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Chemical composition, enantiomeric distributions of chiral monoterpenoids, and *Aedes* mosquito control potential of *Globba schomburgkii* Hook.f. (Zingiberaceae) essential oil

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Globba schomburgkii, traditionally used as a medicinal and culinary plant, has not been comprehensively investigated for its chemical composition. In this study, essential oils from samples collected in Binh Chau (BC) and Con Dao (CD), Vietnam, were analyzed by GC–MS and chiral GC–MS, and their larvicidal potential was assessed against *Aedes aegypti* and *Aedes albopictus* following WHO guidelines. The essential oil BC was dominated by caryophyllene oxide (31.4%) and β -pinene (15.1%), whereas the essential oil (CD) represented a distinct chemotype rich in β -pinene (24.5%), (*E*)- β -caryophyllene (17.8%), and dill apiole (7.2%). Both chemotypes exhibited promising larvicidal activity, highlighting *G. schomburgkii* essential oil as a potential natural agent for mosquito control.

Keywords *Aedes aegypti*, *Aedes albopictus*, Arboviruses, Biopesticide, (–)- β -Pinene, Zingiberaceae

Globba schomburgkii Hook.f. (Zingiberaceae) is widely distributed throughout continental monsoon Asia¹, including Vietnam². *G. schomburgkii* has high economic value as an ornamental and medicinal plant³. Extracts from different parts of *G. schomburgkii* containing high levels of sesquiterpenoids and diterpenoids have exhibited antimicrobial activities^{4,5}. Raj et al. analyzed the essential oil of this plant collected from Pathanamthitta, Kerala (India), and reported that it comprised 8.1% monoterpenoids, 72.9% sesquiterpenoids, 7.6% aliphatic acids, and 6.6% diterpenoids⁶. Identifying Zingiberaceae species solely on the basis of vegetative organs and flowers is challenging. The vegetative parts of many species are morphologically similar and thus unsuitable for reliable identification, while the flowers are structurally complex and often delicate³. In this study, we analyzed the chemical composition of *G. schomburgkii* essential oils by GC–MS and chiral GC–MS, which can be used as chemical fingerprints that can be useful for botanical classification and for describing the aroma of essential oils of this plant species.

Essential oils are being regarded as a promising alternative to synthetic insecticides for the control of disease-transmitting mosquitoes. This study also evaluated the potential of *G. schomburgkii* essential oils for controlling two mosquito species, *Aedes aegypti* and *Aedes albopictus*, through their larvicidal activities and fumigant toxicity. Mosquitoes of the genus *Aedes* serve as important vectors for several arboviruses, including dengue⁷, Zika⁸, yellow fever⁹, and chikungunya^{10–12}.

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Materials and methods

Plant material and essential oil extraction

Plant materials were collected in Con Dao National Park (GPS: 8°43'06"N, 106°37'53"E) (specimen code: GSCD) and Binh Chau Nature Reserve (GPS: 10°30'05"N, 107°28' 43"E) (specimen code: GSBC), Vung Tau in August 2024. Plant identification was performed morphologically by Dr. Van The Pham using relevant taxonomic literature, including Flora of Vietnam¹³ and An Illustrated Flora of Vietnam (Pham, 2000)². The collected specimens were further compared with authenticated digital herbarium records and images available in online virtual herbaria (e.g., Plants of the World Online, Royal Botanic Gardens, Kew; and the Muséum national d'Histoire naturelle herbarium portal). Voucher specimens (GSCD and GSBC) were prepared and deposited in the SIE herbarium for future reference. Plant materials were dried under laboratory temperature conditions with the assistance of air conditioning and fans.

Whole plant (stem, leaves, roots, rhizomes and flowers) (CD: 5.5 kg; BC: 5.5 kg) were cut into small pieces and distilled with water for 6 h using a Clevenger-type apparatus (Witeg Labortechnik, Wertheim, Germany). Essential oil yields were determined as the average of three replicates. The collected oils were dehydrated with anhydrous Na₂SO₄ and kept in airtight glass vials at 4 °C until subsequent analyses and bioassays.

Gas chromatographic—mass spectral analysis

Gas chromatography–mass spectrometry (GC–MS) was performed on a Shimadzu GCMS-QP2010 Ultra with EI ionization at 70 eV, scanning m/z 40–400 at 3.0 scans/s. Separation was achieved on a ZB-5 ms column (60 m × 0.25 mm, 0.25 µm 5% phenyl-arylene 95% dimethylpolysiloxane film; Phenomenex) using helium as the carrier gas (2.0 mL/min, 208 kPa). Injector, detector, and interface temperatures were 260 °C¹⁴. The oven was programmed from 50 to 260 °C at 2 °C/min. Essential oils (1% w/v in dichloromethane) were injected (1 µL, split 1:24.4). Component abundance was calculated from peak areas, and compounds were identified by retention indices (*n*-alkanes) and mass spectra comparison with the data in the Adams, Mondello, and NIST17 libraries^{15–17}.

Chiral GC–MS was performed on a Shimadzu GCMS-QP2010S with EI ionization at 70 eV, using a Restek β-Dex 325 chiral column (30 m × 0.25 mm, 0.25 µm 2,3-di-*O*-methyl-6-*O*-*t*-butyldimethylsilyl β-cyclodextrin incorporated into 14% cyanopropylphenyl/86% dimethyl polysiloxane) Helium was the carrier gas (1.0 mL/min, 53.6 kPa). The oven was programmed from 50 to 120 °C at 1.5 °C/min, then 120 to 200 °C at 2.0 °C/min. Essential oils (5% w/v in dichloromethane) were injected (0.1 µL, split 1:45). Compounds were identified by comparison of retention indices and mass spectra with authentic standards, and enantiomeric ratios were calculated from relative peak areas without correction factors¹⁴.

Larvicidal bioassays

Larvicidal assays followed the protocol of Van et al. (2025)¹⁸. *Aedes* spp. colonies were maintained at Duy Tan University (25 °C; 75 ± 5% RH). Eggs of three species were hatched in tap water, larvae reared on commercial cat food with daily water renewal, and adults supplied with 10% glucose and blood-fed on mice. Essential oil (EO) stock solutions (100–6.25 µg/mL in ethanol; Merck) were prepared, and 25 third–early fourth instar larvae were exposed to 150 mL of each solution in 250 mL glass beakers. Each treatment was conducted in quadruplicate, with ethanol as the negative control and permethrin as the positive control. Mortality was recorded after 24 and 48 h.

Drug interaction analysis

Drug interaction analyses were conducted in accordance with the methodology described by Tran et al.¹⁹. The FICI value was determined using the formulas presented in Eqs. (1)–(5).

$$FICI = FIC(A) + FIC(B) \quad (1)$$

$$FIC(A) = \frac{LC_{50}(A), \text{ combo}}{LC_{50}(A), \text{ alone}} \quad (2)$$

$$FIC(A) = \frac{LC_{50}(B), \text{ combo}}{LC_{50}(B), \text{ alone}} \quad (3)$$

$$LC_{50}(A), \text{ combo} = LC_{50 \text{ total}} \times \frac{rA}{rA + rB} \quad (4)$$

$$LC_{50}(B), \text{ combo} = LC_{50 \text{ total}} \times \frac{rB}{rA + rB} \quad (5)$$

where, rA and rB represent the mass ratios of compounds A and B, respectively. FICI refers to the Fractional Inhibitory Concentration Index, while FIC(A) and FIC(B) refer to the Fractional Inhibitory Concentration of compounds A and B, respectively. The FICI was interpreted as follows: (1) a synergistic effect when $FICI \leq 0.5$; (2) an additive or indifferent effect when $0.5 < FICI \leq 1$; (3) indifferent effect when $1.0 < FICI \leq 4$; and (4) an antagonistic effect when $FICI > 4$.

Fumigation toxicity

Fumigant toxicity was assessed following Van et al.¹⁸. Essential oils were diluted in acetone to 12.5–0.15% (v/v). Filter paper strips (1 × 3 cm) were treated with 10 µL of solution and suspended in 250-mL glass flasks containing

15 unfed adult mosquitoes. Each concentration was tested in quadruplicate, with acetone as the negative control. Mortality was recorded at 0.5–24 h, and mosquitoes unresponsive to gentle agitation were considered dead.

Statistical analysis

Mortality rates and percentage inhibition were subjected to log–probit analysis²⁰ to estimate LC₅₀, LC₉₀, and IC₅₀ values with corresponding 95% confidence intervals, using Minitab® software version 19.2020.1 (Minitab, LLC, State College, PA, USA).

Results and discussion

Chemical composition of essential oil

The chemical profiles of the two essential oil samples CD and BC were significantly different (Table 1). β -Pinene, (*E*)- β -caryophyllene and caryophyllene oxide in CD and BC were 24.5 and 15.1%, 17.8 and 5.6%, 5.8 and 31.4%, respectively. In the CD sample, phenylpropanoids were notably abundant, with dill apiole (7.2%) and asaricin (4.4%) together contributing 12.2% of the total composition, whereas in the BC sample, phenylpropanoids accounted for only 0.6%.

The main components of whole plant essential oil in Kerala (India) were reported to be (*E*)- β -caryophyllene (31.7%), caryophyllene oxide (10.3%), palmitic acid (7.6%), 13,14,15,16-tetranorlabd-8(17)-en-12-al (6.6%), aromadendrene (5.5%) and α -humulene (5.3%). In contrast to this study, the essential oil of Kerala (India) sample contained low levels of monoterpenoids (8.1%)⁶. Our findings revealed comparatively high concentrations of α -pinene (3.8–4.3%) and camphene (4.5–5.1%), in contrast to earlier reports on *Globba* essential oils, where these constituents were detected only at low levels or remained undetected^{6,21,22}. (*E*)- β -Caryophyllene appears to be a widespread constituent within the genus *Globba*, having been reported in notable amounts from various species, including *G. sessiliflora* (20.1% in the rhizome; 12.3% in the aerial parts)²¹, *G. cernua* (24.2% in the rhizome)²², *G. ophioglossa* (20.1% in the rhizome; 1.0% in the whole plant)^{6,22}. Caryophyllene oxide demonstrates a broad distribution across *Globba* species, occurring in both rhizomes and aerial parts. It has been reported in *G. sessiliflora* (8.6% in the rhizome; 3.0% in the aerial parts), *G. cernua* (7.7% in the rhizome), and *G. ophioglossa* (21.8% in the whole plant)^{6,21,22}. Caryophyllene oxide frequently co-occurs with its precursor, the bicyclic sesquiterpene (*E*)- β -caryophyllene, in plant essential oils as a result of oxidative transformation. Although the chemical nature of the subsequent oxidation products remains poorly characterized, the observed inverse relationship between (*E*)- β -caryophyllene and caryophyllene oxide levels in *Globba* oils suggests ongoing oxidative conversion. Hence, the consistent occurrence of (*E*)- β -caryophyllene and caryophyllene oxide may be considered as potential chemotaxonomic markers, providing valuable criteria for the chemical identification and classification of the genus *Globba*.

To the best of our knowledge, this study provides the first comprehensive report on the enantiomeric distribution of chiral monoterpenoids in *G. schomburgkii* essential oils, thereby offering new insights into the chemical stereochemistry of the genus. The enantiomeric distributions of chiral monoterpenoids in the two *G. schomburgkii* essential oils (CD and BC) were comparable for camphene, β -pinene, limonene, and linalool, whereas clear differences were observed for sabinene and α -pinene (Table 2). The enantiomeric distribution of α -pinene and sabinene varied both among individuals and between tissues within a single individual, and the underlying causes of this pronounced variability could not be clearly determined²³. (–)- β -Pinene was consistently found at high levels in both CD and BC samples of *G. schomburgkii* essential oils, a trend also observed in several *Curcuma* species. Notably, *C. aeruginosa* represents an exception, where this enantiomer was 40.9% (Table 2). (–)- β -Pinene has been reported to be present in low concentrations in rhizome, fruit, and flower essential oils of *Zingiber roseum* (0.2–22.8%)²⁴. Monoterpene profiles in essential oils are valuable genetic markers, supporting taxonomic studies and enabling the identification of clones, hybrids, subspecies, and geographic origin of the extracted plant.

Larvicidal activity

Both essential oil samples demonstrated notable larvicidal activity, with 24-h LC₅₀ values against *Ae. aegypti* and *Ae. albopictus* ranging from 38.35 to 41.74 μ g/mL for the CD sample, and from 54.70 to 66.42 μ g/mL for the BC sample (Table 3). The CD sample showed stronger acute toxicity on larvae of two the *Aedes* mosquito species than the BC sample.

The larvicidal activities of the principal constituents of the essential oils are presented in Tables 4 and 5. In this study, caryophyllene oxide exhibited stronger larvicidal activity against two mosquito species *Ae. aegypti* and *Ae. albopictus* than (*E*)- β -caryophyllene. β -Pinene and α -pinene exhibited stronger larvicidal activities than their essential oils. *Piper aduncum* essential oil with dillapiole content of 86.9% exhibited larvicidal activity against *Ae. aegypti* with 24-h LC₅₀ value of 54.5 μ g/mL²⁷. Dillapiole exhibited stronger larvicidal activity against resistant *Ae. aegypti* strains than both α -pinene and β -pinene with 24-h LC₅₀ values ranging from 15.06–17.60 μ g/mL²⁸. (*E*)- β -Farnesene exhibited excellent larvicidal activity against six mosquito vectors *Anopheles stephensi*, *An. subpictus*, *Ae. aegypti*, *Ae. albopictus*, *Culex quinquefasciatus*, and *Cx. tritaeniorhynchus* with 24-h LC₅₀ values ranging from 8.13 to 12.51 μ g/mL²⁹.

Importantly, two highly potent larvicidal constituents reported in the literature, (*E*)- β -farnesene and dillapiole, were also detected among the major components of our oils, but at markedly different abundances between populations. Specifically, (*E*)- β -farnesene accounted for 5.5% in the CD oil but only 0.5% in the BC oil, while dillapiole represented 7.2% in CD versus 0.4% in BC.

The major chemical constituents β -pinene, (*E*)- β -caryophyllene, and caryophyllene oxide exhibited indifferent interactions with one another (Table 6), suggesting that the overall larvicidal activity is primarily driven by the intrinsic potency and relative abundance of active constituents rather than by synergism among these major compounds. Therefore, the higher larvicidal efficacy of the CD oil compared to BC is consistent with

RI _{calc}	RI _{db}	Compounds	CD	BC
923	923	Tricyclene	0.1	0.1
926	925	α -Thujene	tr	tr
934	933	α -Pinene	4.3	3.8
950	950	Camphene	4.5	5.1
973	972	Sabinene	0.6	0.8
979	978	β-Pinene	24.5	15.1
983	984	6-Methylhept-5-en-2-one	–	tr
989	989	Myrcene	0.5	0.1
1005	1005	<i>p</i> -Mentha-1(7),8-diene	–	tr
1025	1025	<i>p</i> -Cymene	0.2	0.2
1030	1030	Limonene	1.9	1.0
1031	1031	β -Phellandrene	0.1	–
1033	1032	1,8-Cineole	0.2	0.3
1035	1034	(<i>Z</i>)- β -Ocimene	0.1	–
1037	1039	2-Heptyl acetate	0.2	tr
1046	1045	(<i>E</i>)- β -Ocimene	0.7	–
1058	1057	γ -Terpinene	tr	–
1070	1069	<i>cis</i> -Linalool oxide (furanoid)	–	tr
1085	1086	Terpinolene	tr	–
1086	1086	<i>trans</i> -Linalool oxide (furanoid)	–	tr
1090	1090	2-Nonanone	tr	–
1098	1098	Perillene	–	tr
1100	1101	Linalool	1.2	0.4
1101	1102	2-Nonanol	0.1	tr
1104	1104	Nonanal	tr	tr
1109	1103	α -Pinene oxide	–	0.1
1121	1121	<i>trans-p</i> -Mentha-2,8-dien-1-ol	–	tr
1126	1126	α -Campholenal	–	0.1
1135	1136	2-Octyl acetate	tr	–
1138	1139	(<i>E</i>)-Myroxide	tr	–
1138	1137	Nopinone	–	0.1
1141	1140	<i>trans</i> -Pinocarveol	0.2	1.1
1145	1145	<i>trans</i> -Verbenol	–	0.2
1147	1145	<i>cis</i> -Pinene hydrate	–	tr
1157	1157	Sabina ketone	–	tr
1160	1160	<i>trans</i> -Pinocamphone	0.1	–
1162	1164	Pinocarvone	0.1	0.2
1172	1170	Borneol	0.1	0.1
1176	1176	<i>cis</i> -Pinocamphone	0.2	tr
1180	1180	Terpinen-4-ol	tr	tr
1186	1186	<i>p</i> -Cymen-8-ol	–	0.1
1188	1186	<i>cis</i> -Pinocarveol	–	tr
1195	1195	α -Terpineol	tr	–
1195	1196	Myrtenal	0.1	0.5
1195	1195	Myrtenol	0.1	0.6
1208	1208	Verbenone	–	tr
1209	1211	1-Octyl acetate	0.1	–
1218	1217	<i>endo</i> -Fenchyl acetate	–	tr
1219	1218	<i>trans</i> -Carveol	–	tr
1229	1229	Bornyl formate	–	tr
1234	1233	2-Nonyl acetate	0.8	0.1
1244	1246	Carvone	–	tr
1249	1249	Linalyl acetate	–	tr
1283	1284	Lavandulyl acetate	tr	–
1285	1285	Bornyl acetate	1.2	0.7
1287	1287	<i>iso</i> -Bornyl acetate	tr	0.1
Continued				

RI _{calc}	RI _{db}	Compounds	CD	BC
1292	1293	2-Undecanone	0.1	–
1295	1294	<i>trans</i> -Pinocarvyl acetate	0.4	–
1299	1299	Perilla alcohol	–	tr
1323	1326	Myrtenyl acetate	1.2	0.1
1336	1335	δ-Elemene	tr	–
1346	1346	α-Terpinyl acetate	0.1	0.2
1348	1348	α-Cubebene	0.1	–
1364	1363	Cypera-2,4-diene	0.1	0.2
1376	1375	α-Copaene	0.3	0.2
1380	1376	<i>trans-p</i> -Menth-6-en-2,8-diol	–	tr
1382	1383	<i>cis</i> -β-Elemene	0.1	tr
1384	1382	β-Bourbonene	0.1	0.1
1390	1390	<i>trans</i> -β-Elemene	1.9	1.5
1404	1407	Cyperene	1.1	5.3
1421	1419	(E)-β-Caryophyllene	17.8	5.6
1429	1430	γ-Elemene	0.4	tr
1453	1452	(E)-β-Farnesene	5.5	0.5
1456	1454	α-Humulene	1.5	1.6
1460	1458	<i>allo</i> -Aromadendrene	–	0.1
1470	1469	Ishwarane	–	0.1
1473	1476	Selina-4,11-diene	–	0.2
1475	1476	γ-Gurjunene	0.3	0.1
1478	1481	(E)-β-Ionone	–	0.1
1481	1480	Germacrene D	0.3	–
1485	1482	Aristolochene	0.2	0.2
1490	1489	β-Selinene	0.4	1.0
1492	1492	Valencene	–	0.1
1495	1498	Asaricin	4.4	0.2
1496	1497	α-Selinene	0.3	0.5
1503	1504	(E,E)-α-Farnesene	0.1	–
1507	1508	β-Bisabolene	tr	–
1513	1512	γ-Cadinene	0.1	0.1
1518	1520	Myristicin	0.4	–
1518	1518	δ-Cadinene	0.2	–
1519	1520	7- <i>epi</i> -α-Selinene	0.1	0.6
1547	1548	Elemicin	0.2	–
1550	1549	α-Elemol	0.1	0.1
1553	1551	(Z)-Caryophyllene oxide	0.2	1.8
1561	1560	Germacrene B	0.5	–
1563	1562	(E)-Nerolidol	1.3	1.0
1580	1576	Spathulenol	0.2	0.2
1586	1587	Caryophyllene oxide	5.8	31.4
1596	1598	Viridiflorol	–	0.4
1601	1607	Humulene epoxide I	–	0.3
1611	1613	Humulene epoxide II	0.4	4.1
1619	1617	Dill apiole	7.2	0.4
1620	1617	9-Cedranone	–	0.2
1623	1617	Cyperotundone A	–	0.2
1636	1636	Caryophylla-4(12),8(13)-dien-5β-ol	0.1	0.1
1640	1642	Caryophylla-4(12),8(13)-dien-5α-ol	0.4	0.6
1657	1655	α-Cadinol	0.4	0.5
1660	1661	<i>neo</i> -Intermedeol	0.2	0.8
1666	1668	Intermedeol	0.3	0.9
1672	1671	14-Hydroxy-9- <i>epi</i> -(E)-caryophyllene	0.2	0.7
1697	1693	Cyperotundone	–	0.3
1801	1809	Ambrial	0.3	0.1
Continued				

RI _{calc}	RI _{db}	Compounds	CD	BC
1841	1841	Phytone	0.1	0.5
1958	1958	Palmitic acid	0.2	1.1
1979	1994	(E)-15,16-Dinorlabda-8(17),11-dien-13-one	0.2	0.1
2020	2022	(E,E)-Geranyl linalool	0.1	0.1
2106	2109	Phytol	0.2	0.2
		Monoterpene hydrocarbons	37.6	26.2
		Oxygenated monoterpenoids	5.3	4.7
		Sesquiterpene hydrocarbons	31.2	18.1
		Oxygenated sesquiterpenoids	9.9	43.9
		Diterpenoids	0.6	0.9
		Phenylpropanoids	12.2	0.6
		Others	1.4	1.2
		Total identified	98.2	95.7

Table 1. Chemical composition of *Globba schomburgkii* essential oils. CD = sample from Con Dao National Park. BC = sample from Binh Chau Nature Reserve. RI_{calc} = Retention indices calculated in reference to a homologous series of *n*-alkanes on a ZB-5 ms column. RI_{db} = Retention indices obtained from the databases^{15–17}. tr = “trace” (<0.05%). Major components are highlighted in **bold**.

Enantiomeris	CD	BC	C.ae	C.ze	C.l	C.ar	C.ca	C.za	
(–)- α -Pinene	75.9	42.4	75.3	56.5	29.4	65.3–88.6	73.9–78.3	77.8	78.4–88.3
(+)- α -Pinene	24.1	57.6	24.7	43.5	70.6	11.4–34.7	21.7–26.1	22.2	11.7–21.6
(–)-Camphene	5.4	4.0	9.3	7.7	nd	nd	15.0–18.7	nd	8.4–9.9
(+)-Camphene	94.6	96.0	90.7	92.3	nd	nd	81.3–85.0	nd	90.1–91.6
(+)-Sabinene	30.9	74.8	nd	nd	nd	19.5–20.6	28.3–37.0	17.8–46.3	nd
(–)-Sabinene	69.1	25.2	nd	--	nd	79.4–80.5	63.0–71.7	53.7–82.2	nd
(+)- β -Pinene	5.9	28.6	59.1	47.8	nd	11.2–24.2	40.0–47.8	38.5–43.5	2.5–2.8
(–)- β -Pinene	94.1	71.4	40.9	52.2	nd	75.8–88.8	52.2–60.0	56.5–61.5	97.2–97.5
(–)-Limonene	38.3	40.3	100	nd	54.4	66.2–87.8	19.2–33.8	14.9–29.9	57.3–58.7
(+)-Limonene	61.7	59.7	0.0	nd	45.6	12.2–33.8	66.2–80.8	70.1–85.1	41.3–42.7
(–)-Linalool	90.8	88.5	37.6	44.7	nd	0.0–100.0	51.5–79.7	100.0	89.1–91.0
(+)-Linalool	9.2	11.5	62.4	55.3	nd	0.0–82.0	20.3–48.5	0.0	9.0–10.9
(–)-Borneol	nd	0.0	0.0	nd	nd	nd	nd	nd	nd
(+)-Borneol	nd	100.0	100.0	nd	nd	nd	nd	nd	nd

Table 2. Enantiomeric distributions of chiral monoterpenoids present in *Globba schomburgkii* essential oils and other members of the *Curcuma* reported in the literature. C.ae.: *Curcuma aeruginosa*²⁵. C.ze.: *Curcuma zedoaria*²⁵. C.l.: *Curcuma longa*^{25,26}. C.ar.: *Curcuma aromatica*²⁶. C.ca.: *Curcuma caesia*²⁶. C.za.: *Curcuma zanthorrhiza*²⁶. nd = compound not detected.

Time (h)	Test organism	LC ₅₀ (95% limits)	LC ₉₀ (95% limits)	χ^2	<i>p</i>
24	<i>Aedes aegypti</i> (CD)	38.35 (35.81–41.00)	51.49 (48.22–55.75)	3.02	0.389
	<i>Aedes albopictus</i> (CD)	41.74 (39.08–44.10)	52.36 (49.76–55.74)	2.93	0.402
	<i>Aedes aegypti</i> (BC)	54.70 (51.56–59.30)	71.33 (65.20–82.51)	1.27	0.531
	<i>Aedes albopictus</i> (BC)	66.42 (61.10–72.51)	114.03 (100.57–135.95)	7.54	0.023
48	<i>Aedes aegypti</i> (CD)	32.17 (29.90–35.01)	42.69 (39.17–47.88)	1.81	0.613
	<i>Aedes albopictus</i> (CD)	33.44 (31.05–36.48)	42.80 (39.29–48.02)	0.27	0.965
	<i>Aedes aegypti</i> (BC)	49.57 (45.73–54.11)	76.73 (69.85–86.68)	3.41	0.182
	<i>Aedes albopictus</i> (BC)	47.57 (43.45–52.16)	91.28 (79.75–109.72)	2.84	0.241

Table 3. Larvicidal activity of *Globba schomburgkii* essential oils against *Aedes aegypti* and *Aedes albopictus* ($\mu\text{g/mL}$).

Time (h)	Compound*	LC ₅₀ (95% limits)	LC ₉₀ (95% limits)	χ ²	p
24	(-)-β-Pinene	30.69 (27.99–33.63)	59.31 (52.04–70.68)	6.242	0.044
	(+)-α-Pinene	12.72 (11.53–13.99)	26.09 (22.79–31.24)	3.345	0.341
	(E)-β-Caryophyllene	63.18 (57.26–69.79)	117.00 (102.08–140.91)	3.686	0.450
	(E)-β-Caryophyllene/α-Pinene (1:1, w/w)	38.27 (35.01–41.85)	71.53 (63.11–84.44)	3.381	0.337
	(E)-β-Caryophyllene/β-Pinene (1:1, w/w)	52.39 (48.37–57.19)	80.22 (73.22–89.93)	11.586	0.009
	Caryophyllene oxide	49.73 (46.24–53.88)	72.90 (66.88–81.44)	5.274	0.153
	Caryophyllene oxide/α-Pinene (1:1, w/w)	39.10 (35.26–43.47)	90.88 (77.46–112.25)	11.486	0.009
	Caryophyllene oxide/β-Pinene (1:1, w/w)	37.05 (33.73–40.78)	79.10 (68.84–94.54)	16.609	0.001
	(E)-β-Caryophyllene/Caryophyllene oxide (1:1, w/w)	83.88 (77.51–89.20)	112.25 (104.75–124.25)	0.011	1.000
	Permethrin	0.00638 (0.00548–0.00744)	0.0232 (0.0182–0.0318)	8.868	0.031
48	(-)-β-Pinene	29.39 (26.70–32.31)	59.59 (51.95–71.66)	6.624	0.085
	(+)-α-Pinene	11.14 (9.87–12.45)	28.04 (23.92–34.69)	4.588	0.205
	(E)-β-Caryophyllene	55.71 (49.69–65.55)	128.43 (108.76–160.19)	14.636	0.006
	(E)-β-Caryophyllene/α-Pinene (1:1, w/w)	33.12 (30.00–36.60)	72.07 (62.28–87.25)	10.893	0.012
	(E)-β-Caryophyllene/β-Pinene (1:1, w/w)	47.66 (43.82–52.18)	76.30 (69.46–85.76)	11.961	0.008
	Caryophyllene oxide	33.58 (30.49–37.03)	74.73 (64.86–89.51)	17.013	0.001
	Caryophyllene oxide/α-Pinene (1:1, w/w)	34.12 (30.81–37.84)	77.90 (66.81–95.28)	18.471	0.000
	Caryophyllene oxide/β-Pinene (1:1, w/w)	33.58 (30.49–37.03)	74.73 (64.86–89.51)	17.013	0.001
	(E)-β-Caryophyllene/Caryophyllene oxide (1:1, w/w)	73.55 (68.21–79.04)	99.93 (92.10–111.12)	0.046	0.997

Table 4. Larvicidal activity of major constituents of *Globba schomburgkii* essential oil against *Aedes aegypti*. All major constituents used in the larvicidal bioassays were purchased from Merck. Caryophyllene oxide (purity ≥ 95%), (E)-β-caryophyllene (purity ≥ 98%), (-)-β-pinene (purity ≥ 99%), and (+)-α-pinene (purity ≥ 98%) were used as reference standards. Permethrin (analytical standard) served as the positive control.

Time	Compound*	LC ₅₀ (95% limits)	LC ₉₀ (95% limits)	χ ²	p
24 h	(-)-β-Pinene	13.69 (12.66–15.38)	23.63 (21.36–26.95)	2.125	0.547
	(+)-α-Pinene	11.53 (10.57–12.56)	20.64 (18.33–24.28)	1.241	0.743
	(E)-β-Caryophyllene	64.06 (59.02–69.87)	99.93 (91.60–111.01)	18.071	0.001
	(E)-β-Caryophyllene/α-Pinene (1:1, w/w)	68.48 (63.07–74.64)	120.01 (105.85–142.88)	1.889	0.596
	(E)-β-Caryophyllene/β-Pinene (1:1, w/w)	63.39 (57.55–70.35)	130.03 (110.88–162.47)	6.175	0.103
	Caryophyllene oxide	49.64 (45.39–54.65)	83.02 (75.29–93.63)	10.011	0.018
	Caryophyllene oxide/α-Pinene (1:1, w/w)	41.68 (38.01–45.76)	81.95 (71.64–97.99)	8.510	0.037
	Caryophyllene oxide/β-Pinene (1:1, w/w)	65.32 (60.95–70.64)	87.52 (79.69–99.99)	0.078	0.994
	(E)-β-Caryophyllene/Caryophyllene oxide (1:1, w/w)	70.29 (65.23–75.85)	103.16 (93.71–117.54)	2.258	0.521
	Permethrin	0.0024 (0.0021–0.0026)	0.0042 (0.0038–0.0049)	4.64	0.031
48 h	(-)-β-Pinene	13.60 (12.28–15.03)	23.62 (21.30–27.04)	2.225	0.527
	(+)-α-Pinene	10.96 (10.02–11.96)	20.03 (17.74–23.61)	1.787	0.618
	(E)-β-Caryophyllene	48.22 (44.10–53.07)	80.68 (73.17–91.01)	8.719	0.069
	(E)-β-Caryophyllene/α-Pinene (1:1, w/w)	57.96 (52.57–64.36)	124.09 (105.88–153.62)	3.246	0.355
	(E)-β-Caryophyllene/β-Pinene (1:1, w/w)	57.21 (51.71–63.74)	125.96 (106.57–158.57)	14.298	0.003
	Caryophyllene oxide	38.47 (35.29–42.12)	63.33 (57.71–71.01)	10.821	0.013
	Caryophyllene oxide/α-Pinene (1:1, w/w)	39.39 (35.94–43.21)	76.86 (67.34–91.56)	10.822	0.013
	Caryophyllene oxide/β-Pinene (1:1, w/w)	62.02 (57.49–67.40)	88.61 (81.39–98.55)	11.85	0.008
	(E)-β-Caryophyllene/Caryophyllene oxide (1:1, w/w)	63.25 (58.58–68.72)	91.68 (84.28–101.68)	11.659	0.009

Table 5. Larvicidal activity of major constituents of *Globba schomburgkii* essential oil against *Aedes albopictus*. All major constituents used in the larvicidal bioassays were purchased from Merck. Caryophyllene oxide (purity ≥ 95%), (E)-β-caryophyllene (purity ≥ 98%), (-)-β-pinene (purity ≥ 99%), and (+)-α-pinene (purity ≥ 98%) were used as reference standards. Permethrin (analytical standard) served as the positive control.

Organisms	FICI(A)		FICI(B)		FICI(A/B)		Active
<i>Aedes aegypti</i>	FICI(α P)	19.135:12.72	FICI(C)	19.135:63.18	FICI(α P/C)	1.80	Indifferent
<i>Aedes aegypti</i>	FICI(α P)	19.55:12.72	FICI(CO)	19.55:49.73	FICI(α P/CO)	2.86	Indifferent
<i>Aedes aegypti</i>	FICI(β P)	26.195:30.69	FICI(C)	26.195: 63.18	FICI(β P/C)	1.27	Indifferent
<i>Aedes aegypti</i>	FICI(β P)	18.525:30.69	FICI(CO)	18.525:49.73	FICI(β P/CO)	1.03	Indifferent
<i>Aedes aegypti</i>	FICI(C)	41.94:63.18	FICI(CO)	41.94:59.03	FICI(C/CO)	1.37	Indifferent
<i>Aedes albopictus</i>	FICI(α P)	34.24:11.53	FICI(C)	34.24: 64.06	FICI(α P/C)	3.50	Indifferent
<i>Aedes albopictus</i>	FICI(α P)	20.84:11.53	FICI(CO)	20.84:49.64	FICI(P/CO)	2.23	Indifferent
<i>Aedes albopictus</i>	FICI(β P)	31.695:13.69	FICI(C)	31.695:64.06	FICI(β P/C)	2.81	Indifferent
<i>Aedes albopictus</i>	FICI(β P)	32.66:13.69	FICI(CO)	32.66:49.64	FICI(P/CO)	3.04	Indifferent
<i>Aedes albopictus</i>	FICI(C)	35.145:64.06	FICI(CO)	35.145:49.64	FICI(C/CO)	1.26	Indifferent

Table 6. Drug interaction analysis results. α P: (+)- α -Pinene. β P: (-)- β -Pinene. C: (*E*)- β -Caryophyllene. CO: Caryophyllene oxide.

Concentration (%)	KT ₅₀ (min)	KT ₉₀ (min)	χ^2	<i>p</i>
25.0	23.62 (20.66–26.64)	47.27 (40.68–58.17)	8.67	0.371
12.5	33.00 (28.43–37.67)	83.45 (71.29–101.95)	18.65	0.017
6.25	58.97 (52.54–65.40)	124.85 (110.01–146.64)	4.32	0.827
3.0	78.94 (70.50–87.51)	187.09 (163.31–222.53)	1.31	0.995
1.5	143.88 (130.34–158.34)	349.91 (302.07–424.21)	11.63	0.168
1.0	285.39 (253.85–326.70)	860.99 (679.08–1202.75)	8.36	0.399

Table 7. Knockdown time of *Aedes aegypti* mosquito exposed to *Globba schomburgkii* essential oil (BC).

Concentration (%)	KT ₅₀ (min)	KT ₉₀ (min)	χ^2	<i>p</i>
25	12.76 (8.45–16.93)	58.78 (46.85–78.45)	8.47	0.389
12.5	20.54 (16.00–24.99)	77.53 (63.51–100.21)	17.29	0.027
6.25	39.31 (33.09–45.62)	133.47 (111.67–167.22)	17.45	0.026
3.0	126.98 (106.67–150.13)	886.92 (640.93–1390.20)	12.75	0.121
1.5	1571.83 (1044.85–2946.88)	16,507.80 (7155.17–65,335.40)	2.23	0.973
1.0	4093.12 (2186.89–13,236.20)	32,315.70 (10,694.30–284,404.00)	2.17	0.975

Table 8. Knockdown time of *Aedes aegypti* mosquito exposed to *Globba schomburgkii* essential oil (CD) (min).

its greater proportion of intrinsically more active constituents, including the higher levels of (*E*)- β -farnesene and dillapiole, as well as differences in other bioactive components (Tables 4 and 5).

Fumigation Toxicity

The comparative bioassays revealed that CD exerted stronger acute toxicity, as evidenced by shorter knockdown times and lower LC₅₀ values at early exposure periods, whereas BC showed more persistent effects at prolonged exposures (Tables 7, 8, 9 and 10). This distinction suggests that CD may be more effective for rapid mosquito control, while BC could be advantageous for longer-term protection.

The α -pinene exhibited strong volatility and fumigant toxicity against *Ae. aegypti* adults with KT₅₀ of 5.36 min³⁰. Cao et al. reported that α -pinene and β -pinene exhibited comparable fumigant activity against *Tribolium castaneum* and *Lasioderma serricorne*³¹. Caryophyllene oxide exhibited stronger fumigant activity than (*E*)- β -caryophyllene against *Dermatophagoides farinae* and *D. pteronyssinus*, with LC₅₀ values ranging from 1.36–1.38 and 1.71–1.75 $\mu\text{g cm}^{-2}$, respectively³². Similarly, Luo et al. reported stronger fumigant toxicity of caryophyllene oxide than (*E*)- β -caryophyllene against *Anopheles sinensis*³³. *Piper aduncum* essential oil (dillapiole 86.9%) exhibited stronger fumigant toxicity than the positive control (malathion) against *An. marajoara* and *Ae. aegypti* at 180 min of exposure²⁷. Camphene exhibited stronger fumigant toxicity than α -pinene and β -pinene against *Sitophilus zeamais* adults³⁴. Thus, the major constituents were responsible for the fumigant toxicity of the essential oil samples against *Ae. aegypti* adults.

Conclusions

The essential oils of *Globba schomburgkii* collected from two Vietnamese locations exhibited two distinct chemotypes associated with geographical origin: the CD chemotype, dominated by β -pinene, (*E*)- β -caryophyllene, and dillapiole, and the BC chemotype, characterized mainly by caryophyllene oxide and β -pinene. Both

Time (min)	LC ₅₀ (%)	LC ₉₀ (%)	χ^2	<i>p</i>
15	143.64 (56.45–1984.72)	1384.56 (266.25–176,862.00)	5.07	0.407
30	13.12 (11.11–15.85)	42.35 (31.64–64.93)	12.07	0.034
60	5.85 (4.91–7.03)	24.43 (18.29–36.24)	3.84	0.573
90	3.22 (2.73–3.80)	11.97 (9.29–16.81)	11.72	0.039
120	1.82 (1.58–2.10)	5.30 (4.28–7.11)	15.92	0.007
180	1.37 (1.22–1.53)	2.89 (2.44–3.70)	3.12	0.682
240	1.09 (0.95–1.24)	2.65 (2.20–3.45)	3.22	0.667
300	0.88 (0.76–0.99)	1.99 (1.68–2.55)	2.35	0.800
360	0.75 (0.66–0.84)	1.49 (1.28–1.85)	0.42	0.995
1440	0.59 (0.54–0.65)	0.88 (0.78–1.07)	1.81	0.875

Table 9. Adulticidal activity of *Globba schomburgkii* essential oil (BC) on *Aedes aegypti*.

Time (min)	LC ₅₀ (%)	LC ₉₀ (%)	χ^2	<i>p</i>
15	15.91 (13.67–19.63)	52.05 (37.65–85.70)	6.73	0.151
30	9.79 (8.18–11.96)	39.52 (28.65–62.87)	9.73	0.045
60	6.38 (5.39–7.61)	23.88 (18.12–35.05)	11.23	0.024
90	4.06 (3.46–4.77)	13.47 (10.58–18.74)	16.99	0.002
120	3.05 (2.67–3.50)	7.36 (6.08–9.58)	14.25	0.007
180	2.54 (2.28–2.85)	4.68 (4.02–5.81)	1.97	0.740
240	2.46 (2.20–2.76)	4.53 (3.89–5.62)	4.17	0.384
300	2.29 (2.06–2.56)	4.04 (3.49–4.97)	2.03	0.731
360	2.10 (1.89–2.35)	3.71 (3.20–4.57)	2.42	0.659
1440	1.51 (1.35–1.68)	2.93 (2.49–3.79)	1.13	0.889

Table 10. Adulticidal activity of *Globba schomburgkii* essential oil (CD) on *Aedes aegypti*.

chemotypes demonstrated promising potential for controlling two *Aedes* mosquito species. However, broader sampling from other regions of Vietnam is required to confirm the full diversity and geographic distribution of chemotypes in this species.

Data availability

Data are provided within the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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