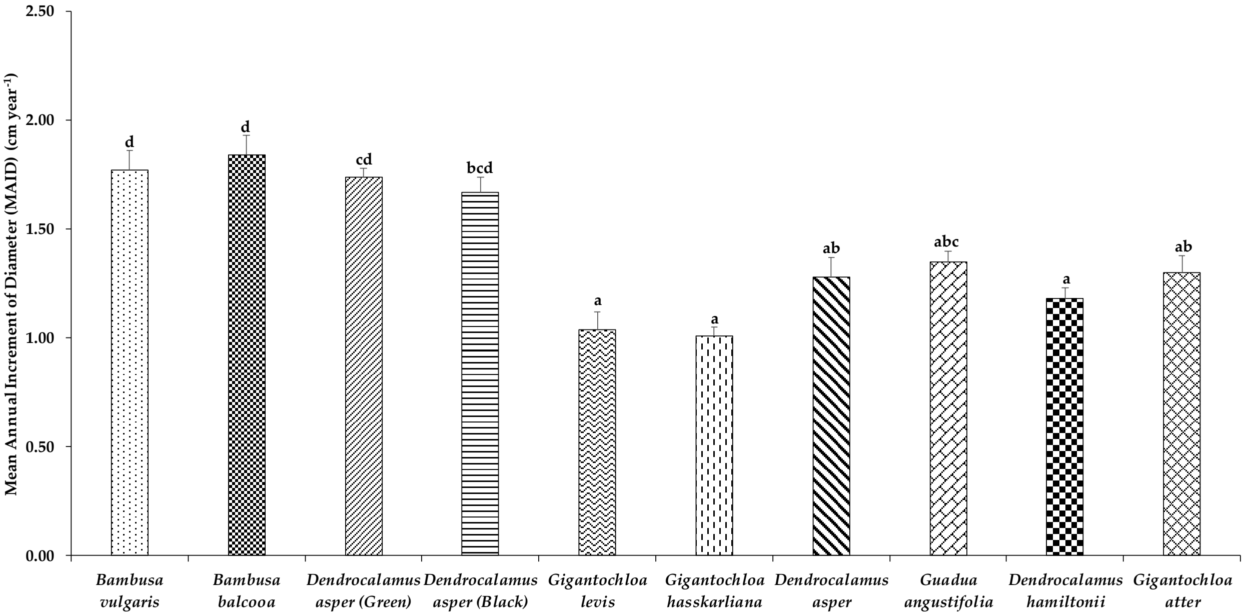

Figure 7.A. Mean annual increment of diameter (MAID) of planted bamboo species

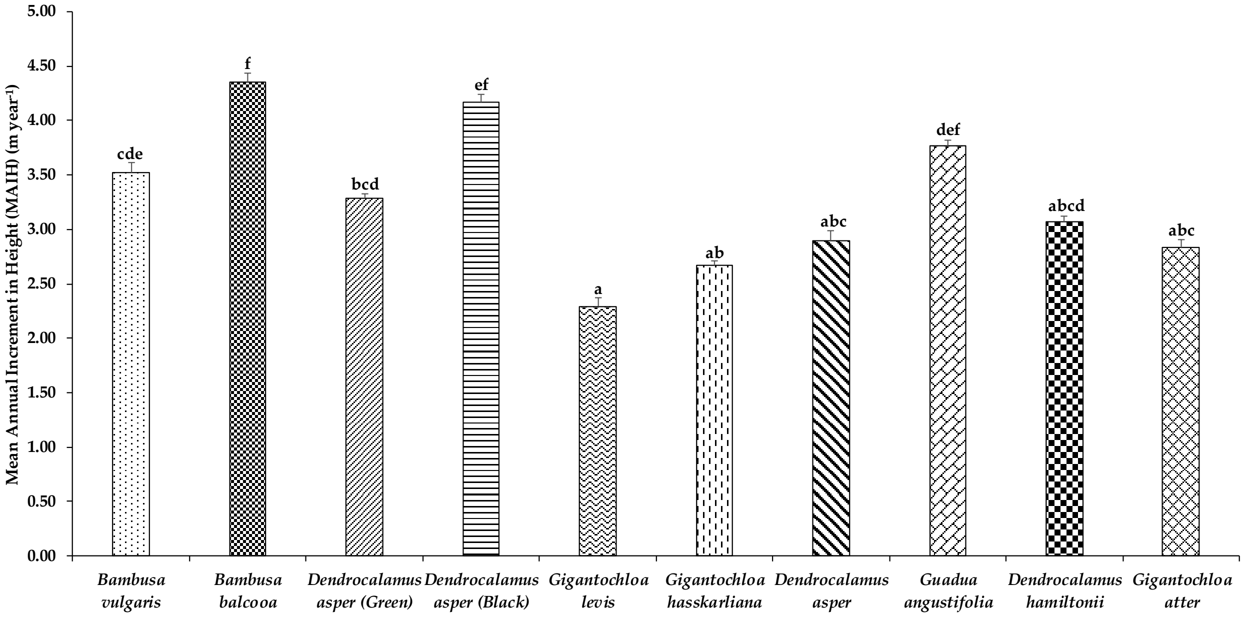

Figure 7.B. Mean annual increment of height (MAIH) of planted bamboo species

By dividing the growth period by either 3-month or 1-year, *B. balcooa* grew 0.96 m per month from November 2019 to February 2020 but only grew at 0.21 m per month from February 2020 to February 2021. This contradicted *G. angustifolia* which had a more stable growth rate with 0.33 m height increment per month from November 2019 to February 2020 and 0.36 m per month from February 2020 to February 2021. However, different things happened to *D. asper* (Black) which grew 0.89 m per month from November 2019 to February 2020, while only growing 0.17 m per month from February 2020 to February 2021. This could be due to the changes or interruption of the fertilizer application schedule to the bamboo plantation during the MCO period. Many other factors could contribute to the growth rate of different bamboo species at a different rate due to the adaptability of the species to their surroundings and environment.

Culm height is very crucial in terms of bamboo yield. Generally, the higher the height of the culm, will contribute to the higher yield of bamboo during the harvesting period.

More products can be produced based on higher bamboo yield. According to Tran (2010), the cutting cycle of some species of the *Dendrocalamus* family in Vietnam is one or two years depending on cultivation levels. If the one-year cutting cycle is applied, 30% of the 96 total bamboo culms can be harvested, and in the case of the two-year cutting cycle, a percentage of 40% is recommended. Following the variations in physical and mechanical properties of bamboo culms observed here, the cutting cycle of three years is an option for the study stands and cutting can take place for all three-year-old culms. According to Hossain et al. (2018), *D. asper* is known as rough bamboo, black bamboo, or giant bamboo and it grows to a height of 20–30 m, with a diameter of 8–20 cm and 20-45 cm long internodes and has relatively thick walls. It can also survive well in semiarid environments with proper management (Mustafa et al. 2021).

However, one- or two-year cutting cycles can be applied as well if necessary. Harvesting is applied when newly established bamboo stands reach the age of six years (Tran 2010). Before the harvesting operations, pruning should be applied. The selected culms to harvest need to be marked with red paint. Culms should be cut just above a node to make sure that water will not accumulate in the hollow intermodal segment to avoid rotting of the base. The remaining stumps should keep at least two nodes to protect the whole rhizome part. Shoots and other culms must be protected from mechanical damages during harvesting.

After the harvest, tending activities were needed before February. Soil loosening at a depth of 15 to 20 cm around clumps in a radius of 1 m was required and fertilizer (1 kg NPK/clump) should be applied. Krishnakumar et al. (2017) mentioned that the highest grand general mean over five years in their study was recorded by *B. balcooa* with 7.39 m. It was reported that *B. balcooa* exhibited consistent and significant superiority over *B. vulgaris* and *B. bambos* at all age gradations.

Figure 7a shows the mean annual increment of diameter (MAID) of the ten bamboo species planted in Sabal, Simunjan. Between the first and second data collection recorded in November 2019 and February 2020, which was within 3 months, and the second and third data collection in February 2020 and February 2021, which was within one year, the increment of the culm diameter was higher within the months compared to within one year. The highest culm diameter recorded for *B. balcooa* in November 2019, February 2020, and February 2021 were 2.51, 3.26, and 3.59 cm, respectively. In 3 months, the diameter increased up to 0.75 cm but only increased to 0.33 cm within one year.

Figure 7b shows the mean annual increment of height (MAIH) of all the bamboo species in this pilot plantation. The mean culm height of *D. asper* black recorded for November 2019, February 2020, and February 2021 were 3.30, 5.98, and 8.00 m, respectively. In a similar trend to the culm diameter, the culm height increased by 2.68 m within 3 months and 2.02 m within one year. Bahru et al. (2018) investigated the early survival rate and growth performance of *Oxytenanthera abyssinica* seedlings of different provenance from Pawe and Sherkole districts in Ethiopia to obtain suitable provenance for the production of high-quality seedlings. Both provenances successfully survived at the greenhouse. The survival rate of seedlings varied from 90 to 91% between provenances. At the age of two years, most of the seedlings developed 2-9 culms per clump. Its culm height attained up to 102 cm, while the root collar diameter (RCD) thickened around 0.5 mm. Mean values of culm height, the number of culms per clump, and RCD between two *O. abyssinica* provenances were 61.18 cm ± 18.36, 2.41 ± 1.32, 0.26 mm ± 0.07, and 67.07 cm ± 15.78, 3.18 ± 1.47, 0.25 mm ± 0.07 respectively, for Pawe and Sherkole districts.

The present study was based on a two-and-a-half-year period. Thus, based on the findings, significant differences were observed in terms of the survival rate and field growth performance among different bamboo species planted in the Sabal Forest Reserve. The survival rate of all the planted bamboo species was greater than 60% in February 2021. *G. atter* depicted the highest survival rate with 98% and the lowest survival rate was recorded for *B. balcooa* with 64%. Meanwhile, for field growth performance, *G. hasskarliana* and *G. angustifolia* recorded the highest mean number of culms per clump in February 2021 with 43 and 28 culms, respectively. On the other hand, in February 2021, *G. angustifolia* dominantly produced the highest mean number of shoots with 1.09. Nonetheless, for the mean culm diameter in February 2021, *D. asper* (Green), *B. balcooa*, and *B. vulgaris* showed the highest mean with 3.61, 3.59, and 3.42 cm, respectively. As for the mean culm height, *B. balcooa* recorded the highest culm height with 8.36 m, followed by *G. angustifolia* and *D. asper* (Black) with 8.17 m and 8.00 m, respectively. In terms of MAID and MAIH, *B. balcooa* depicted the highest growth increment with 1.84 cm $year^{-1}$ and 4.35 m $year^{-1}$, respectively. It is recommended that a long-term monitoring period is necessary to develop a commercial bamboo industry plantation scheme, especially in Sarawak. Notwithstanding, further detailed studies are required to find out the edaphic factors which could affect the survivorship and growth performance of planted bamboo under line planting technique in Sarawak.

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