UNIVERSITI PUTRA MALAYSIA

SPATIAL AND TEMPORAL EFFECTS ON HYDRAULIC CONDUCTANCE AND OTHER ATTRIBUTES OF BAMBOO (*Gigantochloa scortechinii* Gamble)

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Gigantochloa scortechinii Gamble (Buluh Semantan) is one of the most common bamboo species, and abundant with scattered distribution in Peninsular Malaysia. A study was initiated to determine the structure and variation of most ignored part which is rhizome from three different study sites and four consecutive rhizome ages. The study focused on the variation of physiological, anatomical, chemical, and phytochemical attributes in relation to site and rhizome age. This study was conducted at three different locations of Peninsular Malaysia, namely Amanjaya Forest Reserve (Perak), Kenaboi Forest Reserve (Negeri Sembilan), and Ayer Hitam Forest Reserve (Selangor). The sites were selected due to abundant of *G. scortechinii* bamboo species distribution at those areas, and also represented different climatic condition such as elevation, precipitation, and temperature. The destructive sampling of four consecutive rhizomes of the bamboo species *G. scortechinii* was conducted using selective random sampling method from healthy clumps. The four consecutive rhizomes were represented as four different rhizome ages: a) new sprout, b) young, c) premature, and d) mature rhizome.

The results showed that hydraulics conductivity (K) varied significantly ($p<0.01$) among study sites, rhizome ages and their interaction (study site x rhizome ages). Significant correlation was found between K with rhizome morphology; such as number of active buds ($r = 0.455$, $p<0.01$), number of damaged buds ($r = -0.435$, $p<0.01$) and rhizome branches ($r = -0.673$, $p<0.01$). Rhizome morphology such as distance between young and old rhizome, rhizome length, number of internode, rhizome diameter (upper, middle, lower, and mean), rhizome lumen diameter (middle, lower, and mean), rhizome wall thickness upper, middle, lower, and mean), and number of buds (total, active and damaged) varied significantly and correlated with study site. However, rhizome

lumen diameter at upper portion and rhizome branches were found insignificantly different with study site. For rhizome age, significant variation ($p<0.01$) were only found on number of buds, number of active buds, and rhizome branches. Furthermore, number of buds and number of active buds were found decreased with increasing of rhizome age.

All the measured anatomical characteristics are significantly different with study site except ground tissue parenchyma (GTP) diameter, GTP lumen diameter, and fiber (Fi) cell wall thickness at $p<0.05$. With respect to rhizome age, the radial to the tangential ratio (RTR) was found significantly different ($p<0.01$) with a negative relationship with rhizome age which depicted that the RTR decreased with increasing of age. However, the vascular bundle (VB) diameter, GTP diameter, GTP lumen Diameter, GTP cell wall thickness, Fi diameter, Fi cell wall thickness, Fi length, and runkle ratio (RR) were significantly different ($p<0.01$) with a significant relationship ($r=0.343$, 0.400, 0.350, 0.682, 0.367, 0.634, 0.413, and 0.320 respectively) with rhizome age which depicted that they are increased with increasing of rhizome age. All measured anatomical characteristics including the conductance element were found insignificant relationship with K_{bg}, except the GTP diameter and lumen diameter.

Regarding chemical attributes, the results indicate that the ash content (AC), alcohol-acetone soluble (AAS) and holocellulose (HC) were significant different ($p<0.01$) among study sites. Furthermore, AC, hot water soluble (HWS), AAS, lignin (L), and HC were found significantly different ($p<0.01$) with a strong relationship ($r=-0.823$, 0.688, 0.986, 0.945, 0.510 respectively) with rhizome age. The AC showed a significant ($p<0.01$) positive relationship ($r=0.747$) with K_{bg} which depicted that the decreasing of AC in increasing of rhizome age resulted to decreasing of K_{bg}, but, HWS, AAS, L, and HC showed a significant ($p<0.01$) negative relationship ($r=-0.706$, -0.914, -0.857, -0.567 respectively) with K_{bg} which depicted that the increasing of those chemical attributes in increasing of rhizome age resulted to decreasing of K_{bg}.

The AC is suggested to be related with the nutrient elements which are crucial for fast growth of growing organ than the older bamboo organ. The relationship of AC with nutrient elements changes during maturation period is related with all three hypotheses in previous studies which are (a) the ability to absorb nutrient, (b) metabolically active vascular tissues that translocate the nutrient elements, and (c) the dilution effects of quickly increasing of biomass. Results indicate that several nutrient elements such as nitrogen (N), sulfur (S), phosphorus (P), potassium (K), calcium (Ca), sodium (Na), copper (Cu) (all $p<0.01$), and ferum (Fe) ($p<0.05$) concentration were found significantly different with study site. The nutrient elements such as N, P, K, Ca, magnesium (Mg), Cu, and zinc (Zn) were found significantly different ($p<0.01$) and their concentration decreased with increasing rhizome age ($r=-0.912$, -0.834, -0.844, -0.834, -0.899, -0.364, and -0.933 respectively). The changes of N ($r=0.827$), P ($r=0.928$), K ($r=0.871$), Ca ($r=0.903$), Mg ($r=0.836$), and Zn ($r=0.841$) showed a significant ($p<0.01$) strong positive relationship with AC

which depicted that the decreasing of those nutrient elements concentration in increasing of rhizome age resulted to decreasing of AC.

Furthermore, the spatial and age-related effect also showed a great variation in phytochemical composition and concentration. Eighteen compounds were found similar at all three study sites; however, their composition and concentration considerably showed age-dependent. It is suggested that the variation of phytochemical composition and concentration is more affected by rhizome age compared to the study site. Results also revealed various beneficial phytochemical compounds such as 4h-pyran-4-one,2,3-dihydro-3,5-dihydroxy-6-methyl, benzofuran, 2,3-dihydro-, phenol,3,4-dimethoxy-, benzoic acid,4-hydroxy-3,5-dimethoxy-, quinic acid, and n-hexadecanoic acid in the ethanolic extract with potential contribution to the plant-derived biomaterial.

Results from this study could enhance the understanding beyond the lack information of hydraulic conductance in bamboo rhizome and factors that influence the conductivity. The results can be implementing in bamboo management practices to ensure sustainable and profitable production. However, it should be depending on the objective of the targeted product such as for culm/rhizome, bamboo shoot, or bamboo leaves production. This study also attempts to promote the utilization of bamboo specifically the *G. scortechinii* species regarding bio-perspective with its great potential for industries. Authors believed that effort on developing national economic and industries can avoid international treats through good practices such as avoid conversion of forest area into plantation or agricultural land, and also by using abundant indigenous natural resources in forest area with a sustainable management practices.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Doktor Falsafah

KESAN LOKASI DAN MASA TERHADAP PENGANGKUTAN BENDALIR DAN SIFAT-SIFAT LAIN PADA BULUH (*Gigantochloa scortechinii* Gamble)

Oleh

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Gigantochloa scortechinii Gamble (Buluh Semantan) adalah salah satu spesies buluh yang paling biasa, dan banyak ditemui dengan taburan merata di Semenanjung Malaysia. Satu kajian telah jalankan untuk mengkaji struktur dan perbezaan pada bahagian yang paling tidak beri perhatian iaitu umbisi dari tiga tapak kajian dan empat umbisi yang berturutan umur. Kajian ini menekankan pada perbezaan dan hubungan terhadap sifat fisiologi, anatomi, kimia, dan fitokimia yang berkaitan dengan tapak dan umur umbisi. Kajian ini telah dijalankan di tiga lokasi berbeza di Semenanjung Malaysia, iaitu di Hutan Simpan Amanjaya (Perak), Hutan Simpan Kenaboi (Negeri Sembilan), dan Hutan Simpan Ayer Hitam (Selangor). Lokasi-lokasi ini telah dipilih kerana taburan spesis buluh *G. scortechinii* yang banyak, dan juga mewakili keadaan persekitaran yang berbeza seperti ketinggian dari aras laut, taburan hujan, dan suhu. Persampelan dengan kaedah penuaian umbisi buluh spesis *G. scortechinii* yang berturutan telah dijalankan berdasarkan kaedah persampelan rawak terpilih daripada rumpun buluh yang sihat. Empat umbisi yang berturutan adalah bagi mewakili empat umur umbisi: a) tunas, b) muda, c) pra-matang, dan d) matang.

Hasil kajian menunjukkan perbezaan yang ketara ($p<0.01$) pada pengankutan bendalir (K) di antara tapak kajian, umur umbisi dan interaksi mereka (tapah kajian dan umur umbisi). Hubungan yang ketara juga didapati di antara K dengan morfologi umbisi, iaitu bilangan tunas aktif ($r = 0.455$, $p<0.01$), bilangan tunas rosak ($r = 0.435$, $p<0.01$) dan cabang umbisi ($r = -0.673$, $p<0.01$). Morfologi umbisi iaitu jarak diantara umbisi muda dengan tua, panjang umbisi, bilangan ruas, garis pusat umbisi (bahagian atas, tengah, bawah, dan purata), garis pusat lubang umbisi (tengah, bawah, dan purata), ketebalan dinding umbisi (atas, tengah, dan purata), bilangan tunas (jumlah, aktif dan rosak)

berbeza dengan ketara dan menunjukkan hubungan yang ketara dengan tapak kajian. Walau bagaimanapun, garis pusat lubang umbisi pada bahagian atas dan bilangan cabang umbisi tidak berbeza dengan ketara melalui tapak kajian yang berlainan. Bagi umur umbisi, perbezaan yang ketara ($p<0.01$) juga didapati pada bilangan tunas, bilangan tunas aktif, bilangan cabang umbisi. Selanjutnya, bilangan tunas dan bilangan tunas aktif dapati menurun dengan peningkatan usia umbisi.

Semua pemboleh ubah yang dikaji bagi ciri-ciri anatomi berbeza dengan ketara terhadap tapak kajian yang berbeza kecuali garis pusat parenkima, garis pusat lubang parenchyma dan ketebalan dinding sel fiber (FCWT) pada $p<0.05$. Merujuk pada umur umbisi, nisbah ukuran menegak dan melintang (RTR) didapati berbeza dengan ketara ($p<0.01$) dengan hubungan yang negatif dengan umur umbisi dimana menggambarkan bahawa RTR menurun dengan peningkatan umur. Walaubagaimana pun, garis pusat ikatan pembuluh (VB), diameter GTP, garis pusat lubang GTP, ketebalan dinding sel GTP, diameter Fi, ketebalan dinding Fi, ukuran panjang Fi, dan nisbah *runkle* (RR) didapati berbeza dengan ketara ($p<0.01$) dengan hubungan yang ketara (masing-masing $r=0.343$, 0.400, 0.350, 0.682, 0.367, 0.634, 0.413, and 0.320) dengan umur umbisi yang mana menggambarkan peningkatan dengan peningkatan umur umbisi. Ke semua sifat-sifat anatomi termasuk elemen pengangkutan didapati menunjukkan hubungan yang tidak ketara dengan Kbg kecuali ukuran garis pusat dan garis pusat lubang GTP.

Merujuk pada unsur-unsur kimia, hasil kajian menunjukkan kandungan abu (AC), keterlarutan alkohol asetik (AAS) dan holoselulosa didapati berbeza dengan ketara ($p<0.01$) di antara tapak kajian. Selanjutnya, AC, keterlarutan padda air panas (HWS), AAS, lignin (L), dan holoselulosa (HC) menunjukkan perbezaan yang ketara ($p<0.01$) dengan hubungan yang jelas (masing-masing $r=-0.823$, 0.688, 0.986, 0.945, 0.510) dengan umur umbisi. AC menunjukkan hubungan positif ($r=0.747$) yang ketara ($p<0.01$) dengan K_{bg} yang mana menggambarkan bahawa penurunan AC dengan peningkatan umur umbisi menyebabkan penurunan K_{bg}, tetapi, HWS, AAS, L, dan HC menunjukkan hubungan negative (masing-masing $r=-0.706$, -0.914, -0.857, -0.567) yang ketara ($p<0.01$) dengan K_{bg} yang mana menggambarkan bahawa peningkatan unsur-unsur kimia tersebut dalam peninkatan umur umbisi menyebabkan penurunan K_{bg}.

AC di anggarkan berkait dengan unsur-unsur nutrisi yang mana penting bagi pertumbuhan yang cepat bagi organ yang sedang membangun berbanding dengan organ buluh yang lebih tua. Perkaitan AC dengan perubahan unsur-unsur nutrisi semasa tempoh kematangan adalah berkait dengan tiga jangkaan dalam kajian-kajian lepas di mana (a) keupayaan meyerap nutrisi, (b) ikatan tisu-tisu yang aktif secara metaboliknya yang mengangkut unsur-unsur nutrisi, dan (c) kesan penigkatan biomas yang cepat terhadap nisbah pencairan. Hasil kajian menunjukkan bahawa beberapa unsur nutrisi seperti kandungan nitrogen (N), sulfur (S), fosforus (P), potassium (K), kalsium (Ca), kalium (Na), kuprum (Cu) (masing-masing $p<0.01$), dan besi (Fe) ($p<0.05$) didapati berbeza

dengan ketara dengan tapak kajian. Unsur-unsur nutrisi seperti N, P, K, Ca, magnesium (Mg), Cu, dan zink (Zn) didapati berbeza dengan ketara ($p<001$) dan kandungannya menurun dengan peningkatan umur umbisi (masing-masing r=-0.912, -0.834, - 0.844, -0.834, -0.899, -0.364, and -0.933). Perubahan N (r=0.827), P (r=0.928), K (r=0.871), Ca (r=0.903), Mg (r=0.836), and Zn (r=0.841) menunjukkan hubungan positif yang jelas ($p<0.01$) terhadap AC di mana menggambarkan bahawa penurunan kandungan unsur-unsur nutrisi dengan peningkatan umur umbisi menyebabkab penurunan AC.

Seterusnya, kesan lokasi dan perkaitan umur juga menunjukkan kesan yang ketara terhadap variasi komposisi dan kandungan fitokimia. 18 sebatian di dapati sama pada ketiga-tiga tapak kajian; walaubagaimanapun, komposisi dan kandungan adalah bergantung pada umur. Dengan itu dicadangkan bahawa variasi komposisi fitokimia dankandungannya adalah lebih dipengaruhi oleh umur umbisi berbanding tapak kajian. Hasil kajian juga menunjukkan pelbagai sebatian fitokimia yang berfaedah seperti 4h-pyran-4-one,2,3-dihydro-3,5-dihydroxy-6-methyl, benzofuran, 2,3-dihydro-, phenol,3,4-dimethoxy-, benzoic acid,4-hydroxy-3,5-dimethoxy-, quinic acid, and n-hexadecanoic acid dalam ekstrak etanol dengan potensi menyumbang dalam penghasilan sumber biologi berasaskan tumbuhan.

Hasil kaian ini dapat meningkatkan pengetahuan memandangkan kekurangan maklumat pengangkutan bendalir dalam umbisi buluh serta factor-faktor yang mempengaruhi kadar angkutan. Hasil kajian boleh di guna pakai dalam amalan pengurusan buluh bagi memastikan hasil yang pengeluaran yang mampan dan memberi keuntungan. Walau bagaimanapun,ia juga bergantung pada tujuan dan sasaran produk seperti batang/umbisi, rebung, atau daun. Kajian ini juga merupakan langkah untuk menggalakkan penggunaan buluh terutamanya spesis *G. scortechinii* berdasarkan perspektif bio dengan potensi yang baik untuk industri. Penulis juga percaya bahawa usaha untuk meningkatkan ekonomi dan industri nasional dapat mengelakkan tekanan antarabangsa dengan kaedah yang relevan seperti mengelakkan penukaran status hutan kepada status perladangan atau tanah pertanian, dan juga dengan menggunakan sumber semulajadi dari spesis tempatan yang terdapat dalam jumlah yang banyak dan diurus dengan kaedah pengurusan yang mampan.

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α	Alpha
ANOVA	Analysis of Variance
ASTM	American Society for Testing Materials
β	Beta
cm	Centimeter
^{o}C	Degree Celsius
DBH	Diameter at Breast Height (1.3 m from the ground)
DMRT	Duncan's Multiple Range Test
DOA	Department of Agriculture
E	East
E	Transpiration
GC-MS	Gas Chromatography-Mass Spectrometry
m	Meter
m^2	Square Meter
mm	Millimeter
MPa	Mega Pascal
N	North
NHE	Nocturnal Hydraulic Event
F	Flow
FAO	Food and Agriculture Organization
FDPM	Forestry Department Peninsular Malaysia
FR	Forest Reserve
ha	Hectares
K	Hydraulic Conductance
kg	Kilogram
$kg\ s^{-1}$	Kilogram per Second
MPIC	Ministry of Plantation Industries and Commodities
µm	Micrometer
MOA	Ministry of Agriculture
MTIB	Malaysian Timber Industry Board
NIDA	National Institute of Design Ahmedabad
%	Percentage
P	Pressure
R	Resistance
RELMA	Regional Land Management Unit
SEM	Scanning Electron Microscope
TAPPI	Technical Association of the Pulp and Paper Industry
v/v	Volume over volume
Ψ_w	Water Potential

CHAPTER 1

INTRODUCTION

1.1 General Background

Malaysia is the sixth highest bamboo diversity country in Asia after China, Japan, India, Indonesia, and Myanmar; 510, 139, 144, 135 and 97 species in descending order. A totaled of 93 bamboo species found in Malaysia together with Sabah and Sarawak. 60 species recorded around Peninsular Malaysia; inclusive of exotic species in 10 genera. There are Bambusa, Chusquea, Dendrocalamus, Dinochloa, Gigantochloa, Phyllostachys, Racemobambos, Schizostachyum, Thyrostachys and Yushania (Azmy and Abd-Razak, 1991; FAO, 2007). Bamboo can commonly be found up to 1,000 m above sea level, in the logged-over forest, forest fringes, gap area, and river-side, either it dominant in an area or mixed with forest trees in Peninsular Malaysia (Azmy et al., 1997). Natural bamboo stands area in Peninsular Malaysia was estimated about 329 thousand ha accounting to 9 % of total forest reserve area (Razak, 2006). Based on Fourth National Forest Inventory, a total of 57 million clumps were estimated in Peninsular Malaysia (FDPM, 2007).

Bamboo belongs to the class either C3 or C4 photosynthetic pathway is still debated and therefore further research was needed to classify its mechanism of the photosynthetic process (Klienzhenz and Midmore, 2001; Jijeesh and Seethalakshmi, 2008; Duking et al., 2011; Kuehl, 2015). Although bamboo shows its ability as fast-growing species with short maturity cycle (3 – 4 year) than Eucalyptus and rubber trees, it is noted that photosynthetic rates decreased with increasing of age in the case of individual culms. Thus, only actively managed bamboo can be harvested annually, and the harvested biomass regenerated within a year that showed three to four times faster than comparable wood species (Azmy and Abd-Razak, 2001; Lou et al., 2010; Baksy, 2013). Dependent on species, harvester can continuously harvest bamboo for 80 – 120 years without replanting, a rare case in most trees (Blowfield et al., 1996; RELMA, 2003). The harvesting activities on bamboo give minimum adverse effect on the environment rather than logging activities (Azmy and Abd-Razak, 1992; Belcher et al., 2005).

Since the 80s, literature showed bamboo only practices in the ceremony, cottage industry and landscaping in this country - small and medium scale industry. Thus, realizing bamboo remains as underutilized as like other non-wood forest products. Its great potential is rarely exploited largely due to lack of awareness, remain scarce and inconsistent data on resources, uncertainties in the market structure and lack of concrete information on the existing and potential market for bamboo products (Azmy, 1989; Aminuddin, 1995; Azmy, 2004; Behari, 2006; FAO, 2007; FDPM, 2017). Malaysia managed to export

bamboo around RM 250 thousand as the average of last ten years, despite import of bamboo product from the global market was recorded up to RM 30.0 billion from 11 countries (MTIB, 2013). The world market value for bamboo in 2012 tune to RM 33 billion and is expected to reach about RM 65 billion by 2015. China leads ranks with up to 50 % of the world market followed by India. Neighborhood countries like China, India, Japan, Korea and Vietnam has utilized bamboo into a high value-added product that usually produced from timber since a decade ago, i.e. boards, parquet and laminates, paneling, furniture, pulp and paper, textiles and sports equipment (NIDA, 2012).

Bamboo acts as an environmentally benign material for engineered products and construction (Lugt et al., 2006). It uses and trade has been received increasing attention over the last two decades, internationally (FAO, 2007). As a material, mature bamboo ranks is higher than juvenile wood. As well as, the average fracture toughness of bamboo (56.8 MPa $m^{1/2}$) is higher than alloy (33.0 MPa $m^{1/2}$) and significantly higher than Douglas fir (1.6 MPa $m^{1/2}$) and Spruce (7.0 MPa $m^{1/2}$) woods (Amada and Untao, 2001). The average fiber length of *Bambusa vulgaris* and *Gigantochloa scortechinii* are higher (2.55-2.87 mm) than that of rubberwood (1.00-1.10 mm) and Kempas (1.00-1.60 mm) (Abd-Latif et al., 1990). Most literature on bamboo mechanical properties proven its suitability utilized as substitute and alternative resources to timber in such wood-based industries in Malaysia (Abd-Latif,1996; Abd-Latif et al., 1990; Anwar et al., 2004; 2005; Hanim et al., 2010; Febrianto et al., 2012; Nurhazwani et al., 2016; Zaidon et al., 2016; Rawaida et al., 2017).

Besides as food to wood substitutes, bamboo has a long history of medicinal uses and has been applied in Ayurvedic, Chinese herbal medicine and Tibetan medicine in neighboring countries. Generally, all part of bamboo is considered cooling, calming and phlegm-resolving and has a mild sweet taste. Although many species of bamboo had been used as a resource of medicinal products, yet no systematic evaluation has been carried out resulted in difficulty to define the primary active constituent in the ingredients per se (Dharmananda, 2004). Unfortunately, both neither traditional nor scientific information and application recorded beyond this purposes and this great potential in Malaysia. Nowadays, the Malaysian government has been promoting bamboo for industrial purposes through government policies, soft loan, research and higher level academic institution (MPIC, 2009), and involvement in the World Bamboo Day every September 18. Further, Government of Kedah State has planned a long-term special plan through Kedah Bamboo Agenda (KBA) in 2014 targeting various new bamboo-related areas to be explored, including manufacturing, marketing, wholesale, entrepreneurship, tourism and agriculture (MOA, 2014).

Gigantochloa scortechinii (Buluh semantan) is commonly used in Malaysia bamboo-based industries (Razak et al., 2012). It was found dominated in several areas around Peninsular Malaysia, i.e. Segamat (Johor), Kuala Lipis (Pahang), Gerik (Perak) and Nami (Kedah) (Aminuddin, 1995; Azmy and Abd-Razak 2001; Razak et al,.2012). A totaled of 163,010 clumps of *G. schortechinii* or 0.28 % of total bamboo clumps in Peninsular Malaysia was

estimated (FDPM, 2007). The established clump (from three years) of *G. schortechinii* produces large biomass for culms production. The estimated total aboveground biomass of mature *G. schortechinii* culms is 16.32 metric ton ha^{-1} $year^{-1}$ or 3,199 culms ha^{-1} $year^{-1}$ (Azmy and Abd-Razak, 2001). *G. schortechinii* culm from three and half years of age was found suitable for any utilization purpose, as well as for preparation of the declination of wood resources (Hisham et al., 2006).

Research on cultivated bamboo stands, silvicultural treatments including fertilizer application, mulching and thinning had been conducted since two decades ago in this country (Azmy, 1995, 1996, 2000; Azmy et al., 1997; Razak et al., 2011, 2012). Efforts covering on culms morphology, fibre morphology, physical, mechanical and chemical properties had been focus in recent years (Abd-Latif et al., 1990; Abd-Latif and Tarmizi, 1992; Anwar et al., 2005; Hisham et al., 2006; Razak et al. 2010a, Razak et al. 2010b; Azmy et al., 2011; Nordahlia et al., 2012; Razak et al. 2012). However, research on the subterranean part of sympodial bamboo species (especially *G. scortechinii*) considering rhizome and root system was mostly ignored; despite it is the most important part of bamboo stands. Development condition of subterranean part significantly affects bamboo yield and quality for both above and belowground parts (Zhang et al., 2007).

Kleinhenz and Midmore (2001) reported belowground biomass (rhizome + root) of pachymorph rhizome system generally were about 31 % of total biomass. Bamboo rhizome or so-called pseudo rhizome for pachymorph rhizome systems (Ding et al., 1997), basically serves for uptake, conductance, nutrients storage and vegetative reproduction system (Liese, 1998). Due to site adaptations, it's physiological and morphological properties may depict some characteristics modification such as the elongation and diameter, functions, structure, vascular bundles and other biochemical properties; since *G. scortechinii* distributions scattered along the Peninsular Malaysia, and exposed with different microclimatic condition, seasoning, soil and altitude (Ana and Maria, 2009). Furthermore, genetic variation also presents the heritability and plasticity both within and among *G. scortechinii* population (Dhanendiren et al., 2015).

Despite the age-related affect the rate of production (Alvin and Murphy 1988; Weiner et al., 1997), it may or may not affect the stands or clumps. Structural development and modification occur during culms maturations process, and the modification may happen in subterranean part too (Xu et al., 2014). Several observations have shown that culms structural development and modification influences cell wall thickness, ground tissues parenchyma, lignification, hydraulic conductivity (Hisham et al., 2006; Razak et al., 2006; Maya et al., 2013) and chemical attributes (Li et al., 2007; Wi et al., 2017). Therefore, this study provided important information on the variation of hydraulic conductance, morphological, anatomical, chemical and phytochemical attributes regarding bamboo's rhizome spatial and their age-related effect.

1.2 Problem Statement

As a primitive grass, bamboos are well adapted to site condition where did they grow and resulted to exhibit and massive growth with wide distribution. Bamboo has vast potential in various field of industry in Malaysia regarding its high productivity, short rotation, high economic value, and an advantage for sustainable management (Littelwood et al., 2013; Liu et al., 2016). Its potential should not be overlooked (since it covered such industries like food, nutraceutical and cosmetics, medicinal, engineered product, bio-product and renewable energy in another country) due to the perception that bamboo is not industrially popular and is poor man timber, and Malaysia still has abundant resources such as timber, food resources and petroleum. As a fact, Malaysia facing trend where demand is increased while the extraction of raw material is decreased in almost all industrial sector.

National Timber Industry Policy, 2009 - 2020 has exposed five commercial bamboo species such as *Dendrocalamus asper*, *Gigantochloa scortechinii, Gigantochloa levis, Gigantochloa wrayi,* and *Gigantochloa atriviolaceae* Widjaja for plantation as an alternative raw materials in wood-based industries, particularly to meet the global demand for the protection of the environment and forest conservation (MPIC, 2009). Previous studies prove that bamboo engineered product can compete or even better than several light wood engineered product.

Moreover, effort towards development green technology and overcoming the depletion of resources issues, government also give greater emphasis to promoting renewable energy (RE) and energy efficiency (EE) through Eighth Malaysia Plan 2001 - 2005, Ninth Malaysia Plan 2005 – 2010 and continue with Tenth Malaysia Plan 2011 – 2015 (PMD, 2010). In the meantime, several studies show that bamboo possesses potential in producing bio-fuel for RE. Research by Universiti Teknologi Petronas (UTP), Malaysia found that *G. scortechinii* has potential in order to produce bio-oil yield by using Fast Pyrolysis technique on *G. scortechinii* char, bio-oil, and gas with bio-oil (Molly, 2013).

However, in conjunction to implement government policy, ones should get comprehensive information to avoid unnecessary mistake and wastage. The systematic information regarding the spatial and age-related effect of bamboo is still limited and typically ignored, whereas it is essential before ones can carry out with any upstream activities. It may indicate the site species suitability, either species allocation strategies are to survive by structural modification on their characteristics, or to maintain their characteristics without prioritizing survivability especially when a species is chosen for a monoculture plantation. All those figures were needed and may significantly influence the upstream operation and also the yield, at last.

Therefore, this study is necessary to investigate the spatial and age-related effects of bamboo (*G. scortechinii*), and focused on the subterranean part (rhizome) with considering that it is the most important part for bamboo stands itself (Zhang et al., 2007). This study was conducted to provide important information to enhance the management operation on bamboo stands. This study also important as a preliminary study to explore Malaysian bamboo's potential regarding bio-perspective such as nutraceutical, pharmaceutical and medicinal potential as it is far behind compared to other bamboo producing countries. International treats regarding economic and industries due to forest's conversion into plantation could also be avoid using this abundant natural resources of (bamboo; *G. scortechinii*) indigenous species.

1.3 Justification of the Study

Literatures show that the suitable individual bamboo's (culms) age to be harvest is at age three to three and half years. But, this is just based on studies of the properties of bamboo culms such as mechanical, anatomical, and chemical properties. In term of sustainable production mode, it is important to understand its productivity and physiological status regarding its function. Different bamboo parts possess different physiological functions that contribute to high growth performance and sustainable stand production. Forest management and harvesting operator (entrepreneur) could not simply look into one-off harvesting operation on bamboo stand because bamboo possess continuous productivity and the growth performance of new sprouts are solely depends on the stimulation of rhizome buds (encompass precipitation, relative humidity, soil moisture, soil fertility, *etc*.) and the sources of energy and nutrients from its interconnected rhizomes. The new sprout has neither photosynthetic leaves nor rooting system to ensure its rapid elongation (Zhang *et al.* 1996; Rodrigues *et al.* 2003).

Therefore, either the culms or rhizome that aims to be harvest, two questions should be considered first before the harvesting operation take place; a) is the culm/rhizome at certain age is still productive and physiologically active?; and b) is the culm/rhizome at certain age is still need to support the new sprout's growth for sustainable production? Why these two questions do really means to ensure sustainable and profitable production? If the answer of the first question is 'yes', then why it should be harvest instead of remain it until reached at certain age for environmental goods such as for carbon storage and transpiration function. If the answer for second question is 'yes', then why the rush to harvest instead of remain the culm/rhizome until reach a certain age, and this will help to ensure good healthy level of new sprout growth, which means ensure the sustainable production and hence sustain the profit level in future.

One of the approaches that can be used to answer both above question is by understanding the hydraulic conductance of bamboo rhizome. This is because of the fundamental function of rhizome [important for nutrient uptake, storage, water absorption and conductance, and the vegetative reproduction system (Li

et al. 1998; Liese 1998)] in a bamboo clump. Therefore, the main hypothesis testing in present study was:

H_o = the hydraulic conductance is not affect by age factor

H_a = the hydraulic conductance significantly affect by age factor

If H_o is approve, it is consider that no modification or changes occur on conducting elements in rhizome. But if H_a is approve, there must be reason or factors that influence the conductivity in rhizome such as modification of conducting element, accumulation of substances, and other attributes changes that are interesting to define.

1.4 Objectives of the Study

The general objectives of this study were to investigate the spatial and age-related effects on hydraulic conductance, morphological, anatomical, chemical (major and minor) and phytochemical attributes variation of subterranean part of this species.

The specific objectives of this study were:

a) to determine the variation of physiological (hydraulic conductance, K_{bg}), morphological, anatomical, major chemical, and minor chemical (nutrient elements) attributes of rhizome in relation with spatial (study site) and age,
b) to investigate the relationship of K_{bg} changes during maturation period with morphological, anatomical, and chemical attributes, and
c) to identify the rhizome's phytochemical compounds of *Gigantochloa scortechinii* in relation with spatial (study site) and age as the first effort focus on bamboo's rhizome usage contributed to plant-derived biomaterials in Malaysia.

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BIODATA OF STUDENT

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Thesis: SPATIAL AND TEMPORAL EFFECTS ON HYDRAULIC CONDUCTANCE AND OTHER ATTRIBUTES OF BAMBOO (*Gigantochloa scortechinii* Gamble)

Major Field: Bioresource Management

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Born on 24th September 1985 in FELDA Lok Heng Timur, Kota Tinggi, Johor Darul Takzim. Married on May 2012 and blessed with three daughters; Nur A'liah, Nur Lathifah, and Nur A'zimah. He received Bachelor of Science (Forestry) from Faculty of Forestry, Universiti Putra Malaysia in 2007, and Master of Science in Silviculture from Faculty of Forestry, Universiti Putra Malaysia in 2013. Working experience as Special Graduate Research Allowance (SGRA) at Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Serdang (August 2017 to January 2018), Research Assistant at Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, Serdang (December 2013 to February 2014), Research Assistant at Faculty of Forestry, Universiti Putra Malaysia, Serdang (September 2012 to November 2013), Assistant Forest Conservator at Perak State Forestry Department, Ipoh (April 2010 to March 2012), Research Assistant at Malaysian Aids Council, Kuala Lumpur (June to November 2009), Graduate Research Fellowship (GRF) (assist lecturer on Non-wood forest products and Agroforestry subject) at Faculty of Forestry, Universiti Putra Malaysia, Serdang (July 2007 – June 2009), and Research Assistant at Faculty of Forestry, Universiti Putra Malaysia, Serdang (May to September 2007).

LIST OF PUBLICATIONS

Johar Mohamed, Hazandy Abdul Hamid, Ahmad Ainuddin Nuruddin and Nik Muhamad Nik Abdul Majid (2019). Anatomical characteristics of *Gigantochloa scortechinii* bamboo rhizome in relation with hydraulic conductance. *BioResources,* 14(4): 9082-9099. DOI: 10.15376/biores.14.4.9082-9099 (SJR – Q2)

Johar Mohamed, Hazandy Abdul Hamid, Ahmad Ainuddin Nuruddin and Nik Muhamad Nik Abdul Majid (2019). Chemical attributes of *Gigantochloa scortechinii* bamboo rhizome in relation with hydraulic conductance. *BioResources*, 14(4): 8155-8173. DOI: 10.15376/biores.14.4.8155-8173 (SJR – Q2)

Johar Mohamed, Hazandy Abdul Hamid, Ahmad Ainuddin Nuruddin and Nik Muhamad Nik Abdul Majid (2018). Spatial and age-related effects on phytochemical compounds of ethanolic extract of *Gigantochloa scortechinii* rhizome. *Preprints*, 2018090122. DOI: 10.20944/preprints201809.0122.v1

Hazandy Abdul Hamid, Johar Mohamed*, Nik Muhamad Nik Abdul Majid, and Ahmad Ainuddin Nuruddin (Prepare for Submission, October 2019). Macronutrient elements of *Gigantochloa scortechinii* bamboo rhizome in relation with ash content. *International Journal of Plant Science* (SJR - Q2)

Johar Mohamed*, Hazandy Abdul Hamid, Nik Muhamad Nik Abdul Majid, and Ahmad Ainuddin Nuruddin (Prepare for Submission, November 2019). Changes of micronutrient elements of *Gigantochloa scortechinii* bamboo rhizome. *International Journal of Plant Science* (SJR - Q2)

Proceedings

Hazandy Abdul Hamid, Johar Mohamed, Ahmad Ainuddin Nuruddin and Nik Muhamad Nik Abdul Majid (2019). Chemical attributes of *Gigantochloa scortechinii* bamboo rhizome in relation with hydraulic conductance in *Forest Research and Cooperation for Sustainable Development*. XXV IUFRO World Congress, 29 September – 5 October 2019, Curitiba, Brazil.

Johar Mohamed, Hazandy Abdul Hamid, Ahmad Ainuddin Nuruddin and Nik Muhamad Nik Abdul Majid. Spatial and Age-Related Effects on Morphology and Hydraulic Conductivity of Gigantochloa scortechinii in *Environmental Conservation: Role of Plant Physiology*. 25th Malaysian Society of Plat Physiology Conference, 18-20 August 2015, Sunway Lost World Hotel, Tambun, Ipoh, Perak.

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Gigantochloa scortechinii Gamble (Buluh Semantan) is one of the most common bamboo species, and abundant with scattered distribution in Peninsular Malaysia. The study focused on the variation of hydraulic conductivity (K), anatomical, chemical, and phytochemical attributes in relation to site and rhizome age. This study was conducted at three different locations of Peninsular Malaysia, namely Amanjaya Forest Reserve (Perak), Kenaboi Forest Reserve (Negeri Sembilan), and Ayer Hitam Forest Reserve (Selangor) due to the species distribution, and represented different climatic condition; elevation, precipitation, and temperature. Destructive sampling of four consecutive rhizomes of *G. scortechinii* was conducted using selective random sampling method from healthy clumps. Four consecutive rhizomes were represented four different rhizome ages: a) new sprout, b) young, c) premature, and d) mature rhizome.The results showed that K varied significantly ($p<0.01$) among study sites, rhizome ages and their interaction. Significant correlation was found between K with rhizome morphology; number of active buds, number of damaged buds, and rhizome branches. All measured anatomical characteristics including the conductance elements were found insignificant relationship with K except the parenchyma diameter and lumen diameter. Regarding chemical attributes, results indicate that decreasing of ash content in increasing of rhizome age resulted to decreasing of K, but, increasing of hot water solubility, alcohol-acetone solubility, lignin, and holocellulose were found inversely. The ash content is suggested to be related with the nutrient elements which are crucial for fast growth of growing organ than the older bamboo organ. Results also revealed various beneficial phytochemical compounds in the ethanolic extract of *G. scortechinii* rhizome with potential contribution to the plant-derived biomaterial. Results from this study could enhance the understanding beyond the lack information of hydraulic conductance in bamboo rhizome and factors that influence the conductivity. The results can be implementing in bamboo management practices to ensure sustainable and profitable production.