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REVIEW

Review on Malaysian *Goniothalamus* essential oils and their comparative study using multivariate statistical analysis

Natasa Mohd Shakri[1], Wan Mohd Nuzul Hakimi Wan Salleh[1,*] and Shazlyn Milleana Shaharudin[2]

[1]Department of Chemistry, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris (UPSI), 35900 Tanjong Malim, Perak, MALAYSIA

[2]Department of Mathematics, Faculty of Science and Mathematics, Universiti Pendidikan Sultan Idris (UPSI), 35900 Tanjong Malim, Perak, MALAYSIA

*Corresponding author. Email: wmnhakimi@fsmt.upsi.edu.my

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Abstract

The genus *Goniothalamus* is belonging to the Annonaceae family, consists of ca. 2500 species and found in tropical Southeast Asia. The *Goniothalamus* essential oils were recognized to possess considerable biological activities with varied chemical composition. This article aims to overview the medicinal uses, chemical compositions, and biological activities of Malaysian *Goniothalamus* essential oils considered as a medicinal plants, widely used as traditional herbal medicines in the treatment of various diseases. The data were collected from the scientific electronic databases including SciFinder, Scopus, Elsevier, PubMed and Google Scholar. Ten *Goniothalamus* species have been reported for their essential oils and biological activities. It can be observed that the major components were α-cadinol, terpinen-4-ol, β-eudesmol, β-selinene, linalool, limonene, α-copaene, 1,8-cineole and β-cubebene. In addition, the selected chemical components from the bark, leaf and root oils were analysed using Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) and were able to cluster in four groups based on relationships and chemical patterns in essential oils. This multivariate data analysis may be used for the identification and characterization of essential oils from different *Goniothalamus* species that are to be used as raw materials of traditional herbal products.

Keywords: Annonaceae, *Goniothalamus*, essential oil, principal component analysis, hierarchical cluster analysis

Introduction

Known as the most powerful therapeutic agents, essential oils are usually used as an alternative medicine known as aromatherapy to support human health and well-being. Additionally, essential oils have also been commonly used in the cosmetics, food, and agricultural industries. Essential oils are usually extracted from a natural source and have that particular plant's fragrance (Winska et al., 2019; Salleh et al., 2014a). The essential oil is normally stored within the plant's oil cells, glands, and vessels. It is released from the flowers as a fragrant fragrance, or retained in the plant's seeds, fruits, leaves, barks or roots until it gradually evaporates (Burger et al., 2019; Salleh et al., 2014b). Essential oils from aromatic and medicinal plants have been known since antiquity to possess biological activity, most notably antibacterial, antifungal and antioxidant properties (Salleh et al., 2015a, 2015b, 2015c, 2016a, 2016b, 2016c). Annonaceae is one of the plant families which numerous report on essential oils, due to its wide use in various traditional medicines and believed to have high medicinal values.

Annonaceae family is the largest family of the order Magnoliales consisting of approximately 135 genera and more than 2,500 species. The family has a source of edible fruit that can be considered to have economic importance. *Goniothalamus* is a genus of the Annonaceae family, with approximately 160 species of trees and shrubs frequently found in tropical Southeast Asia throughout Indochina and Malaysia (Anary et al., 2016; Aslam et al., 2016). The botanical characteristics are simple, strongly aromatic bark, having few leaves that are simple, alternate and exstipulate. The secondary nerves are also oblique, straight and parallel to

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scalariform reticulations. The axillary flowers are characteristically woody, fusiform and often dark green (Wiart, 2006, 2007; Nielsen, 1993). *Goniothalamus* species have been used as traditional medicines in Malaysia but information about the volatile composition quality of essential oils from these herbal materials is still limited. Previous studies have described the biological activities of various *Goniothalamus* species such as antibacterial (Funnimid et al., 2019), antimicrobial (Ghani et al., 2010), antifungal (Duc et al., 2016), antioxidant (Iqbal et al., 2015), and cytotoxicity activities (Kim et al., 2013). The available information on the essential oils of Goniothalamus species was collected via electronic searches such as Pubmed, SciFinder, Scopus, Google Scholar, and Web of Science.

This work aims to give an overview of all published studies on the chemical composition and biological activities of Malaysian *Goniothalamus* essential oils. In addition, the multivariate statistical analysis was also determined for the leaf, bark and root oils of selected *Goniothalamus* species. Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were used to characterize their essential oils components.

Traditional uses

Goniothalamus species are used to induce abortion, antiaging, body pain, rheumatism, skin irritation, typhoid fever, tympanites, stomach ache and fever in widespread medicinal commodities. Table 1 shows several *Goniothalamus* species and their medicinal uses.

Table 1. Medicinal uses of several *Goniothalamus* species

Species	Local name	Part	Medicinal uses
G. amuyon	*amúyon*	Seeds	Used to treat scabies, rheumatism and tympanites (Ahmad et al., 1991)
		Fruits	Used to treat stomachache (Quisumbing, 1951)
G. cheliensis		Stems	Used for the treatment of liver cancer, lung carcinoma and chronic cough (Jiang et al., 2011)
G. dolichocharpus	*bihidieng*	Roots	It is boiled and taken orally by the Kelabit community to ease stomachache (Quisumbing, 1951)
G. giganteus	*penawar hitam*	Roots	Used in abortion and treatment of colds (Wiart, 2006)
		Leaves	Heated leaves are applied to swellings (Wiart, 2006)
G. lanceolatus	*selukai*	Leaves	Used as a traditional remedy for fever, skin infection, postpartum, abortion, as well as a cancer treatment (Wiart, 2007)
G. laoticus	*Khao Lam-dong*	Stem bark	Used traditionally as a tonic and a febrifuge by the local people in the northeastern part of Thailand (Wu et al., 1991)
G. macrophyllus	*selayak hitam*	Leaves	Used to allay fever (Alkofahi et al., 1988)
		Roots	Used as a postpartum remedy and to cause abortion, antiaging purposes, rheumatisms, skin complaints, eliminate excessive gas in the body and used as a lotion to treat body pains (Alkofahi et al., 1988)
G. marcanii		Leaves	Used treating for infectious diseases in early childhood (Mahiwan et al., 2013)
G. malayanus	*kenanga paya*	Roots	Used for the treatment of rheumatism and fever (Ahmad et al., 1991)
		Stem bark	Used to treat measles and as insect repellents (Ahmad et al., 1991)
G. scortechinii	*gajah beranak*	Leaves	Used as a postpartum protective remedy and were used to improve blood circulation (Burkill, 1966)
G. sesquipedalis		Leaves	Used to treat fever, cough, colds, snakebite, pains, and infectious and inflammatory diseases (Akter et al., 2018)

G. tapis	*kenarak*	Roots	Used as an abortifacient during early months of pregnancy, an infusion of the roots is used to treat typhoid fever (Inayat-Hussain et al., 1999)
G. uvarioides	*belindung*	Roots	Used as postpartum protective remedies, abortifacients, and to treat typhoid fever, rheumatism, and headache (Moharam et al., 2012)
G. velutinus	*kayu tas hitam*	Leaves	Used as a traditional medicine for treating headache, food poisoning, as well as snakebite remedies, induce abortion and as a post-partum remedy (Inayat-Hussain et al., 1999)

Chemical composition of Malaysian *Goniothalamus* essential oils

There are ten species of *Goniothalamus* originated from Malaysia that were successfully reported for their essential oil composition. The essential oils of ten local *Goniothalamus* which were *G. andersonii, G. clemensii*, *G. macrophyllus*, *G. malayanus*, *G. ridleyi, G. tapis*, *G.tapisoides*, *G. velutinus*, *G. uvarioides,* and *G. woodii* have been investigated (Jusoh et al., 2015; Moharam et al., 2010; Ghani et al., 2010; Ahmad et al., 2010; Jantan et al., 2005). The plant parts used for the extraction of essential oils includes flower, fruit, leaf, stem, bark, and root. However, most of the essential oils from Malaysian *Goniothalamus* were extracted from bark, leaf and root. Table 2 shows the major components identified in *Goniothalamus* essential oils, whereas Figure 1 so its chemical structures.

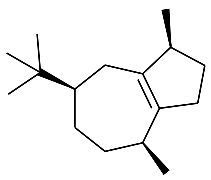
Table 2. Major components identified in Malaysian *Goniothalamus* essential oils

Species	**Locality**	**Parts**	**Yield (%)**	**Total components (%)**	**Major components**	**References**
G. andersonii	Sarawak	Leaf	0.70	25 (85.30)	Guaiol (28.60%) **(1)**, elemol (19.60%), β-caryophyllene (7.70%)	Jantan et al., 2005
G. clemensii	Sarawak	Bark	2.80	23 (98.10%)	α-Cadinol (41.60%) **(2)**, agarospirol (19.00%), elemol (16.10%)	Moharam et al., 2010
G. macrophyllus	N. Sembilan	Root	0.05	14 (42.50%)	Cyperene (9.80%) **(3)**, geranyl acetate (9.40%), camphene (7.50%)	Ghani et al., 2010
G. macrophyllus	N. Sembilan	Twig	0.14	21 (90.00%)	Geranyl acetate (45.50%) **(4)**, geraniol (17.00%), linalool (12.70%), camphene (7.50%)	Ghani et al., 2010
G. macrophyllus 1	Pahang	Bark	0.80	42 (97.80%)	Terpinen-4-ol (38.80%) **(5)**, 1,8-cineole (18.10%), geranyl acetate (11.10%), geraniol (9.70%)	Jantan et al., 2005
G. macrophyllus 2	Sarawak	Bark	0.70	41 (96.40%)	Terpinen-4-ol (42.70%) **(5)**, β-ocimene (25.40%), α-terpineol (10.00%), 1,8-cineole (5.80%)	Jantan et al., 2005
G. malayanus	Sarawak	Bark	0.96	36 (93.90%)	β-Eudesmol (32.20%) **(6)**, γ-eudesmol (21.80%), (*E*)-nerolidol (9.10%), elemol (6.70%), α-eudesmol (6.60%)	Jantan et al., 2005
G. malayanus 1	Sarawak	Leaf	0.32	35 (86.30%)	β-Selinene (33.60%) **(7)**, viridiflorol (13.10%), epiglobulol (7.70%)	Jantan et al., 2005
G. malayanus 1	Sarawak	Root	0.18	36 (90.50%)	β-Eudesmol (27.80%) **(6)**, γ-eudesmol (18.80%), (*E*)-nerolidol (6.50%), α-eudesmol (6.00%), elemol (5.10%)	Jantan et al., 2005
G. malayanus 2	Sarawak	Leaf	0.32	35 (86.20%)	β-Selinene (33.60%) **(7)**, viridiflorol (13.10%), epiglobulol (7.70%)	Jantan et al., 2005

G. malayanus 2	Sarawak	Root	0.18	35 (90.00%)	β-Eudesmol (27.80%) **(6)**, γ-eudesmol (18.80%), (*E*)-nerolidol (6.50%), α-eudesmol (6.00%), elemol (5.10%)	Jantan et al., 2005
G. ridleyii 1 (Fresh)	Kelantan	Bark	0.11	50 (89.50%)	Linalool (15.20%) **(8)**, citronellal (10.90%), β-eudesmol (9.80%), limonene (7.50%), elemol (7.40%)	Jusoh et al., 2015
G. ridleyii 1 (Fresh)	Kelantan	Stem	0.03	47 (90.10%)	β-Eudesmol (27.10%) **(6)**, γ-eudesmol (20.80%), (*Z*)-nerolidol (9.50%), elemol (6.60%)	Jusoh et al., 2015
G. ridleyii 1 (Fresh)	Kelantan	Fruit	0.12	49 (89.80%)	β-Cubebene (20.70%) **(9)**, elemol (20.20%), hedycaryol (9.40%), β-eudesmol (9.10%), viridifloral (6.10%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Bark	0.38	39 (94.60%)	Linalool (15.80%) **(8)**, citronellal (12.90%), limonene (10.60%), β-eudesmol (7.60%), safrole (7.50%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Leaf	0.90	48 (95.10%)	Linalool (23.40%) **(8)**, α-copaene (19.80%), β-caryophyllene (11.40%), 1,8-cineole (7.00%), terpinen-4-ol (6.10%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Stem	0.03	35 (93.30%)	β-Eudesmol (27.80%) **(6)**, δ-eudesmol (19.90%), (*Z*)-nerolidol (7.50%), elemol (7.10%), linalool (5.50%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Branch	0.27	37 (93.10%)	β-Selinene (35.90%) **(7)**, viridifloral (16.30%), (*Z*)-nerolidol (5.90%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Root	0.15	47 (92.80%)	Cyperene (22.80%) **(3)**, α-copaene (10.90%), α-eudesmol (8.10%), hedicaryol (4.60%)	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Kelantan	Fruit	0.83	37 (93.20%)	β-Cubebene (17.20%) **(9)**, elemol (15.90%), β-eudesmol (9.50%), hedicaryol (8.50%), viridifloral (8.40%)	Jusoh et al., 2015
G. tapis	Sarawak	Root	0.98	36 (88.00%)	Cyperene (16.20%) **(3)**, α-copaene (8.70%), α-eudesmol (5.70%), β-elemene (5.30%), γ-amorphene (5.20%)	Ahmad et al., 2010
G. tapis 1	Sarawak	Bark	2.85	23 (82.70%)	Limonene (12.70%) **(10)**, linalool (13.00%), safrole (11.20%), citronellal (6.30%), α-eudesmol (5.80%)	Moharam et al., 2010
G. tapis 1	Sarawak	Leaf	2.23	26 (92.40%)	α-Copaene (23.80%) **(11)**, linalool (18.50%), β-caryophyllene (14.20%), 1,8-cineole (7.60%)	Moharam et al., 2010
G. tapis 2	Sarawak	Bark	2.85	22 (83.00%)	Limonene (12.70%) **(10)**, linalool (13.00%), safrole (11.20%), citronellal (6.30%), α-eudesmol (5.80)	Ahmad et al., 2010
G. tapis 2	Sarawak	Leaf	2.23	29 (93.60%)	α-Copaene (23.80%) **(11)**, linalool (18.50%), β-caryophyllene (14.40%), 1,8-cineole (7.60%)	Ahmad et al., 2010
G. tapisoides 1	Sarawak	Bark	3.86	23 (99.00%)	1,8-Cineole (47.90%) **(12)**, terpinen-4-ol (22.50%), p-menthene (6.90%), α-pinene (6.60%), γ-terpinene (6.60%)	Moharam et al., 2010

G. tapisoides 1	Sarawak	Leaf	3.05	26 (99.40%)	1,8-Cineole (79.00%) **(12)**, α-pinene (9.60%), α-terpineol (4.40%)	Moharam et al., 2010
G. tapisoides 1	Sarawak	Root	1.45	20 (99.70%)	1,8-Cineole (56.10%) **(12)**, terpinen-4-ol (19.60%), γ-terpinene (5.70%)	Moharam et al., 2010
G. tapisoides 2	Sarawak	Bark	3.86	24 (92.60%)	1,8-Cineole (47.90%) **(12)**, terpinen-4-ol (22.50%), α-pinene (6.60%), γ-terpinene (6.60%)	Ahmad et al., 2010
G. tapisoides 2	Sarawak	Leaf	3.05	28 (99.50%)	1,8-Cineole (79.00%) **(12)**, α-pinene (9.60%), α-terpineol (4.40%)	Ahmad et al., 2010
G. tapisoides 2	Sarawak	Root	1.45	19 (95.60%)	1,8-Cineole (56.10%) **(12)**, terpinen-4-ol (19.6%), γ-terpinene (5.70%)	Ahmad et al., 2010
G. uvarioides	Sarawak	Leaf	0.27	51 (92.10%)	β-Cubebene (15.20%) **(9)**, elemol (9.70%), *epi*-α-cadinol (6.20%) α-muurolene (4.80%)	Jantan et al., 2005
G. uvarioides	Sarawak	Bark	0.98	28 (87.20%)	β-Eudesmol (31.50%) **(6)**, γ-eudesmol (16.00%), hedycaryol (13.60%), α-eudesmol (5.60%), (*Z*)-nerolidol (5.20%)	Jantan et al., 2005
G. uvarioides	Sarawak	Root	0.35	28 (85.50%)	Terpinen-4-ol (39.50%) **(5)**, 1,8-cineole (14.00%), α-terpineol (6.30%), *p*-cymene (5.10%)	Jantan et al., 2005
G. velutinus	Sarawak	Bark	1.40	45 (93.90%)	α-Cadinol (14.00%) **(2)**, α-eudesmol (9.70%), t-muurolol (9.10%), β-selinene (6.10%), γ-muurolene (5.20%)	Moharam et al., 2010
G. woodii	Sarawak	Bark	1.80	36 (97.00%)	α-Cadinol (21.90%) **(2)**, elemol (12.60%), agarospirol (8.00%)	Moharam et al., 2010

Figure 1. Chemical structures of several major components identified from *Goniothalamus* essential oils.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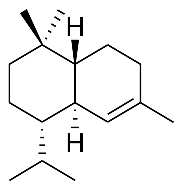

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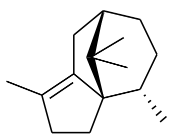
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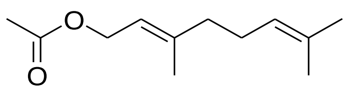

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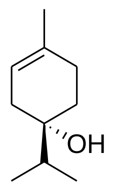

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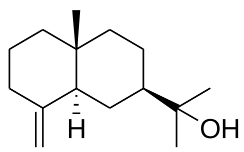

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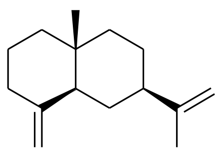
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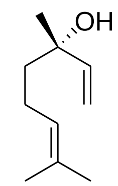

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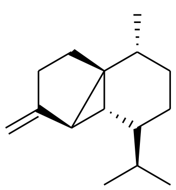
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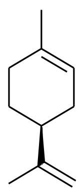
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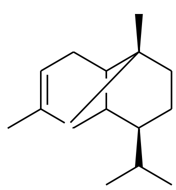
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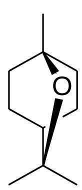

(12)

The bark oil was extracted from nine species of *Goniothalamus* which are *G. clemensii*, *G. macrophyllus*, *G. malayanus*, *G. ridleyi*, *G. tapis*, *G. tapisoides*, *G. uvarioides*, *G. velutinus*, and *G. woodii*. Seven species were found for its richness in oxygenated sesquiterpenes. They were α-cadinol (41.6%), β-eudesmol (32.2%), γ-eudesmol (21.8%), agarospirol (19.0%), elemol (16.1%), hedycaryol (13.6%), α-eudesmol (9.7%), t-muurolol (9.1%), (*E*)-nerolidol (9.1%), cubenol (7.7%), and (*Z*)-nerolidol (5.2%). In addition, sesquiterpene hydrocarbons were also found in the bark oils of Malaysian *Goniothalamus*. They were revealed by the presence of β-selinene (6.1%) found in the bark oil of *G. velutinus*. Furthermore, oxygenated monoterpenes were found in four local *Goniothalamus* bark oils. They were found in the bark oil of *G. macrophyllus*, *G. ridleyi*, *G. tapis*, and *G. tapisoides*. They were characterised by 1,8-cineole (47.9%), terpinen-4-ol (42.7%), linalool (15.8%), α-terpineol (10.0%), and geraniol (9.7%). Moreover, monoterpene hydrocarbons were also found as the major group components in four bark oils of *Goniothalamus* collected from Malaysia. (*Z*)-β-Ocimene (25.4%) and limonene (7.5%-12.7%) were found in the bark oil of *G. macrophyllus*, *G. ridleyi* and *G. tapis*. Meanwhile, p-menthene (6.9%), α-pinene (6.6%), and γ-terpinene (6.6%) were found in the bark oil of *G. tapisoides*. Geranyl acetate (11.1%), an ester was the major component of *G. macrophyllus* bark oil. Aldehyde which is citronellal (6.3%-12.9%) and phenyl propanoid which is safrole (5.3%-11.2%) were found in the bark oil of *G. ridleyi* and *G. tapis*, respectively.

Five essential oils of Malaysian *Goniothalamus* have been extracted by using leaf parts which are *G. andersonii*, *G. malayanus*, *G. tapis*, *G. tapisoides*, and *G. uvarioides*. The leaf oils were dominated by sesquiterpene hydrocarbons, oxygenated sesquiterpenes, monoterpene hydrocarbons, and oxygenated monoterpenes. Four out of five species have sesquiterpene hydrocarbons as their major components. They were identified as β-selinene (33.6%), α-copaene (23.8%), β-cubebene (15.2%), β-caryophyllene (14.4%), and α-muurolene (4.8%). In addition, oxygenated sesquiterpenes were also found in the leaf oil which was guaiol (28.6%), elemol (19.6%), viridiflorol (13.1%), and epi-globulol (7.7%). Moreover, oxygenated monoterpenes which were 1,8-cineole (7.6%-79.0%), linalool (18.5%), and α-terpineol (4.4%) were found in two leaf oils identified as *G. tapis* and *G tapisoides*. Besides, α-pinene (9.6%) was the only monoterpene hydrocarbon found from the leaf oil of *G. tapisoides*.

The root oils of Malaysian *Goniothalamus* have been extracted from five species which were identified as *G. macrophyllus*, *G. malayanus*, *G. tapis*, *G. tapisoides*, and *G. uvarioides*. The components can be classified as oxygenated sesquiterpenes, sesquiterpene hydrocarbons, oxygenated monoterpenes, monoterpene hydrocarbons and ester. The root oil of *G. malayanus* was dominated by oxygenated sesquiterpenes which were characterized by elemol (5.1%), (*E*)-nerolidol (6.5%), and γ-eudesmol (18.8%). β-eudesmol (5.0%-27.8%) and α-eudesmol (5.7%-6.0%) was found in both *G. malayanus* and *G. tapis* root oils. Next, sesquiterpene hydrocarbons found in the root oils were cyperene (9.8%-16.2%), α-copaene (8.7%), β-elemene (5.3%), and γ-amorphene (5.2%). Furthermore, oxygenated monoterpenes were found in the root oils of *G. tapisoides* and *G. uvarioides* which are 1,8-cineole (14.0%-56.1%), terpinen-4-ol (19.6%-39.5%), and α-terpineol (6.3%). Monoterpene hydrocarbons which were camphene (7.5%), γ-terpinene (5.7%), and p-cymene (5.1%) were found in the root oils of *G. macrophyllus*, *G. tapisoides*, and *G. uvarioides*. Last but not least, geranyl acetate (9.4%) which is an ester was found in the root oil of *G. macrophyllus*. Meanwhile, the fruit oil only reported from *G. ridleyii* with β-cubebene, elemol, and β-eudesmol as the major components (Jusoh et al., 2015).

Biological activities

Although many members of the genus *Goniothalamus* are renowned for their valuable essential oils, the genus is still poorly explored as far as its biological activities of essential oil are concerned. A search of the literature revealed the occurrence of antimicrobial and antiplatelet aggregation and platelet-activating factor

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(PAF) receptor antagonistic activities that have been reported from the Malaysian *Goniothalamus* essential oils.

The antimicrobial activity of root and twig oils of *G. macrophyllus* has been reported by Ghani et al. (2010). The oils were found to demonstrate the notable antimicrobial activity with the MIC values below the cut-off point of 1 mg/mL. The root oils were considerably more active than the twig oil in inhibiting all the bacterial and fungal strains except *P. aeruginosa*. The root oils had the strongest inhibitory effect against VISA24, *S. epidermidis* and *C. albicans* with the MIC values of 0.3 mg/mL. The twig oils demonstrated moderate to weak activity toward all bacterial strains tested with the MIC values ranging from 2.5 to 5 mg/mL. Both dermatophytes, *T. rubrum* and *M. cannis* however showed similar susceptibility to the twig and root oils with the MIC values of 2.5 mg/mL.

Moharam et al. (2010) reported antiplatelet aggregation and platelet-activating factor (PAF) receptor antagonistic activity against nine *Goniothalamus* essential oils (*G. velutinus*, *G. woodii*, *G. clemensii*, *G. tapis* and *G. tapisoides*). The bark oil of *G. velutinus* was the most effective sample as it inhibited both arachidonic acid (AA) and ADP-induced platelet aggregation with IC_{50} values of 93.6 and 87.7 µg/mL, respectively. Among the studied oils, the bark oils of *G. clemensii*, *G. woodii*, *G. velutinus* and the root oil of *G. tapis* showed significant inhibitory effects on PAF receptor binding, with IC_{50} values ranging from 3.5 to 10.5 µg/mL.

Multivariate statistical analysis

Ten Malaysian *Goniothalamus* species (28 samples) have been selected for this study which are *G. andersonii*, *G. clemensii*, *G. macrophyllus*, *G. malayanus*, *G. ridleyi*, *G. tapis*, *G. tapisoides*, *G. uvarioides*, *G. velutinus*, and *G. woodii*. Information on plant materials used for multivariate statistical analysis as shown in Table 3.

Table 3. Information on plant materials used for multivariate statistical analysis.

Species	**Collection Site**	**Parts**	**Lable**	**References**
G. clemensii	Sematan, Sarawak	Bark	**GCB**	Moharam et al., 2010
G. macrophyllus 1	Fraser Hill, Pahang	Bark	**GMB1**	Jantan et al., 2005
G. macrophyllus 2	Lawas, Sarawak	Bark	**GMB2**	Jantan et al., 2005
G. malayanus	Kota Samarahan, Sarawak	Bark	**GLB**	Jantan et al., 2005
G. ridleyii 1 (Fresh)	Gua Musang, Kelantan	Bark	**GRB1**	Jusoh et al., 2015
G. ridleyii 2 (Dry)	Gua Musang, Kelantan	Bark	**GRB2**	Jusoh et al., 2015
G. tapis 1	Lawas, Sarawak	Bark	**GTB1**	Moharam et al., 2010
G. tapis 2	Lawas, Sarawak	Bark	**GTB2**	Ahmad et al., 2010
G. tapisoides 1	Sematan, Sarawak	Bark	**GOB1**	Moharam et al., 2010
G. tapisoides 2	Lawas, Sarawak	Bark	**GOB2**	Ahmad et al., 2010
G. uvaroides	Merapok, Sarawak	Bark	**GUB**	Jantan et al., 2005
G. velutinus	Sematan, Sarawak	Bark	**GVB**	Moharam et al., 2010
G. woodii	Sematan, Sarawak	Bark	**GWB**	Moharam et al., 2010
G. andersonii	Kota Samarahan, Sarawak	Leaf	**GAL**	Jantan et al., 2005
G. malayanus 1	Kota Samarahan, Sarawak	Leaf	**GLL1**	Jantan et al., 2005
G. malayanus 2	Kota Samarahan, Sarawak	Leaf	**GLL2**	Jantan et al., 2005
G. tapis 1	Lawas, Sarawak	Leaf	**GTL1**	Moharam et al., 2010
G. tapis 2	Lawas, Sarawak	Leaf	**GTL2**	Ahmad et al., 2010
G. tapisoides 1	Sematan, Sarawak	Leaf	**GOL1**	Moharam et al., 2010
G. tapisoides 2	Sematan, Sarawak	Leaf	**GOL2**	Ahmad et al., 2010
G. uvarioides	Merapok, Sarawak	Leaf	**GUL**	Jantan et al., 2005

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G. macrophyllus	Pasoh Negeri Sembilan	Root	**GMR**	Ghani et al., 2010
G. malayanus 1	Kota Samarahan, Sarawak	Root	**GLR1**	Jantan et al., 2005
G. malayanus 2	Kota Samarahan, Sarawak	Root	**GLR2**	Jantan et al., 2005
G. tapis	Lawas, Sarawak	Root	**GTR**	Ahmad et al., 2010
G. tapisoides 1	Sematan, Sarawak	Root	**GOR1**	Moharam et al., 2010
G. tapisoides 2	Sematan, Sarawak	Root	**GOR2**	Ahmad et al., 2010
G. uvaroides	Merapok, Sarawak	Root	**GUR**	Jantan et al., 2005

Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were used to characterize their essential oils components. The components common to all essential oils were used to determine the similarity among species with a CA performed with the software Statistica 7.0. The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) was used to cluster groups based on Euclidean distance. The PCA was carried out with the software Statistica 7.0. PCA was used to reveal interrelationships among the ten species of the genus *Goniothalamus* based on the essential oil common components of these species (Wickramagamage, 2010; Shaharudin et al., 2013, 2018).

The HCA analysis revealed four distinct groups for each leaf bark, leaf, and root oils, based on the Euclidian distance as illustrated in Figure 2, Figure 3 and Figure 4, respectively. For *Goniothalamus* bark oils, the first group, Cluster I consisted of *G. clemensii*, *G. velutinus* and *G. woodii*. Cluster II included *G. macrophyllus* (1 and 2) and *G. tapisoides* (1 and 2). Meanwhile, Cluster III consisted of *G. malayanus* and *G. uvaroides*, whereas Cluster IV contained *G. ridleyi* (1 and 2) and *G. tapis* (1 and 2). For *Goniothalamus* leaf oil, the first group, Cluster I consisted of *G. andersonii* and *G. uvarioides*. Cluster II included *G. malayanus* (1 and 2), whereas Cluster III consisted of *G. tapis* (1 and 2). In addition, Cluster IV consisted of *G. tapisoides* (1 and 2). For *Goniothalamus* root oils, the first group, Cluster I consisted of *G macrophyllus*, while Cluster II comprised *G. tapisoides* (1 and 2) and *G. uvaroides*. Meanwhile, Cluster III consisted of *G. malayanus* (1 and 2), whereas Cluster IV contained *G. tapis*.

Furthermore, to evaluate the accuracy of this classification, the cluster obtained was confirmed by PCA analysis. Similarly, the bark, leaf and roots oils of *Goniothalamus* were divided into four groups each, Cluster I-IV. The results were obtained by PCA based on forty-one (bark oil), thirty-four (leaf oil), and thirty-one (root oil) chemical components. Three factors explained 51.50% (bark oil), 59.76% (leaf oil), and 65.99% (root oil) of accumulated variation of the data analysed. The first three are considered the most important as they represent ≥50% of the accumulated variation. Furthermore, these results also may be correlated with other factors involving a genetic determination that could also be modulated by biotic pressures, volatile constituents during flowering influenced by pollinators, and during the vegetative phase by pathogens and herbivores, or differences in environmental conditions (Silva et al., 2007). Thus, the variation pattern in essential oil composition may reflect selective pressures in different ecological and geographical environments (ecotypes).

Figure 2. PCA and UPGMA analyses of the composition of Malaysian *Goniothalamus* bark oils

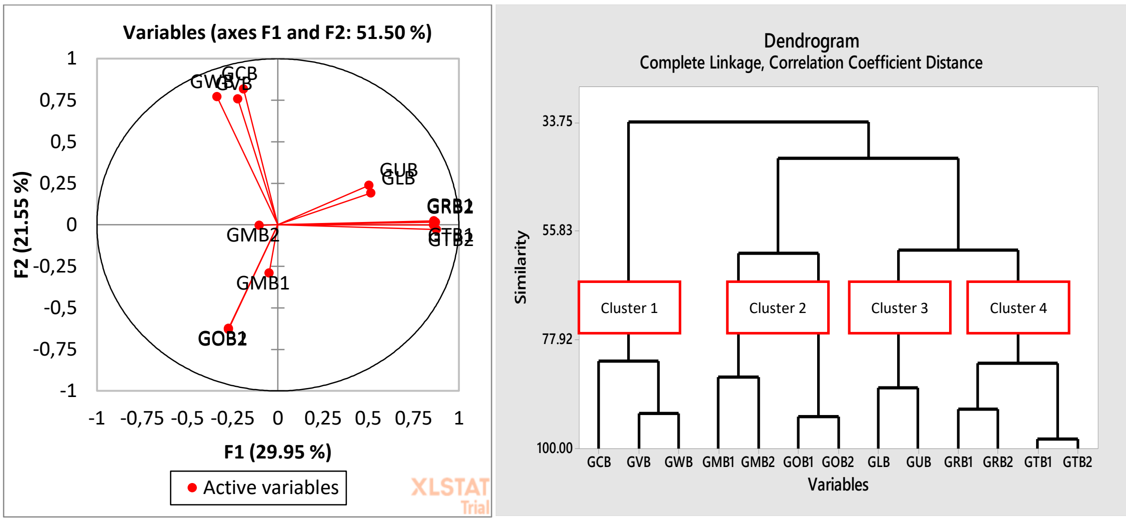


Figure 3. PCA and UPGMA analyses of the composition of Malaysian *Goniothalamus* leaf oils

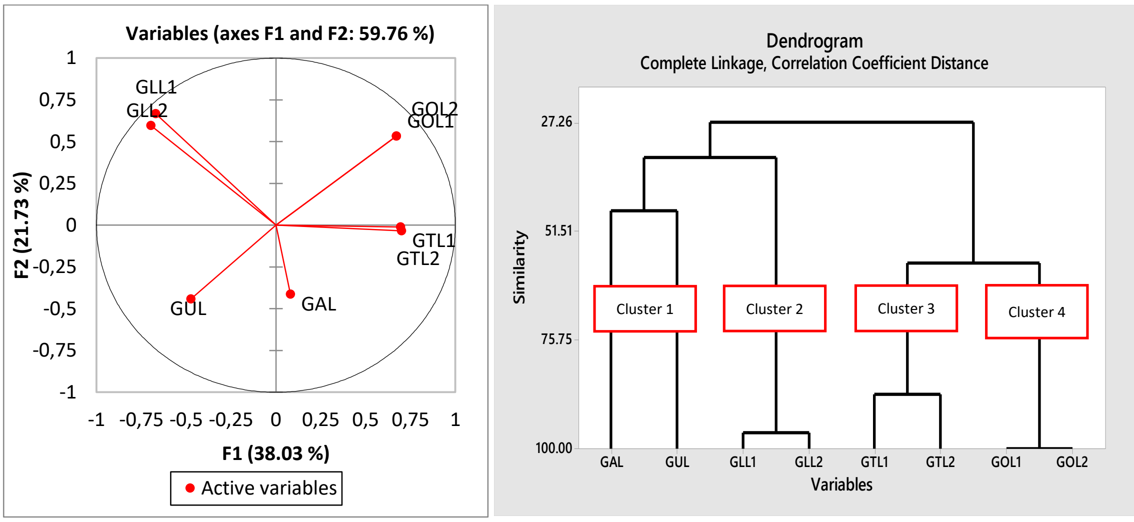
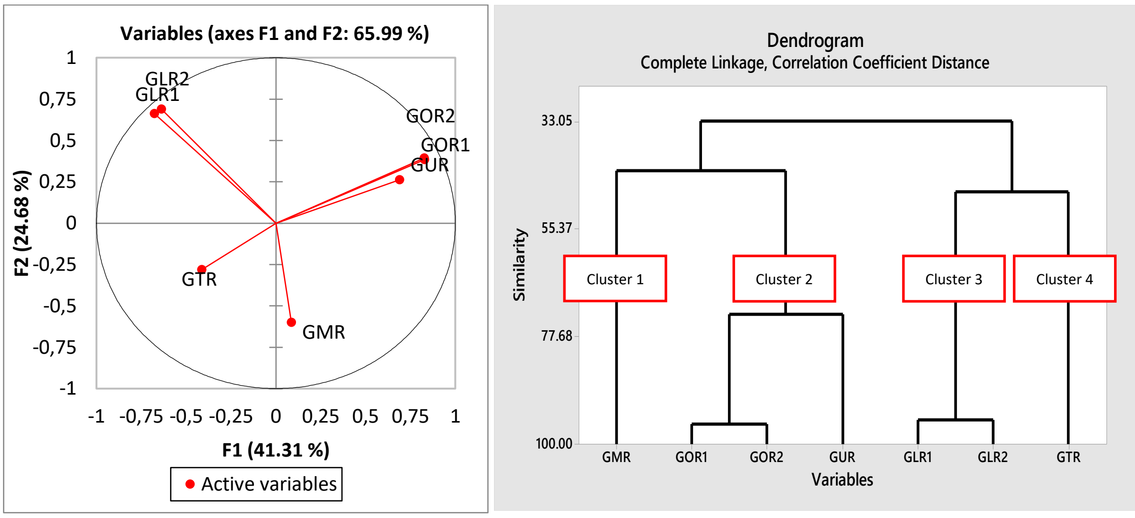


Figure 4. PCA and UPGMA analyses of the composition of Malaysian *Goniothalamus* root oils



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Conclusion

In conclusion, our study reports a review of Malaysian *Goniothalamus* essential oils and their chemical variability. This information is critical when selecting species with economic potential for the pharmaceutical and cosmetics industry. In addition, the multivariate data analysis may be used as quality control tools for the identification and characterization of essential oils from different *Goniothalamus* species that are to be utilized as raw materials in traditional herbal products. Further studies need to be carried out to determine fingerprints and chemical compositions of other *Goniothalamus* species and those collected from different origins.

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CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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