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Chemical Compositions, and Antimicrobial and Mosquito Larvicidal Activities of Essential Oils from Four *Syzygium* Species *Syzygium formosum* (Wall.) Masam., *S. syzygioides* (Miq.) Merr. & L.M. Perry, *S. megacarpum* (Craib) Rathakr. & N.C. Nair, and *S. chantaranothaianum* W.K. Soh & J. Parn

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ABSTRACT

Chemical compositions in the leaf essential oils of four *Syzygium* species were first identified by the GC-FID/MS analysis. Monoterpene hydrocarbons (39.6-51.1%), and sesquiterpene hydrocarbons (27.0-37.8%) were the main chemical classes in *S. formosum* and *S. syzygioides* leaf oils, whereas sesquiterpene hydrocarbons (83.0-83.8%) were predominant in *S. Megacarpum* and *S. chantaranothaianum* leaf essential oils. Bicyclogermacrene (9.1-37.0%) was the principal compounds in these essential oils. All the tested essential oils with the MIC values of 16-128 µg/mL were comparable to the positive control streptomycin against Gram-positive bacteria *Staphylococcus aureus* and *Bacillus cereus*, and Gram-negative bacterium *Pseudomonas aeruginosa*. The leaf essential oils of *S. formosum, S. syzygioides*, and *S. chantaranothaianum* with the MIC values of 16-128 µg/mL were comparable to the positive control cycloheximide against the yeast *Candida albicans*. Four samples also exhibited good larvicidal activity against the mosquito *Aedes aegypti* with the 24-h and 28-h LC_{50} values of 25-40 µg/mL

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Syzygium; essential oils; antimicrobial; mosquito larvicidal

1. Introduction

Numerous factors can influence the synthesis, yield, and composition of chemical components in essential oils, as well as their existence from inside the plants until their final isolation. By mean of this, the influential aspects have been researched, especially for economically significant crops, in an effort to maximize the growing conditions, and harvest timing while achieving increased yields of premium essential oils that meet market demands (1–3). Therefore, it is crucial to understand the variables that affect species' chemical variability and production. Physiological changes, environmental influences, geographic variances, genetic factors, plant material/space requirements, and the necessity for time collection are a few of these (4,5).

Syzygium is one of the largest genera in the family Myrtaceae with ca. 1200 evergreen trees and shrubs (6). The plants of this genus were recorded to distribute from Africa through Asia, Malesia and Australia to the Pacifica islands (6). The Clove (*S. aromaticum*) is a well-known economically crucial species, in which its unopened flower buds are used as a precious spice (7). Medicinally, *Syzygium* plant extracts and isolated compounds have also a broad panel of pharmacological activities, such as antimicrobial, antidiabetic, anti-inflammatory, and nephroprotective activities (7,8). It is also recognized that *Syzygium* plants are rich in essential oils containing terpenoid compounds. As an example, the antibacterial essential oil of *S. cumini* leaves was characterized by the presence of major components pinocarveol (15.1%), and α-terpeneol (8.9%) (9). Among 49 species recorded in Vietnam, some of them have been objects in phytochemical studies to identify chemical profiles in their essential oils. β-Caryophyllene (42.53–64.53%) can be seen as the main compound in the leaf essential oils of two Vietnamese *Syzygium* species *S. caryophyllatum* and *S. lineatum*, whereas the leaf essential oil of *S. hancei* was represented by γ-guaiene (11.07%) (10).

Regarding biological activities, *Syzygium* species showed potentials in antimicrobial and mosquito larvicidal treatments. The leaf essential oil of *S. grande*

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inhibited the growth of *Escherichia coli*, *Klebsiella pneumoniae*, *Proteus vulgaris*, *P. aeruginosa*, *S. aureus*, and *B. subtilis* with the MIC values of 0.25–0.75 mg/mL (11). The Clove essential oil controlled wound infections in mice caused by methicillin resistant *S. aureus* via its interaction with imipenem (12). *S. zeylanicum* leaf essential oil exhibited remarkably effective and eco-friendly larvicides against *Anopheles subpictus*, *An. albopictus*, and *Culex tritaeniorhynchus* larvae (13). The Clove essential oil was also reported to protect against *An. stephensi* larvae with the LC_{50} and LC_{90} values of 57.49 and 93.14 ppm, respectively (14).

The current study aims to report the chemical identification of essential oils of four wild *Syzygium* species, collected from the North Central Coast region of Vietnam, including *S. formosum* (Wall.) Masam. (local name: Trâm lá chụm ba), *Syzygium syzygioides* (Miq.) Merr. & Perry (Trâm kiền kiền), *S. megacarpum* (Craib) Rathakr. & N.C.Nair (Trâm lá lớn), and *Syzygium chantaranothaianum* W. K. Soh & J. Parn. (Trâm chan lốt), as well as their antimicrobial, and mosquito larvicidal activities.

2. Materials and methods

2.1. Plant materials

The fresh leaves of four studied species (7-year-old plants) were collected from Pu Hoat Natural Reserve, Nghean, Vietnam in 04/2022. The Latin names were identified by the co-author Le Thi Huong. The geographic coordinates included *S. formosum* (19°40′3″N and 104°55′30″), *S. syzygioides* (19°44′36″ and 104°48′2″), *S. megacarpum* (19°48′31″ and 105°5′47″), and *S. chantaranothaianum* (19°42′21″ and 104°50′2″). The voucher specimens, including SL-01 (*S. formosum* leaves), SL-02 (*S. syzygioides* leaves), SL-03 (*S. megacarpum* leaves), and SL-04 (*S. chantaranothaianum* leaves), have been deposited in Faculty of Biology, College of Education, Vinh University. The obtained samples (2.5 kg each) were immediately cut into pieces, and immersed in distilled water at a ratio of 1:1, w/v. They were then hydro-distilled using a Clevenger apparatus for 3.5 h to give the yellow essential oils. The yields of extraction, which were calculated following dried materials, reached a range of 0.15–0.25%.

2.2. GC-FID/MS analysis

Gas chromatography with flame ionization detection (GC-FID) was carried out following the conditions (15–18): Agilent Technologies HP-5 MS column (30 m x 0.25 mm, film thickness 0.25 µm), Helium carrier gas (1.1 mL/min), injector temperature of 260°C, detector temperature of 270°C, column temperature program: 65°C (3 min hold), increase to 230°C (4°C/min), 230°C (10 min hold), inlet pressure of 6.0 kPa, split mode injection (split ratio, 10:1), 1.1 µL injection volume.

Gas chromatography-mass spectrometry (GC-MS) was performed in the same manner: Agilent Technologies HP 7890A Plus Chromatograph (Santa Clara, CA, USA), HP-5 MS (30 m × 0.25 mm, film thickness 0.25 µm) column, HP 5973 MSD mass detector, Helium carrier gas (1.1 mL/min), MS ionization voltage of 70 eV, emission current of 40 mA, acquisitions range of 40–400 amu, a sampling rate of 1.0 scan/s. The GC was operated under the same circumstances as GC-FID. The retention indices (RI) based on a series of n-alkanes, co-injection with pure compounds (Sigma-Aldrich, St. Louis, MO, USA) or identified essential oil components, MS search (NIST 17 and Wiley 10^{th} Version libraries), and comparison with the literature MS fragmentation were used to identify the chemical components of the essential oils (15–18). It was mainly based on the GC peak area (FID response) and without the use of correction factors, the relative concentrations (%) of the constituents were computed. The measurements were made three times.

2.3. Antimicrobial assay

Antimicrobial effect of six leaf essential oils was performed using the broth dilution method (19). Seven pathogenic bacterial strains have been used, including three Gram-positive bacterial strains *Enterococcus faecalis* ATCC299212, *Staphylococcus aureus* ATCC25923, and *Bacillus cereus* ATCC14579, three strains of Gram-negative bacterial strains *Escherichia coli* ATCC 25,922, *Pseudomonas aeruginosa* ATCC27853, and *Salmonella enterica* ATCC13076, and one yeast strain *Candida albicans* ATCC 10,231.

The selection of investigated concentrations was based on our previous publication (19), in which the tested essential oil was active with the specific concentration ranges. Stock solution of essential oil was prepared by DMSO (1%). Dilution series (2-fold) were prepared from 512 to 16 µg/mL by distilled water. They were then transferred to 96-well plates. Bacteria grown in double-strength Mueller-Hinton broth were standardized to 5×10^5 CFU/mL. The last row of well plates containing only the serial dilutions of samples without microorganisms was used as a positive control (no growth). Distilled water and medium served as a negative control (no antimicrobial agent). Streptomycin and nystatin were used as standards for antibacterial and anti-yeast activities, respectively. Experiments were repeated in triplicate. The results

were displayed by the MIC values (the lowest dose at which bacterial growth is totally inhibited).

2.4. Mosquito larvicidal assay

Eggs of *Ae. aegypti* were purchased from Institute of Biotechnology, VAST, and maintained at the Laboratory of Department of Pharmacy of Duy Tan University, Da Nang, Vietnam. For the assay (20,21), aliquots of *Syzygium* essential oils, dissolved by DMSO (1% stock solution), were placed in a 300-mL beaker and added to distilled water, containing 20 larvae (3^{th} and early 4^{th} instars). In each experiment, a set of controls using DMSO was also run for comparison. Mortality was calculated after 24 h and 48 h of exposure during which no nutritional supplement was added. The experiments have been carried out at room temperature. Each test was carried out with 3 replicates with several concentrations (100, 50, 25, 12.5, 6.0, 3.0, 1.5, and 0.75 µg/mL). Permethrin with the same tested concentrations was used as a positive control. The acute larvicidal effects on *Ae. aegypti* were recorded for 24 h and 48 h treatments. The data obtained were subjected to log-probit analysis to obtain LC_{50} values, LC_{90} values, and 95% confidence limits using XLSTAT v. 2018.5 (Addinsoft, Paris, France).

3. Results and discussion

A total of 46 compounds were identified in the leaf essential oil of *S. formosum*, which accounted for 94.1% (Table 1). This leaf essential oil was dominated by monoterpene hydrocarbons (51.1%), sesquiterpene hydrocarbons (27.0%), and oxygenated sesquiterpenes (15.2%). Oxygenated monoterpenes presented in a trace amount of 0.8%. The principal compounds were monoterpene hydrocarbons (*E*)-*β*-ocimene (18.0%) and *β*-pinene (16.8%), and sesquiterpene hydrocarbon bicyclogermacrene (9.1%). There were lesser percentages of *cis*-*β*-elemene (7.6%), spathulenol (6.6%), *α*-pinene (6.3%), (*Z*)-*β*-ocimene (3.8%), *β*-caryophyllene (3.2%), myrcene (2.4%), viridiflorol (2.1%), alismol (1.8%), germacrene D (1.6%), limonene (1.4%), and cubeban-11-ol (1.1%). The remaining compounds were observed with amounts of less than 1.0%.

Similar to *S. formosum* leaf essential oil, the extraction of *S. syzygioides* leaves gave a yellow essential oil with 47 identified compounds (94.9%), which was predominated by monoterpene hydrocarbons (39.6%) and sesquiterpene hydrocarbons (37.8%). Oxygenated sesquiterpenes were also significant with 16.6%, whereas oxygenated monoterpenes was present in a trace mount of 0.9%. *α*-Pinene (15.2%), (*Z*)-*β*-ocimene (10.3%), and (*E*)-*β*-ocimene (7.1%) can be seen as characteristic monoterpene hydrocarbons. The principal sesquiterpene hydrocarbon, once again, was bicyclogermacrene (16.5%). Spathulenol (7.4%) was the most abundant compound in the group of oxygenated sesquiterpenes. Obviously, the amounts of *α*-pinene, bicyclogermacrene, and (*Z*)-*β*-ocimene in *S. syzygioides* leaf essential oil were higher than those in *S. formosum* leaf essential oil by 8.9, 7.4, and 6.5%, respectively. However, in contrast to *S. formosum* leaf essential oil, *β*-pinene (0.9%) and *cis*-*β*-elemene (1.1%) have been identified as minor compounds in *S. syzygioides* leaf essential oil. Likewise, the highest amount compound, (*E*)-*β*-ocimene in *S. formosum* leaf oil was associated with only 7.1% in *S. syzygioides* leaf essential oil.

The yellow essential oil of *S. megacarpum* leaf was obtained with 31 identified compounds (94.2%) that was almost entirely sesquiterpene hydrocarbons (83.8%) in character. In the meantime, their oxygenated derivatives reached 9.9%. Monoterpene hydrocarbons were not prevalent with 0.3%, while phenyl ethyl hexanoate (0.2%) represented as a non-terpenic compound only. The percentage of major compound bicyclogermacrene (37.0%) was recorded to outnumber the ones in the leaf essential oils of *S. formosum* and *S. syzygioides* by 27.9 and 20.5%, respectively. The percentages of *β*-caryophyllene and germacrene D in the leaf essential oils of *S. formosum* and *S. syzygioides* are not remarkable, but they achieved significant amounts of 9.4 and 16.4% in the leaf essential oils of *S. megacarpum*, respectively. Likewise, with 11.2%, *cis*-*β*-elemene in *S. megacarpum* leaf essential oil was found to outstrip that in the two first essential oils. *S. megacarpum* leaf oil also contained lower levels of spathulenol (3.6%), caryophyllene oxide (2.3%), *δ*-elemene (2.0%), *α*-humulene (1.9%), and *δ*-cadinene (1.0%).

Considering *S. chantaranothaianum* species, 36 compounds were identified in its leaf essential oil, which represented 96.2%. In the same manner with *S. megacarpum* leaf essential oil, sesquiterpene hydrocarbons (83.0%) were predominant in this oil sample, followed by oxygenated sesquiterpenes (12.2%), and monoterpene hydrocarbons (1.0%). Resembling *S. megacarpum* leaf essential oil, oxygenated monoterpenes were completely absent. The leaf essential oil of *S. chantaranothaianum* was associated with the appearance of two major components *β*-caryophyllene (19.4%) and bicyclogermacrene (24.7%). In addition, there have been accompanied by smaller percentages, such as germacrene D (7.9%), *δ*-elemene (7.5%), *cis*-*β*-elemene (5.4%), germacrene B (4.3%), and *γ*-elemene (3.1%), *δ*-selinene (1.6%), 9-*epi*-(*E*)-caryophyllene (1.3%), and aromadendrene and *α*-humulene (1.1%).

Table 1. The Identified Compounds (%) in the Essential Oils of Four *Syzygium* Leaves.

No.	RI_E	RI_L	Constituents	*S. formosum*	*S. syzygioides*	*S. megacarpum*	*S. chantaranothaianum*
1.	930	924	*α*-Thujene	0.3	0.3		
2.	939	932	*α*-Pinene	**6.3**	**15.2**		
3.	978	969	Sabinene	0.8	0.1		
4.	984	974	*β*-Pinene	**16.8**	0.9	0.3	
5.	991	988	Myrcene	2.4	0.9		
6.	1010	1002	*α*-Phellandrene	0.1	2.1		
7.	1029	1022	*O*-Cymene	0.5	1.0		
8.	1033	1024	Limonene	1.4	0.7		
9.	1035	1025	*β*-Phellandrene	0.2			
10.	1038	1032	(Z)-*β*-Ocimene	3.8	**10.3**		
11.	1049	1044	(*E*)-*β*-Ocimene	**18.0**	**7.1**		1.0
12.	1063	1054	*γ*-Terpinene	0.1			
13.	1093	1086	Terpinolene	0.4	0.4		
14.	1101	1095	Linalool	0.3	0.4	0.2	
15.	1131	1128	*allo*-Ocimene		0.6		
16.	1185	1174	Terpinen-4-ol		0.1		
17.	1257	1253	Linalyl acetate	0.3	0.4		
18.	1290	1282	*trans*-Linalool oxide acetate	0.2			
19.	1347	1335	*δ*-Elemene	0.4	0.5	2.0	**7.5**
20.	1384	1372	Geranyl acetate	0.3			
21.	1388	1374	*α*-Copaene	0.2	0.2	0.5	
22.	1402	1389	*cis*-*β*-Elemene	**7.6**	1.1	**11.2**	**5.4**
23.	1424	1409	*α*-Gurjunene		0.3	0.2	0.3
24.	1436	1417	*β*-Caryophyllene	3.2	3.8	**9.4**	**19.4**
25.	1444	1434	*γ*-Elemene	0.2			3.1
26.	1445	1436	*α*-*trans*-Bergamotene		0.7		
27.	1449	1440	*β*-Gurjunene		0.1	0.4	
28.	1452	1442	*α*-Maalinene		0.2		
29.	1455	1443	Aromadendrene	0.3	3.6	0.7	1.1
30.	1459	1444	Selina-5,11-diene		0.4		0.2
31.	1460	1445	(Z)-*β*-Farnesene				
32.	1462	1449	Guaia-1 (5), 6-diene				0.3
33.	1470	1467	*α*-Humulene	0.9	1.1	1.9	1.1
34.	1475	1469	Striatene				
35.	1478	1470	9-*epi*-(*E*)-Caryophyllene	0.6	1.6	0.7	1.3
26.	1489	1478	*γ*-Muurolene		0.7	0.6	0.7
37.	1491	1480	Valecene				0.5
38.	1493	1482	*α*-Amorphene	0.2	0.3	0.2	0.4
39.	1497	1484	Germacrene D	1.6	1.1	**16.4**	**7.9**
40.	1503	1489	*β*-Selinene	0.6	1.6	0.8	0.3
41.	1505	1498	*δ*-Selinene				1.6
42.	1511	1499	Viridiflorene	0.4	1.0		0.1
43.	1513	1500	Bicyclogermacrene	**9.1**	**16.5**	**37.0**	**24.7**
44.	1521	1511	*δ*-Amorphene			0.2	0.6
45.	1528	1513	*γ*-Cadinene	0.2	0.4	0.3	0.3
46.	1535	1522	*δ*-Cadinene	0.9	0.9	1.0	1.4
47.	1552	1537	*α*-Cadiene	0.2			
48.	1559	1545	Selina-3,7 (11)-diene				0.5
49.	1568	1561	(*E*)-Nerodiol			0.6	
50.	1576	1566	Germacrene B	0.4	0.5	0.3	4.3
51.	1583	1570	Dendrolasin		1.2		
52.	1586	1575	Globulol			0.5	
53.	1587	1576	Palustrol	0.4	0.5		0.7
54.	1596	1580	Spathulenol	**6.6**	**7.4**	3.6	1.1
55.	1603	1582	Caryophyllene oxide			2.3	
56.	1603	1589	Viridiflorol	2.1	2.9		2.6
57.	1610	1591	Guaiol			0.2	
58.	1612	1595	Cubeban-11-ol	1.1	1.7		2.9
59.	1620	1600	Rosifoliol	0.4	0.5		0.5
60.	1620	1602	Ledol	0.4		0.3	0.4
61.	1629	1608	Humulene epoxide II			0.3	
62.	1645	1627	1-*epi*-Cubenol	0.3	0.2		1.9
63.	1649	1630	*γ*-Eudesmol				0.2
64.	1650	1640	Phenyl ethyl hexanoate			0.2	
65.	1655	1644	Alismol	1.8			
66.	1656	1638	*epi*-*α*-Cadinol	0.4	2.1	0.5	0.4
67.	1658	1640	*epi*-*α*-Muurolol	0.2			0.2
68.	1661	1644	*α*-Muurolol		0.2		
69.	1671	1652	*α*-Cadinol	0.8	0.6	0.9	0.7
70.	1674	1658	*neo*-Intermedeol	0.7	0.5	0.5	0.6

(*Continued*)

Table 1. (Continued).

No.	RI_E	RI_L	Constituents	*S. formosum*	*S. syzygioides*	*S. megacarpum*	*S. chantaranothaianum*
			Total	**94.1**	**94.9**	**94.2**	**96.2**
			Monoterpene hydrocarbons	51.1	39.6	0.3	1.0
			Oxygenated monoterpenes	0.8	0.9		
			Sesquiterpene hydrocarbons	27.0	37.8	83.8	83.0
			Oxygenated sesquiterpenes	15.2	16.6	9.9	12.2
			Non-tepernic compounds			0.2	

RI_E: Retention indices relative to *n*-alkanes (C_7-C_{30}) on HP-5 MS column.
RI_L: Retention indices from NIST standard database.
Bold: Compounds with greater than 5%.

To date, there were several GC-MS analytical studies on Vietnamese S*yzygium* species. (*Z*)-*β*-Ocimene (20.3%) and caryophyllene oxide (13.2%) were characteristic compounds of *S. nervosum* leaf oil from Southern Vietnam (22). Another example is that *β*-caryophyllene (23.40%), bicyclogermacrene (21.23%), and (*Z*)-*β*-ocimene (10.61%) established as the main compounds in the leaf essential oil of *S. tsoongii*, also collected from North Central Coast region of Vietnam (23). Thereby, it might be possibly concluded that monoterpene hydrocarbons and sesquiterpene hydrocarbons seem to be characters of the essential oils of Vietnamese S*yzygium* plants.

The obtained oils have been subjected to antimicrobial activity against three Gram-positive bacteria *E. faecalis*, *S. aureus*, and *B. cereus*, three Gram-negative bacteria *E. coli*, *P. aeruginosa*, and *S. enterica*, and one yeast *C. albicans*. As shown in Table 2, four samples showed powerful antimicrobial activity against Gram-positive bacteria *S. aureus* and *B. cereus* since these leaf oils possessed the MIC values better than those of the positive control streptomycin. In another case, the leaf essential oils of *S. megacarpum* (MIC = 16 μg/mL) and *S. syzygioides* (MIC = 32 μg/mL) were comparable with streptomycin (MIC = 32 μg/mL) against Gram-positive bacterium *E. faecalis*, while two remaining essential oils exerted the same MIC value of 64 μg/mL.

Regarding the Gram-negative bacteria, the MIC values assigning to four essential oils against *P. aeruginosa* orderly run as *S. megacarpum* and *S. chantaranothaianum* (MIC = 32 μg/mL) > *S. syzygioides* (MIC = 64 μg/mL) > *S. formosum* and streptomycin (MIC = 128 μg/mL). However, all samples failed to inhibit *E. coli* and *S. enterica*. Of the yeast *C. albicans*, the leaf oils of *S. formosum* and *S. syzygioides* were associated with the MIC value of 16 μg/mL, as compared with that of the standard cycloheximide (MIC = 32 μg/mL). The leaf essential oil of *S. chantaranothaianum* induced an equivalent MIC value of 32 μg/mL to that of cycloheximide, whereas the leaf essential oil of *S. megacarpum* was strongly active against *C. albicans* with the same MIC value of 64 μg/mL. As can be seen, the leaf essential oils of *S. formosum* and *S. syzygioides* are better than two remaining essential oils in antimicrobial assay against *C. albicans*. It may be due to the abundance of monoterpene hydrocarbons in these two samples.

This is the first time that Vietnamese *Syzygium* plants have been subjected to antimicrobial assays. The obtained results match well with previous reports. For instance, the Gram-positive bacterium *Bacillus subtilis* was susceptible to the leaf essential oils of *S. aromaticum* and *S. polyanthum* (MIC = 31.25 μg/mL), but these oils were inactive to *E. coli* (23). Essential oil of clove *S. aromaticum* showed remarkable antimicrobial activity against 20 different isolates of *Listeria monocytogenes* at both concentrations of 1 and 10 μg/mL growth medium, and inhibited *Streptococcus mutans* with the MIC value of 30 μg/mL (24,25).

The 24-h and 48-h larvicidal activity of four *Syzygium* leaf essential oils against mosquito *Aedes aegypti* is shown in Table 3. It noted that essential oils have been considered actively larvicidal action if the

Table 2. Antimicrobial Activity of *Syzygium* Leaf Oils.

	Gram (+)			Gram (-)			Yeast
Samples	*E. faecalis*	*S. aureus*	*B. cereus*	*E. coli*	*P. aeruginosa*	*S. enterica*	*C. albicans*
S. formosum leaf oil	64	64	32	–	128	–	16
S. syzygioides leaf oil	32	64	32	–	64	–	16
S. megacarpum leaf oil	16	64	32	–	32	–	64
S. chantaranothaianum leaf oil	64	32	32	–	32	–	32
Streptomycin	32	128	256	256	128	256	–
Cycloheximide	–	–	–	–	–	–	32

"-": inactive.

Table 3. Mosquito Larvicidal Activity of *Syzygium* Leaf Oils Against *Ae. Aegypti*.

Samples	LC_{50} (95% confidence levels)	LC_{90} (95% confidence levels)	χ^2	*p*
24-h treatment				
S. formosum leaf oil	30.1829 (28.1738–33.4702)	38.8101 (34.6692–47.9616)	0.0405804	0.980
S. syzygioides leaf oil	40.0409 (35.9258–43.1261)	50.6895 (47.2371–55.5091)	0.0178952	0.999
S. megacarpum leaf oil	28.3124 (26.4661–30.5315)	39.0577 (35.3101–46.0244)	0.0512473	0.975
S. chantaranothaianum leaf oil	27.5695 (25.4163–30.0059)	43.0427 (38.3092–51.1411)	6.11088	0.106
Permethrin (control)	0.0094 (0.0082–0.0107)	0.0211 (0.0185–0.0249)	57.6	0.000
48-h treatment				
S. formosum leaf oil	25.5460 (24.0321–27.6987)	33.0007 (30.1325–38.8792)	0.0010657	0.999
S. syzygioides leaf oil	39.2594 (35.1459–42.4376)	49.2314 (45.7001–53.9207)	0.0105410	1.000
S. megacarpum leaf oil	26.7038 (24.9437–29.2504)	35.7358 (32.3128–42.5290)	0.440285	0.802
S. chantaranothaianum leaf oil	26.6563 (24.6262–28.9373)	40.9687 (36.5517–48.6822)	6.15491	0.104

LC_{50} value is less than 100 μg/mL (20). Based on this criterion, all studied samples exhibited good larvicidal activity with the 24-h and 48-h LC_{50} values of around 25–40 μg/mL, as well as the 24-h and 48-h LC_{90} values of around 33–50 μg/mL. In detail, the leaf essential oils of *S. megacarpum* and *S. chantaranothaianum* having the respective 24-h LC_{50} values of 27 and 28 μg/mL are better than those of *S. formosum* leaf oil (LC_{50} = 30 μg/mL) and *S. syzygioides* leaf oil (LC_{50} = 40 μg/mL). This can be explained by the high concentration of sesquiterpene hydrocarbons, especially in terms of bicyclogermacrene. However, *S. formosum* leaf essential oil with the highest percentages of *β*-pinene (16.8%), (*E*)-*β*-ocimene (18.0%), and *cis*-*β*-elemene (7.6%) induced the lowest 48-h LC_{50} value of 25 μg/mL, and the lowest 24-h and 48-h LC_{90} values of 33–38 μg/mL. Significantly, our current results are superior to previous analogs. The leaf essential oils of Indian *S. lanceolatum* and Brazilian *S. jambolana* generated the LC_{50} values of 55.11 and 433 μg/mL, respectively (26,27). The leaf essential oil of another Brazilian *S. aromaticum* caused the LC_{50} value of > 90 μg/mL against *A. aegypti* (28). Thereby, it is expected that Vietnamese *Syzygium* essential oils are now promising agents for antimicrobial and mosquito repellency drug developments.

4. Conclusion

The current results exhibited a great variation in chemical compositions of four *Syzygium* leaf essential oils. Monoterpene hydrocarbons (39.6–51.1%) and sesquiterpene hydrocarbons (27.0–37.8%) represented the leaf essential oils of *S. formosum* and *S. syzygioides*, whereas the leaf essential oils of *S. megacarpum* and *S. chantaranothaianum* were dominated by sesquiterpene hydrocarbons (83.0–83.8%). Bicyclogermacrene (9.1–37.0%) was detected in four studied essential oils. *β*-Pinene (16.8%) and (*E*)-*β*-ocimene (18.0%) were also characteristics of *S. formosum* leaf oil, *S. syzygioides* leaf essential oil also contained *α*-pinene (15.2%), (Z)-*β*-ocimene (10.3%), spathulenol (7.4%), and (*E*)-*β*-ocimene (7.1%). *cis*-*β*-Elemene (5.4–11.2%), *β*-caryophyllene (9.4–19.4%), and germacrene D (7.9–16.4%) were found in the leaf essential oils of *S. megacarpum* and *S. chantaranothaianum*. All the tested oils with the MIC values of 16–128 μg/mL were comparable or better than the positive control streptomycin against Gram-positive bacteria *S. aureus* and *B. cereus*, and Gram-negative bacterium *P. aeruginosa*. In the same manner, the leaf essential oils of *S. formosum*, *S. syzygioides*, and *S. chantaranothaianum* with the MIC values of 16–128 μg/mL were comparable or better than the positive control cycloheximide against the yeast *C. albicans*. Four oil samples have so far shown good larvicidal activity against mosquito *Ae. aegypti* with the 24-h and 28-h LC_{50} values of 25–40 μg/mL, and the 24-h and 28-h LC_{90} values of 33–50 μg/mL.

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