Article

Essential Oils from Vietnamese Asteraceae for Environmentally Friendly Control of Aedes Mosquitoes

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Abstract: Mosquitoes, in addition to being a biting nuisance, are vectors of several pathogenic viruses and parasites. As a continuation of our work identifying abundant and/or invasive plant species in Vietnam for use as ecologically friendly pesticidal agents, we obtained the essential oils of Blumea lacer, Blumea sinuata, Emilia sonchifolia, Parthenium hysterophorus, and Sphaeranthus africanus; analyzed the essential oils using gas chromatographic techniques; and screened the essential oils for mosquito larvicidal activity against Aedes aegypti and Aedes albopictus. The most active larvicidal essential oils were B. sinuata, which was rich in thymohydroquinone dimethyl ether (29.4%), (E)-β-caryophyllene (19.7%), α-pinene (8.8%), germacrene D (7.8%), and α-humulene (4.3%), (24-h LC₅₀ 23.4 and 29.1 µg/mL) on Ae. aegypti and Ae. albopictus, respectively, and Emilia sonchifolia, dominated by 1-undecene (41.9%) and germacrene D (11.0%), (24-h LC₅₀ 30.1 and 29.6 µg/mL) on the two mosquito species. The essential oils of P. hysterophorus and S. africanus were also active against mosquito larvae. Notably, B. sinuata, P. hysterophorus, and S. africanus essential oils were not toxic to the non-target water bug, Diplomychus rusticus. However, E. sonchifolia essential oil showed insecticidal activity (24-h LC₅₀ 48.1 µg/mL) on D. rusticus. Based on these results, B. sinuata, P. hysterophorus, and S. africanus essential oils appear promising for further investigations.

Keywords: Blumea lacer; Blumea sinuata; Emilia sonchifolia; Parthenium hysterophorus; Sphaeranthus africanus; essential oil composition; larvicidal activity

1. Introduction

The Asteraceae is the largest family of flora in the world, comprising about 1550 genera and about 23,000 species [1]. In Vietnam, there are about 126 genera and 379 species from this family [2]. Many species are used as medicines, for isolation of essential oils, or as ornamentals [2].

Blumea lacer (Burm. f.) DC. (syn. Conyza lacer Burm. f., Blumea bodinieri Vaniot, Blumea dregeanoides Sch. Bip. ex A. Rich., Blumea duclouxii Vaniot, Blumea glandulosa DC., Blumea subcapitata DC., Blumea velutina (H. Lév. and Vaniot) H. Lév. and Vaniot, Conyza velutina H. Lév., and Senecio velutinus H. Lév. and Vaniot) is found in China, Bhutan, India, Japan, Laos, Malaysia, Myanmar, Nepal, New Guinea, Pakistan, Sri Lanka, Thailand, and Vietnam [1].
The pharmacognosy and phytochemistry of *B. lacer* have been reviewed [3]. In traditional medicine, *B. lacer* has been used as an expectorant, diuretic, astringent, antispasmodic, antipyreric, antioxidant, antiinflammatory, liver tonic, and stimulant [4]. The leaves of *B. lacer* are fragrant, and in Vietnam, are used as a vegetable as well as a medicine to treat boils and stop bleeding [5].

*Blumea sinuata* (Lour.) Merr. (syn. *Blumea lacti* (Wall. ex Roxb.) DC., *Conyza laciniata* Roxb., Asteraceae) [6] is native to southern China, India, Pakistan, Sri Lanka, Bhutan, Nepal, Myanmar, Malaysia, Indonesia, the Philippines, and Vietnam, naturally ranging from southern China and India, south through Indonesia, Malaysia, Myanmar, Thailand, and Vietnam [1]. Its leaves and stems are used to treat boils, remove toxins from the body, and stop bleeding. Leaves of *B. sinuata* have been used to treat influenza, rheumatism, bone pain, or pain due to injury or swelling [3]. A review of the medicinal chemistry, phytochemistry, and pharmacology of the *Blumea* genus has been published [7].

*Emilia sonchifolia* (L.) DC. (syn. *Cacalia sonchifolia* L., *Crassocephalum sonchifolium* Less., *Emilia mucronata* Wall., *Emilia purpurea* Cass., *Emilia rigidula* DC., *Emilia scabra* DC., *Emilia sinica* Miq., *Senecio ecalyculatus* Sch. Bip., *Senecio rapae* F. Br., *Senecio sonchifolius* Moench) is a pantropical weed of Old World origin [8]. Ethnobotanically, the plant has been used to treat eye sores, convulsion, cuts, wounds, rheumatism, and insect bites [9]. In Vietnam, the leaves and young tops are used as vegetables, and the whole plant is used as medicine to reduce fever [5].

*Parthenium hysterophorus* L. (syn. *Argyrochaeta bipinnatifida* Cav., *Argyrochaeta parviflora* Cav., *Echetrosis pentasperma* Phil., *Parthenium lobatum* Buckley, *Parthenium pinnatifidum* Stokes) is believed to be native to the Gulf of Mexico, including Honduras, Guatemala, and Mexico, as well as the West Indies [10]. The plant was introduced to Australia, India, southern China, and Vietnam, where it became a noxious weed [11,12]. Nevertheless, the plant has shown potential medicinal applications [13–15].

*Sphaeranthus africanus* L. (syn. *Sphaeranthus cochinchenensis* Lour., *Sphaeranthus glaber* DC., *Sphaeranthus globosus* Wall. ex DC., *Sphaeranthus hildebrandtii* Baker, *Sphaeranthus indicus* Kurz, *Sphaeranthus laevigatus* Wall. ex DC., *Sphaeranthus microcephalus* Vatke, *Sphaeranthus microcephalus* Willd., *Sphaeranthus ovalis* Steetz, *Sphaeranthus paniculatus* Cass., *Sphaeranthus sphenocleoides* Oliv. and Hiern, *Sphaeranthus suberiflorus* Hayata) is native to Africa (Kenya, Tanzania, Mozambique, and Madagascar), tropical Asia (Bangladesh, Borneo, Cambodia, south-central and southeastern China, Hainan, India, Malaya, Myanmar, Nepal, Philippines, Sri Lanka, Taiwan, Thailand, and Vietnam), and Australia (Northern Territory, Queensland, and Western Australia) [16]. In Vietnam, a decoction of the leaves of *S. africanus* is used to prepare a mouthwash to treat sore throats [5]. Several biologically active carvotacetones have been isolated from *S. africanus* extracts [17–19].

*Aedes* mosquitoes (Culicidae) are acknowledged vectors of numerous pathogenic viruses. *Aedes aegypti* (L.) is known to transmit the yellow fever, Zika, dengue, and chikungunya viruses [20], whereas *Aedes albopictus* (Skuse) is a vector for West Nile, Japanese encephalitis, and Eastern equine encephalitis, as well as dengue and chikungunya viral pathogens [21]. Dengue fever is widespread in Southeast Asia, including Vietnam, and causes considerable health and economic burden [22]. Both chikungunya [23] and Zika [24] viral infections are emerging diseases in the region. Though synthetic insecticides have been used to control mosquito populations, there is growing concern regarding insecticidal resistance [25,26], environmental degradation [27,28], and harm to non-target organisms [29,30]. Essential oils have been recognized as potential alternatives to synthetic insecticides for control of insect pests, including mosquitoes [31,32].

As part of our research into the identification of readily available native and invasive plants in Vietnam as sources of essential oils for ecologically friendly pest control agents [33–36], we investigated *B. lacer*, *B. sinuata*, *E. sonchifolia*, *P. hysterophorus*, and *S. africanus* essential oils for mosquito larvicidal activity against *Aedes aegypti* (L.) and *Aedes albopictus* (Skuse) (Diptera: Culicidae) mosquitoes. These species of mosquitoes are the principal vectors of the dengue fever virus in Vietnam [37]. To test selectivity, we
screened the essential oils against the non-target water bug, *Diplonychus rusticus* (Fabricius), a predator of mosquito larvae. There have been several reviews on the potential pesticidal utility of essential oils to control mosquito populations [38–41].

2. Results and Discussion
2.1. Essential Oil Compositions
2.1.1. *Blumea lacera*

Floral, leaf, and stem essential oils of *B. lacera* were obtained at 1.10, 1.56, and 0.35%, respectively. The chemical compositions of *B. lacera* essential oils are presented in Table 1. The most abundant chemical components in the essential oils of *B. lacera* were (E)-β-caryophyllene (23.8, 27.2, and 11.7%), germacrene D (18.5, 21.0, and 11.2%), thymohydroquinone dimethyl ether (5.0, 4.1, and 28.4%), γ-curcumene (5.9, 7.7, and 4.7%), ar-curcumene (8.0, 3.7, and 1.9%), and α-zingiberene (4.7, 7.1, and 4.6%) in the flowers, leaves, and stems, respectively.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compound                        | Floral % | Leaf % | Stem % |
|------------------|----------------|---------------------------------|----------|--------|--------|
| 931              | 933            | α-Pinene                        | 0.5      | 0.1    | 0.1    |
| 949              | 950            | Camphene                        | tr       | tr     | —      |
| 971              | 972            | Sabinene                        | 0.1      | tr     | —      |
| 990              | 986            | Saframal                        | 0.1      | 0.4    | tr     |
| 1024             | 1025           | γ-Cymene                        | 0.1      | tr     | tr     |
| 1028             | 1030           | Limonene                        | tr       | tr     | —      |
| 1057             | 1054           | γ-Terpine                        | tr       | tr     | —      |
| 1063             | 1086           | 2,6,6-Trimethyl-1,4-cyclohexadiene-1-carboxaldehyde | 0.1 | tr | tr |
| 1099             | 1101           | Linalool                         | 0.2      | 0.1    | tr     |
| 1101             | 1105           | Filifolone                       | 1.2      | 0.9    | 0.1    |
| 1105             | 1107           | Nonanal                          | 0.1      | 0.1    | —      |
| 1108             | 1106           | 4-is-Chrysantheneone             | 0.1      | 0.1    | —      |
| 1112             | 1110           | (E)-4,8-Dimethylona-1,3,7-triene | 0.1      | tr     | tr     |
| 1122             | 1124           | Chrysantheneone                  | 1.3      | 1.0    | 0.1    |
| 1129             | 1129           | 1,3,8-p-Menthatriene             | —        | —      | 0.1    |
| 1136             | 1138           | trans-Chrysanthenol              | 0.3      | 0.2    | 0.1    |
| 1159             | 1152           | Alibene                          | tr       | tr     | 0.2    |
| 1223             | 1215           | Isothymyl methyl ether           | —        | —      | tr     |
| 1229             | 1229           | Thymyl methyl ether              | 0.1      | 0.1    | 1.0    |
| 1238             | 1239           | Carvacyl methyl ether            | tr       | tr     | 0.1    |
| 1256             | 1261           | cis-Chrysanthenyl acetate        | 0.1      | —      | —      |
| 1284             | 1285           | Bornyl acetate                   | —        | —      | 0.1    |
| 1290             | 1289           | Thymol                           | —        | tr     | —      |
| 1345             | 1345           | Silphiene                        | —        | —      | tr     |
| 1374             | 1375           | α-Copaene                        | 0.1      | 0.1    | tr     |
| 1380             | 1381           | cis-β-Elemene                    | tr       | 0.1    | 0.1    |
| 1382             | 1382           | β-Bourbonene                     | tr       | tr     | tr     |
| 1386             | 1387           | β-Cubebeine                      | 0.1      | 0.1    | tr     |
| 1388             | 1390           | trans-β-Elemene                  | 1.6      | 2.1    | 1.1    |
| 1394             | 1392           | 2-Ethylidene-6-methyl-3,5-heptadienal | 0.9      | 0.6    | —      |
| 1413             | 1411           | Thymohydroquinone dimethyl ether | 5.0      | 4.1    | 28.4   |
| 1419             | 1417           | (E)-β-Caryophyllene              | 23.8     | 27.2   | 11.7   |
| 1428             | 1430           | β-Copaene                        | 0.2      | 0.1    | 0.1    |
| 1431             | 1432           | trans-α-Bergamotene              | 0.3      | 0.2    | 0.2    |
| 1434             | 1443           | Dimethoxy-p-cymene               | 0.1      | tr     | 0.5    |
| 1445             | 1446           | epi-β-Santene                    | —        | —      | 0.1    |
| 1446             | 1453           | Geranyl acetone                  | 0.1      | tr     | tr     |
| 1451             | 1452           | (E)-β-Farnesene                  | 0.9      | 0.8    | 0.5    |
| 1455             | 1454           | α-Humulene                       | 3.7      | 3.5    | 1.5    |
| 1459             | 1457           | allo-Aromadendrene               | 0.1      | 0.1    | tr     |
| 1461             | 1461           | cis-Cadin-1(6),4-diene           | 0.1      | 0.1    | —      |
| 1471             | 1475           | trans-Cadin-1(6),4-diene         | tr       | —      | —      |
| 1473             | —              | Unidentified (43, 148, 218)      | 0.4      | 0.2    | 1.0    |
| 1475             | 1480           | Thymyl isobutyratate             | 0.9      | 0.5    | 2.7    |
| 1477             | 1481           | γ-Curcumene                      | 5.9      | 7.7    | 4.7    |
Table 1. Cont.

| RI\textsubscript{calc} | RI\textsubscript{db} | Compound | Floral | Leaf | Stem |
|------------------------|----------------------|----------|--------|------|------|
| 1480 1479             | 1482 1483            | ar-Curcumene | 8.0    | 3.7  | 1.9  |
| 1482 1490             | 1488 1489            | Germacrine D  | 18.5   | 21.0 | 11.2 |
| 1488 1497             | 1491 1492            | Neryl isobutyrate | tr    | tr   | 0.2  |
| 1491 1493             | 1497 1499            | β-Selinene | 0.4    | 0.3  | 0.2  |
| 1502 1504             | 1506 1508            | trans-Murola-4(14),5-diene | tr    | 0.1  | 0.1  |
| 1506 1508             | 1510 1514            | χ-Zingiberene | 5.7    | 7.1  | 4.6  |
| 1510 1516             | 1512 1518            | Germacrene D | 0.5    | 0.3  | 0.3  |
| 1512 1514             | 1516 1520            | β-Sesquiphellandrene | 3.6    | 3.8  | 2.4  |
| 1516 1522             | 1520 1524            | (E)-Nerolidol | 0.4    | 0.2  | 0.1  |
| 1520 1524             | 1528 1532            | Thymyl 2-methylbutanoate | 0.9    | 0.4  | 1.1  |
| 1528 1532             | 1536 1540            | Neryl 2-methylbutanoate | 0.9    | 0.8  | 3.3  |
| 1536 1540             | 1548 1552            | Neryl isovalerate | 0.8    | 0.5  | 1.3  |
| 1548 1552             | 1556 1560            | Caryophyllene oxide | 1.4    | 1.4  | 0.5  |
| 1556 1560             | 1564 1568            | Humulene epoxide I | 0.2    | 0.2  | 0.1  |
| 1564 1568             | 1566 1570            | Humulene epoxide II | 0.1    | 0.1  | tr   |
| 1566 1570             | 1572 1576            | Zingiberenol | 0.3    | 0.2  | 0.3  |
| 1572 1576             | 1578 1582            | 7-epi-cis- Sesquisabinene hydrate | 0.2    | 0.1  | 0.3  |
| 1578 1582             | 1584 1588            | Caryophylla-4(12),8(13)-dien-5α-ol | 0.1    | 0.1  | 0.1  |
| 1584 1588             | 1590 1594            | Caryophylla-4(12),8(13)-dien-5β-ol | 0.1    | 0.3  | 0.3  |
| 1590 1594             | 1596 1598            | (25,5E)-Caryophyll-5-en-12-al | 1.0    | 1.1  | 0.4  |
| 1596 1598             | 1602 1606            | γ-Cadinol | 0.8    | 0.8  | 3.0  |
| 1602 1606             | 1608 1612            | μ-Murolol | 0.4    | 0.3  | 0.4  |
| 1608 1612             | 1614 1618            | δ-Cadinol | 0.1    | 0.1  | 0.1  |
| 1614 1618             | 1620 1624            | β-Eudesmol | —      | —    | 0.1  |
| 1620 1624             | 1626 1630            | α-Cadinol | 1.2    | 1.0  | 1.3  |
| 1626 1630             | 1632 1636            | Selin-11-en-4α-ol | tr    | 0.1  | 0.1  |
| 1632 1636             | 1638 1642            | Intermedeol | tr    | —    | 0.1  |
| 1638 1642             | 1644 1648            | 6-Methoxythymyl isobutyrate | 0.2    | 0.1  | 0.9  |
| 1644 1648             | 1650 1654            | 14-Hydroxy-9-epi-(E)-caryophyllene | —     | —    | —    |
| 1650 1654             | 1656 1660            | 4-Himachalen-1β-ol (2-Himachalen-6β-ol) | 0.7    | 0.5  | 0.8  |
| 1656 1660             | 1658 1662            | α-Bisabolol | 0.1    | 0.1  | —    |
| 1658 1662             | 1660 1664            | (Z,6Z)-Farnesal | 0.1    | 0.1  | —    |
| 1660 1664             | 1666 1670            | Pentadecanal  | —      | 0.2  | 0.2  |
| 1666 1670             | 1672 1676            | Xanthorrhizol | —     | —    | 0.1  |
| 1672 1676             | 1678 1682            | (Z)-Nerolidyl isobutyrate | 0.2    | —    | —    |
| 1678 1682             | 1684 1688            | Unidentified (43, 71, 145, 162) | 0.3    | 0.2  | 1.8  |
| 1684 1688             | 1690 1694            | Unidentified (43, 57, 71, 85, 145, 162) | 0.5    | 0.3  | 1.0  |
| 1690 1694             | 1696 1700            | (E)-Phytol  | tr     | 0.2  | 0.1  |
| 1696 1700             | 1702 1706            | Pentacosane | tr    | tr   | 0.1  |
| 1702 1706             | 1708 1712            | Monoterpane hydrocarbons | 0.6    | 0.1  | 0.1  |
| 1708 1712             | 1710 1714            | Oxygenated monoterpenoids | 13.0   | 9.3  | 44.9 |
| 1710 1714             | 1716 1720            | Sesquiterpene hydrocarbons | 76.1   | 80.1 | 41.5 |
| 1716 1720             | 1722 1726            | Oxygenated sesquiterpenoids | 7.6    | 6.8  | 7.7  |
| 1722 1726             | 1728 1732            | Others | 0.4    | 0.9  | 0.6  |
| 1728 1732             | 1734 1738            | Total identified | 97.7   | 97.3 | 94.7 |

RI\textsubscript{calc} = Retention indices determined with reference to a homologous series of \textit{n}-alkanes on a ZB-5 ms column. RI\textsubscript{db} = Retention indices from the databases. tr = trace (<0.05%). % = percent of total essential oil composition.

A \textit{B. lacera} leaf essential oil sample from Idaban, Nigeria, was found to contain thymohydroquinone dimethyl ether (33.9%) and (\textit{E})-β-caryophyllene (10.7%) as major components [42]. Similarly, the two essential oil samples from aerial parts of \textit{B. lacera} from central Vietnam were rich in (\textit{E})-β-caryophyllene (12.0 and 8.3%), thymohydroquinone dimethyl ether (11.4 and 6.6%), and caryophyllene oxide (21.7 and 11.9%) [43]. Joshi and co-workers have noted large variations in essential oil compositions in samples from different geographical regions of India with thymohydroquinone dimethyl ether ranging from 0.4 to 28.7% and (\textit{E})-β-caryophyllene from 0.5 to 25.5% [44]. In contrast, a previous examination of the essential oil from the aerial parts of \textit{B. lacera} from Biratnagar, Nepal, found the oil to be dominated by (\textit{Z})-lachnophyllum ester (25.5%), (\textit{Z})-lachnophyllic acid (17.0%), germacrene D (11.0%), (\textit{E})-β-farnesene (10.1%), bicyclogermacrene (5.2%), (\textit{E})-caryophyllene (4.8%),...
and (E)-nerolidol (4.2%) [45]. Both the essential oil and (Z)-lachnophyllum ester showed cytotoxic, antibacterial, and antifungal activity. Interestingly, neither lachnophyllum esters nor lachnophyllic acids were detected in the essential oils from Vietnam. It is not clear what factors contribute to the large variations in essential oil compositions, but environmental influences (climate, altitude, latitude, and edaphic conditions), seasonality, phenology, genotype variation, or extraction method have often been attributed to rationalize essential oil compositional differences [46].

2.1.2. *Blumea sinuata*

The fresh aerial parts of *B. sinuata* were hydrodistilled using a Clevenger apparatus to obtain the essential oil in 0.16% yield. The essential oil composition of *B. sinuata* is shown in Table 2. The major components in the essential oil of *B. sinuata* were thymohydroquinone dimethyl ether (29.4%), (E)-β-caryophyllene (19.7%), α-pinene (8.8%), germacrene D (7.8%), and α-humulene (4.3%). As far as we are aware, there is only one previous report on the essential oil of *B. sinuata* (as *B. laciniata*, from Dapoli region, Maharashtra, India) [47]. The GC–MS analysis, however, is not reliable, so a meaningful comparison of the compositions is not possible.

**Table 2. Essential oil composition of *Blumea sinuata* from Vietnam.**

| RI<sub>calc</sub> | RI<sub>db</sub> | Compound | % |
|------------------|----------------|----------|---|
| 925              | 925            | α-Thujene | tr |
| 933              | 933            | α-Pinene  | 8.8|
| 949              | 950            | Camphene  | tr |
| 952              | 953            | Thuja-2,4(10)-diene | tr |
| 970              | 972            | Dimethyltrisulfide | tr |
| 977              | 978            | β-Pinene  | tr |
| 985              | 986            | 6-Methylhept-5-en-2-one | tr |
| 988              | 989            | Myrcene   | 0.1|
| 989              | 989            | 2-Pentylfuran | tr |
| 1007             | 1007           | α-Phellandrene | tr |
| 1025             | 1025           | p-Cymene  | 0.1|
| 1029             | 1030           | Limonene  | 0.1|
| 1031             | 1031           | β-Phellandrene | tr |
| 1045             | 1045           | (E)-β-Ocimene | tr |
| 1100             | 1101           | Linalool  | 0.1|
| 1106             | 1107           | Nonanal   | 0.1|
| 1107             | 1107           | 1-Octen-3-yl acetate | tr |
| 1110             | 1108           | p-Mentha-2,8-dien-1-ol | tr |
| 1113             | 1113           | (E)-1,5-Dimethylnona-1,3,7-triene | tr |
| 1146             | 1145           | trans-Verbenol | tr |
| 1159             | 1161           | Albene    | 0.3|
| 1196             | 1195           | α-Terpineol | tr |
| 1207             | 1206           | Decanal   | tr |
| 1230             | 1229           | Thymyl methyl ether | 0.4|
| 1239             | 1239           | Carvacryl methyl ether | tr |
| 1266             | 1272           | Nonanoic acid | 0.1|
| 1284             | 1285           | Bornyl acetate | 0.3|
| 1323             | 1326           | Myrtenyl acetate | tr |
| 1346             | 1348           | α-Cubebene | 0.1|
| 1350             | 1348           | α-Longipinene | tr |
| 1359             | 1361           | Neryl acetate | 0.3|
| 1371             | 1371           | Decanoic acid | 1.5|
| 1375             | 1375           | α-Copaene | 1.2|
| 1383             | 1382           | β-Bourbonene | 0.1|
| RI_{calc} | RI_{db} | Compound | %         |
|-----------|--------|----------|-----------|
| 1387      | 1387   | β-Cubebe  | 0.4       |
| 1389      | 1390   | trans-β-Elemene | 0.3       |
| 1415      | 1411   | Thymohydroquinone dimethyl ether | 29.4      |
| 1420      | 1417   | (E)-β-Caryophyllene | 19.7      |
| 1430      | 1430   | β-Copaene | 0.2       |
| 1433      | 1432   | trans-α-Bergamotene | 0.1       |
| 1441      | 1439   | (Z)-β-Farnesene | 0.1       |
| 1447      | 1446   | epi-β-Santalene | 0.1       |
| 1453      | 1452   | (E)-β-Farnesene | 3.5       |
| 1456      | 1454   | α-Humulene | 4.3       |
| 1460      | 1457   | allo-Aromadendrene | 0.5       |
| 1475      | 1478   | γ-Muurolene | 0.1       |
| 1479      | 1481   | (E)-β-Ionone | 0.1       |
| 1482      | 1483   | Germacrene D | 7.8       |
| 1484      | 1483   | trans-β-Bergamotene | 0.5       |
| 1489      | 1489   | β-Selinene | 0.1       |
| 1492      | 1492   | trans-Muurola-4(14),5-diene | 0.1       |
| 1496      | 1497   | α-Selinene | 0.7       |
| 1498      | 1497   | α-Muurolene | 0.2       |
| 1504      | 1504   | (E,E)-α-Farnesene | 1.1       |
| 1508      | 1508   | β-Bisabolene | 0.1       |
| 1513      | 1514   | γ-Cadinene | 0.1       |
| 1518      | 1515   | Dihydrolachnophyllum ester B | 1.0       |
| 1518      | 1518   | δ-Cadinene | 0.8       |
| 1522      | 1519   | trans-Calamene | 0.1       |
| 1524      | 1523   | 7-epi-cis-Sesquisabinene hydrate | 0.2       |
| 1561      | 1562   | (E)-Nerolidol | 0.4       |
| 1564      | 1561   | 7-Hydroxyfarnesene | 0.2       |
| 1571      | 1568   | Palustrol | 0.2       |
| 1579      | 1580   | Neryl isovalerate | 0.6       |
| 1583      | 1587   | Caryophyllene oxide | 3.6       |
| 1593      | 1593   | Salvial-4(14)-en-1-one | 0.1       |
| 1605      | 1605   | Ledol | 0.2       |
| 1611      | 1611   | Humulene epoxide II | 0.4       |
| 1613      | 1610   | (Z)-Sesquilavandulol | 0.2       |
| 1617      | 1611   | β-Atlantol | 0.2       |
| 1629      | 1628   | 1-epi-Cubenol | 0.1       |
| 1635      | 1635   | Caryophylla-4(12),8(13)-dien-5α-ol | 0.1       |
| 1638      | 1636   | Caryophylla-4(12),8(13)-dien-5β-ol | 0.5       |
| 1640      | 1639   | allo-Aromadendrene epoxide | 0.1       |
| 1643      | 1643   | τ-Cadinol | 0.3       |
| 1645      | 1645   | τ-Muurolo  | 0.2       |
| 1647      | 1653   | Pogostol | 0.2       |
| 1656      | 1655   | α-Cadinol | 0.8       |
| 1671      | 1671   | 14-Hydroxy-9-epi-(E)-caryophyllene | 0.3       |
| 1680      | 1683   | 15-Hydroxy-α-muurolo  | 0.3       |
| 1686      | 1683   | Germacr-4(15),5,10(14)-trien-1α-ol | 0.5       |
| 1716      | 1715   | Pentadecanal | 0.4       |
| 1841      | 1841   | Phytone | 0.1       |
| 1862      | 1856   | (Z)-Lanceol acetate | 2.6       |
|           |        | Monoterpene hydrocarbons | 9.1       |
|           |        | Oxygenated monoterpenoids | 30.5      |
|           |        | Sesquiterpene hydrocarbons | 42.4      |
|           |        | Oxygenated sesquiterpenoids | 12.2      |
|           |        | Others | 3.5       |
|           |        | Total identified | 97.8      |

RI_{calc} = Retention indices determined with reference to a homologous series of n-alkanes on a ZB-5 ms column. RI_{db} = Retention indices from the databases. tr = trace (<0.05%). % = percent of total essential oil composition.
2.1.3. Emilia sonchifolia

Hydrodistillation of the fresh aerial parts of *E. sonchifolia* gave a 0.51% yield of essential oil. A total of 43 compounds were identified, accounting for 93.2% of the total composition (see Table 3). Gas chromatographic analysis of *E. sonchifolia* essential oils revealed the oil to be dominated by 1-undecene (41.9%) and germacrene D (11.0%). The essential oil composition of *E. sonchifolia* from Vietnam is in marked contrast to the essential oils from Belagavi, Karnataka, India [48] or Ojo State, Nigeria [49]. The *E. sonchifolia* sample from India was rich in the sesquiterpene hydrocarbons, (E)-β-caryophyllene (22.7%) and γ-muurolene (32.1%). The essential oil from Nigeria was also rich in sesquiterpene hydrocarbons, namely (E)-β-caryophyllene (15.7%), γ-gurjunene (8.6%), and γ-himachalene (25.2%). The differences in essential oil compositions may be due to genetic or environmental factors.

Table 3. Essential oil composition of *Emilia sonchifolia* from Vietnam.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compound | %   |
|------------------|-----------------|----------|-----|
| 882              | 880             | 2-Butylfuran | 0.3 |
| 933              | 932             | α-Pinene | 2.4 |
| 949              | 950             | Camphene | 0.2 |
| 977              | 978             | β-Pinene | 1.2 |
| 989              | 989             | Myrcene | 0.8 |
| 991              | 987             | 1-Decene | 0.4 |
| 1024             | 1024            | p-Cymene | 1.7 |
| 1029             | 1030            | Limonene | 1.5 |
| 1046             | 1045            | (E)-β-Octene | 0.8 |
| 1091             | 1091            | 1-Undecene | 41.9 |
| 1335             | 1335            | δ-Elemene | 0.6 |
| 1367             | 1367            | Cyclooctatetraene | 0.3 |
| 1375             | 1375            | α-Copaene | 0.3 |
| 1387             | 1387            | β-Cubebene | 0.4 |
| 1389             | 1390            | trans-β-Elemene | 1.4 |
| 1418             | 1417            | (E)-β-Caryophyllene | 2.2 |
| 1428             | 1427            | γ-Elemene | 0.6 |
| 1452             | 1452            | (E)-β-Farnesene | 0.2 |
| 1454             | 1454            | α-Humulene | 2.8 |
| 1459             | 1461            | Precocene I (=6-Demethoxyageratocromene) | 0.8 |
| 1474             | 1475            | γ-Muurolene | 0.6 |
| 1480             | 1480            | Germacrene D | 11.0 |
| 1492             | 1492            | 1-Pentadecene | 0.2 |
| 1497             | 1497            | α-Muurolene | 0.5 |
| 1503             | 1503            | (E,E)-α-Farnesene | 0.3 |
| 1506             | 1508            | β- Bisabolene | 1.4 |
| 1511             | 1512            | γ-Cadinene | 0.4 |
| 1517             | 1518            | δ-Cadinene | 0.8 |
| 1527             | 1528            | Kessane | 0.5 |
| 1557             | 1557            | Germacrene B | 0.6 |
| 1561             | 1561            | (E)-Nerolidol | 1.1 |
| 1566             | 1566            | 1,5-Epoxyosalvial-4(14)-ene | 0.9 |
| 1575             | 1576            | Spathulenol | 1.0 |
| 1580             | 1577            | Caryophyllene oxide | 1.3 |
| 1607             | 1607            | Humulene epoxide I | 1.2 |
| 1626             | 1629            | iso-Spathulenol | 0.7 |
| 1637             | 1644            | allo-Aromadendrene epoxide | 0.8 |
| 1640             | 1640            | γ-Cadinol | 0.3 |
| 1642             | 1644            | γ-Muurolol | 0.5 |
| 1653             | 1655            | α-Cadinol | 3.8 |
| 1659             | —               | Unidentified (43, 79, 91, 105, 133(100%), 163, 206) | 1.1 |
| 1666             | —               | Unidentified (41, 55, 81(100%), 93, 164, 206) | 1.2 |
| 1827             | —               | Unidentified (41, 55, 81, 122(100%), 151, 191) | 2.8 |
| 1839             | 1841            | Phytene | 0.8 |
| 2113             | 2109            | Phytol | 3.8 |

Monoterpene hydrocarbons 8.7
Oxygenated monoterpensoids 0.0
Sesquiterpene hydrocarbons 24.7
Oxygenated sesquiterpenoids 11.6
Diterpenoids 3.8
Others 44.4
Total identified 93.2

RI<sub>calc</sub> = Retention indices determined with reference to a homologous series of n-alkanes on a ZB-5 ms column.
RI<sub>db</sub> = Retention indices from the databases. tr = trace (<0.05%). % = percent of total essential oil composition.
2.1.4. Parthenium hysterophorus

Hydrodistillation of the fresh aerial parts of *P. hysterophorus* gave a yield of 0.05% (w/w) as a colorless/pale yellow essential oil. Gas chromatography–mass spectral analysis of the essential oil revealed a total of 75 identified (97.8% of the total) compounds (see Table 4).

Table 4. Essential oil composition of *Parthenium hysterophorus* from Vietnam.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compound                        | %   |
|-------------------|----------------|---------------------------------|-----|
| 922               | 923            | Tricyclene                       | 0.1 |
| 925               | 925            | α-Thujene                        | tr  |
| 932               | 932            | α-Pinene                         | 1.0 |
| 949               | 950            | Camphene                         | 2.2 |
| 972               | 972            | Sabine                           | 0.6 |
| 978               | 978            | β-Pinene                         | 3.0 |
| 978               | 978            | 1-Octen-3-ol                     | 0.3 |
| 986               | 986            | Octan-3-one                      | tr  |
| 989               | 989            | Myrcene                          | 14.4|
| 1025              | 1025           | p-Cymene                         | 0.1 |
| 1030              | 1030           | Limonene                         | 1.0 |
| 1031              | 1031           | β-Phellandrene                   | 0.5 |
| 1036              | 1035           | (Z)-β-Ocimene                    | tr  |
| 1046              | 1046           | (E)-β-Ocimene                    | 3.1 |
| 1051              | 1051           | 2,3,6-Trimethylhepta-1,5-diene    | 0.1 |
| 1058              | 1058           | γ-Terpinene                      | tr  |
| 1081              | 1079           | 1-Nonen-3-ol                     | 0.2 |
| 1086              | 1086           | Terpinolene                      | tr  |
| 1099              | 1098           | Perillene                        | 0.1 |
| 1101              | 1101           | Linalool                         | 0.1 |
| 1114              | 1114           | 4,8-Dimethylnona-1,3,7-triene     | 0.4 |
| 1140              | 1139           | (E)-Myroxide                     | tr  |
| 1182              | 1180           | Terpin-4-ol                      | 0.1 |
| 1189              | 1187           | Cryptone                         | tr  |
| 1286              | 1286           | Cogeijerene                      | 4.8 |
| 1332              | 1331           | Bicycloelemene                   | 0.1 |
| 1335              | 1335           | δ-Elemene                        | 0.3 |
| 1347              | 1348           | α-Cubebe                         | 0.1 |
| 1370              | 1367           | Cyclosativenol                   | 0.2 |
| 1376              | 1375           | α-Copaene                        | 0.3 |
| 1379              | 1380           | Daucone                          | 0.2 |
| 1382              | 1383           | cis-β-Elemene                    | 0.4 |
| 1384              | 1385           | β-Bourbonone                     | 0.5 |
| 1388              | 1387           | β-Cubebe                         | 0.7 |
| 1390              | 1390           | trans-β-Elemene                  | 0.9 |
| 1392              | 1392           | Sativene                         | 0.1 |
| 1416              | 1414           | α-Cedrene                        | 0.1 |
| 1421              | 1418           | (E)-β-Caryophyllene              | 12.6|
| 1430              | 1432           | γ-Elemene                        | 0.7 |
| 1433              | 1432           | trans-α-Bergamotene              | 0.1 |
| 1441              | 1439           | (Z)-β-Farnesene                  | 0.1 |
| 1442              | 1442           | Guai-6,9-diene                   | 0.1 |
| 1445              | 1447           | iso-Germacrene D                 | 0.1 |
| 1454              | 1452           | (E)-β-Farnesene                  | 0.2 |
| 1456              | 1454           | α-Humulene                       | 1.5 |
| 1476              | 1478           | γ-Murolene                       | 2.5 |
| 1484              | 1483           | Germacrene D                     | 23.2|
| 1490              | 1489           | β-Selinene                       | 0.2 |
| 1493              | 1492           | trans-Murola-4(15),5-diene       | 0.1 |
| 1496              | 1497           | Bicyclogermacrene                | 0.8 |
Table 4. Cont.

| RI_{calc} | RI_{db} | Compound                  | %   |
|-----------|---------|---------------------------|-----|
| 1499      | 1500    | α-Muurolene               | 0.5 |
| 1505      | 1504    | (E,E)-α-Farnesene         | 3.3 |
| 1508      | 1508    | β-Bisabolene              | 0.1 |
| 1514      | 1514    | γ-Cadinene                | 0.1 |
| 1516      | 1515    | Cubebol                   | 0.2 |
| 1519      | 1520    | δ-Cadinene                | 0.6 |
| 1525      | 1524    | β-Sesquiphellandrene      | 0.2 |
| 1533      | 1532    | Selina-4(15),7(11)-dienen | 0.4 |
| 1560      | 1560    | Germacrene B              | 0.4 |
| 1562      | 1560    | (E)-Nerolidol             | 0.6 |
| 1566      | 1571    | iso-Shobunol              | 2.8 |
| 1578      | 1576    | Spathulenol               | 0.5 |
| 1584      | 1587    | Caryophyllene oxide       | 2.4 |
| 1604      | 1609    | Carotol                   | 1.8 |
| 1611      | 1611    | Humulene epoxide II       | 0.2 |
| 1628      | 1624    | Muurola-4,10(14)-dien-1α-ol | 0.6 |
| 1630      | 1629    | iso-Spathulenol           | 0.3 |
| 1634      | 1632    | Muurola-4,10(14)-dien-1β-ol | 1.4 |
| 1641      | 1644    | allo-Aromadendrene epoxide | 0.7 |
| 1644      | 1643    | τ-Cadinol                 | 0.1 |
| 1646      | 1645    | τ-Murrolo                 | 0.1 |
| 1648      | 1651    | α-Muurolol (=δ-Cadinol)   | 0.6 |
| 1657      | 1655    | α-Cadinol                 | 0.6 |
| 1865      | 1860    | Platambin                 | 0.3 |
| 2109      | 2109    | Phytol                    | 0.5 |

RI_{calc} = Retention indices determined with reference to a homologous series of n-alkanes on a ZB-5 ms column. RI_{db} = Retention indices from the databases. tr = trace (<0.05%). % = percent of total essential oil composition.

The major components in the *P. hysterophorus* essential oil were germacrene D (23.2%), myrcene (14.4%), (E)-β-caryophyllene (12.6%), cogeijerene (4.8%), (E,E)-α-farnesene (3.3%), (E)-β-oicem (3.1%), and β-pinene (3.0%). Though most of these compounds are commonly present in essential oils, cogeijerene (1,2,3,7,8,8a-hexahydro-4,8a-dimethylnaphtalene) is a relatively rare component of essential oils. The compound was originally isolated and characterized from *Geijera parviflora* [50], but it has also been found in the essential oils of *Geijera parviflora* (4.3%) [51], *Scaligeria tripartita* (1.0%) [52], and *Artemesia annua* (0.1%) [53]. The essential oil composition is qualitatively similar to an essential oil sample from Lavras, Minas Gerais, Brazil, with germacrene D (35.9%), myrcene (7.6%), (E)-β-caryophyllene (8.5%), and β-pinene (7.6%) [54]. However, neither cogeijerene nor (E,E)-α-farnesene were reported from the Brazilian sample.

2.1.5. *Sphaeranthus africanus*

The essential oil from the aerial parts of *S. africanus* was obtained at 0.25% yield. The major components in *S. africanus* essential oil were 1-decen-3-ol (36.9%), α-pinene (21.0%), τ-cadinol (7.5%), 3-octyl propionate (5.6%), and (E)-β-caryophyllene (5.5%) (see Table 5). In contrast, the *S. africanus* (as *S. indicus*) essential oil from India was composed of thymohydroquinone dimethyl ether (18.2%), α-agarofuran (11.8%), 10-epi-β-eudesmol (7.9%), and silen-11-en-4α-ol (12.7%) [55]. The compositional differences in the essential oils from Vietnam and India may be attributed to genetic differences or environmental factors.
Table 5. Essential oil composition of *Sphaeranthus africanus* from Vietnam.

| RI\text{calc} | RI\text{db} | Compound                        | %   |
|--------------|-------------|---------------------------------|-----|
| 926          | 925         | α-Thujene                       | tr  |
| 934          | 933         | α-Pinene                        | 21.0|
| 950          | 950         | Camphene                        | 0.1 |
| 953          | 953         | Thuja-2,4(10)-diene             | tr  |
| 973          | 972         | Sabinene                        | 0.1 |
| 978          | 978         | β-Pinene                        | 0.2 |
| 979          | 982         | 1-Octen-3-ol                    | 0.2 |
| 989          | 989         | Myrcene                         | 0.1 |
| 1025         | 1025        | p-Cymene                         | 0.2 |
| 1029         | 1030        | Limonene                        | 0.1 |
| 1046         | 1045        | (E)-β-Ocimene                    | 0.2 |
| 1081         | 1079        | 1-Nonen-3-ol                    | 0.1 |
| 1099         | 1099        | (2Z)-Hexenyl propanoate         | 0.9 |
| 1106         | 1107        | Nonanal                          | 0.1 |
| 1108         | 1107        | 1-Octen-3-yl acetate            | 0.7 |
| 1110         | 1110        | Vinyl 2-ethylhexanoate           | 0.3 |
| 1120         | 1118        | 3-Octyl acetate                 | 0.4 |
| 1194         | 1184        | 1-Decen-3-ol                    | 36.9|
| 1205         | 1218        | 3-Octyl propionate              | 5.6 |
| 1216         | 1218        | 3-Nonyl acetate                 | 0.1 |
| 1229         | 1229        | Thymyl methyl ether             | 0.2 |
| 1242         | 1242        | Cumaraldehyde                   | 0.1 |
| 1250         | 1249        | 6-Methylidodecane               | 0.2 |
| 1260         | 1294        | 2,2,4,4,6,8,8-Heptamethylmononane| 2.6 |
| 1295         | 1294        | trans-Farnesylacetate           | 0.1 |
| 1322         | 1322        | Myrtenyl acetate                | 0.1 |
| 1345         | 1349        | 7-epi-Silphiperfol-5-ene        | 0.3 |
| 1380         | 1382        | Modheph-2-ene                   | 2.4 |
| 1387         | 1385        | α-Isocoumarone                  | 0.4 |
| 1409         | 1413        | β-Isocoumarone                  | 0.4 |
| 1411         | 1411        | Thymohydroquinone dimethyl ether| 0.4 |
| 1418         | 1417        | (E)-β-Caryophyllene             | 5.5 |
| 1452         | 1452        | (E)-β-Farnesene                 | 0.1 |
| 1454         | 1454        | α-Humulene                      | 0.4 |
| 1458         | 1458        | allo-Aromadendrene              | 0.5 |
| 1460         | 1461        | Precocene 1 (=6-Demethoxyageratochromene) | 0.5 |
| 1479         | 1480        | Germacrene D                    | 0.1 |
| 1496         | 1497        | α-Murolene                      | 0.1 |
| 1511         | 1512        | γ-Cadinene                      | 0.8 |
| 1515         | 1518        | Isosyoxybunone                  | 0.5 |
| 1516         | 1518        | δ-Cadinene                      | 0.3 |
| 1579         | 1577        | Caryophyllene oxide             | 1.1 |
| 1595         | 1597        | Dimethyl-α-ionone               | 0.2 |
| 1600         | 1600        | β-Isoopene                      | 0.1 |
| 1601         | 1604        | Geranyl isovalerate             | 0.1 |
| 1623         | 1624        | Muurola-4,10(14)-dien-1β-ol     | 0.1 |
| 1631         | 1631        | Caryophylla-4(12),8(13)-dien-5α-ol | 0.1 |
| 1634         | 1634        | Caryophylla-4(12),8(13)-dien-5β-ol | 0.2 |
| 1640         | 1641        | α-Cadinol                       | 7.5 |
| 1651         | 1652        | δ-Himachalol                    | 1.5 |
| 1662         | 1660        | Selin-11-en-4β-ol               | 0.1 |
| 1671         | 1672        | Jatamansone                     | 2.0 |
| 1834         | 1836        | Neophytadiene                   | 0.4 |
| 1839         | 1841        | Phytone                         | 0.3 |
| 2103         | 2102        | Phytol                          | 2.0 |
|              |             | Monoterpene hydrocarbons        | 22.0|
|              |             | Oxygenated monoterpenoids       | 1.1 |
|              |             | Sesquiterpene hydrocarbons      | 10.9|
|              |             | Oxygenated sesquiterpenoids     | 13.4|
|              |             | Diterpenoids                    | 2.3 |
|              |             | Others                          | 48.9|
|              |             | Total identified                | 98.5|

RI\text{calc} = Retention indices determined with reference to a homologous series of \textit{n}-alkanes on a ZB-5 ms column.

RI\text{db} = Retention indices from the databases. tr = trace (<0.05%). % = percent of total essential oil composition.
2.2. Mosquito Larvicidal Activity

The essential oils of *B. lacera*, *B. sinuata*, *E. sonchifolia*, *P. hysterophorus*, and *S. africanus* were screened for mosquito larvicidal activity against *Aedes aegypti* (the yellow fever mosquito) and *Aedes albopictus* (the Asian tiger mosquito), as previously described [34,56]. The essential oils were also screened for possible insecticidal activity against the non-targeted water bug, *D. rusticus*, as previously reported [33,36]. The larvicidal and insecticidal activities for the essential oils are summarized in Table 6.

Table 6. *Aedes* larvicidal and *Diplonychus rusticus* insecticidal activities of Vietnamese Asteraceae essential oils.

| Essential Oil                  | 24 h  | 48 h  | 24 h  | 48 h  |
|-------------------------------|-------|-------|-------|-------|
|                               | LC₅₀  | LC₉₀  | LC₅₀  | LC₉₀  |
| *Blumea lacera* leaf          | 64.7  | 96.4  | 55.1  | 83.4  |
| *Blumea sinuata* aerial parts | 23.4  | 36.2  | 17.4  | 27.3  |
| *Emilia sonchifolia* aerial parts | 30.1  | 40.8  | 26.2  | 36.6  |
| *Parthenium hysterophorus* aerial parts | 47.6  | 63.4  | 36.3  | 57.7  |
| *Sphaeranthus africanus* aerial parts | 50.7  | 74.4  | 44.2  | 65.3  |
| *Blumea lacera* leaf          | 116.7 | 155.8 | 99.4  | 147.4 |
| *Blumea sinuata* aerial parts | 29.1  | 104.7 | 12.4  | 36.5  |
| *Emilia sonchifolia* aerial parts | 29.6  | 46.3  | 23.4  | 40.7  |
| *Parthenium hysterophorus* aerial parts | 44.4  | 66.4  | 33.8  | 63.6  |
| *Sphaeranthus africanus* aerial parts | 36.9  | 56.4  | 28.8  | 44.4  |

*Due to insufficient data for probit analysis, the LC₅₀ was determined using the Reed–Muench method [57].

According to Dias and Moraes [39], essential oils and their components are considered to be active with larvicidal LC₅₀ values less than 100 µg/mL. However, we have recently amended the activity definition: essential oils with 24-h LC₅₀ < 10 µg/mL are considered “exceptionally active”, those with 24-h LC₅₀ between 10 and 50 µg/mL are “very active”, those with 24-h LC₅₀ between 50 and 100 µg/mL are “moderately active”, and LC₅₀ >100 µg/mL are “inactive” [58]. Thus, *B. lacera* leaf essential oil was only marginally active against *Ae. aegypti* and inactive against *Ae. albopictus*.

The essential oil of *B. sinuata*, on the other hand, showed very good *Aedes* larvicidal activities with 24-h LC₅₀ values of 23.4 and 29.1 µg/mL against *Ae. aegypti* and *Ae. albopictus*, respectively, as well as 48-h LC₅₀ values of 17.4 and 12.4 µg/mL. Importantly, *B. sinuata* essential oil showed no mortality at the highest concentration tested (100 µg/mL) against the non-target water bug, *Diplonychus rusticus*. The larvicidal activities observed can be partly attributed to the major components. *Ayapana triplinervis* essential oil, rich in thymohydroquinone dimethyl ether (84.5%), showed larvicidal activity against *Ae. aegypti* (24-h LC₅₀ = 86.2 µg/mL) [59]. *(E)-β*-Caryophyllene has shown insecticidal activity against *Ae. aegypti* larvae (LC₅₀ 39–88 µg/mL), as well as *Ae. albopictus* larvae (LC₅₀ 40–45 µg/mL) [33,35,36]. Likewise, α-pinene has demonstrated larvicidal activities against both *Ae. aegypti* and *Ae. albopictus* with LC₅₀ values ranging 40–65 and 29–69 µg/mL, respectively [35], germacrene D showed good
larvicidal activity on *Ae. aegypti* (LC$_{50}$ = 18.8 µg/mL) [60], and α-humulene was larvicidal with 24-h LC$_{50}$ values of 44.4 and 43.9 µg/mL against *Ae. aegypti* and *Ae. albopictus*, respectively [36].

Although *E. sonchifolia* essential oil showed moderately active mosquito larvicidal activity (24-h LC$_{50}$ = 30.1 and 29.6 µg/mL against *Ae. aegypti* and *Ae. albopictus*, respectively), it was also insecticidal to the non-target insect, *Diplonychus rusticus* with a 24-h LC$_{50}$ of 48.1 µg/mL. Thus, the *E. sonchifolia* essential oil is not selectively toxic and should not be considered further for this purpose.

The *Parthenium hysterophorus* essential oil showed good mosquito larvicidal activity with 24-h LC$_{50}$ values of 47.6 and 44.4 µg/mL against *Ae. aegypti* and *Ae. albopictus*, respectively. Notably, the essential oil showed no lethality to the non-target insect, *Diplonychus rusticus*. Several of the major components of the *P. hysterophorus* essential oil have previously shown larvicidal activity against *Ae. aegypti*, including germacrene D (LC$_{50}$ = 18.8 µg/mL) [60], myrcene (LC$_{50}$ = 35.8 µg/mL) [61], (E)-β-caryophyllene (LC$_{50}$ = 61.1 µg/mL) [36], and β-pinene (22.9 µg/mL) [33]. Larvicidal activity on *Ae. albopictus* has also been reported for myrcene [61] and (E)-β-caryophyllene [33] (LC$_{50}$ = 27.0 and 56.9 µg/mL, respectively). The larvicidal activities of the major components, therefore, likely account for the observed larvicidal activities of the *P. hysterophorus* essential oil.

The essential oil of *S. africanus* showed moderate larvicidal activity with 24-h LC$_{50}$ values of 50.7 and 36.9 µg/mL, respectively, on *Ae. aegypti* and *Ae. albopictus*. In a previous study, the *S. africanus* (as *S. indicus*) essential oil from India was screened for mosquito larvicidal activity against *Culex quinquefasciatus* and *Ae. aegypti* [62]. The larvicidal activities were very modest, however (24-h LC$_{50}$ = 130 and 140 µg/mL, respectively). Unfortunately, the essential oil characterization in this study is not reliable.

3. Materials and Methods

3.1. Plant Material

The details of plant material collection and hydrodistillation are summarized in Table 7. During this process, botanical identification and confirmation was conducted by Dr. Huong, L.T., Faculty of Biology, College of Natural Science Education, Vinh University, Vietnam. In addition, voucher specimens with codes LTH 881, LTH 284, LTH 286, LTH 327, and LTH 332 were preserved in the plant specimen room, Vinh University, Vietnam. Aerial parts were shredded and hydrodistilled for 5 h using a Clevenger-type apparatus (Witeg Labortechnik, Wertheim, Germany). Essential oil isolation yields of three consecutive replicates were used to calculate the average yield. The essential oils were dried over anhydrous Na$_2$SO$_4$ and stored in sealed glass vials at 4 °C until use in analysis and bioactivity assays.

| Plant Species | Collection Location (GPS) | Part | Mass Plant Material (kg) | Extraction Yield (%/w/w) | Collection Time |
|---------------|---------------------------|------|--------------------------|---------------------------|-----------------|
| *B. lacera*   | Nghia Dan District, Nghe An Province (19°23′05″ N, 105°25′51″ E). | Aerial parts | 3.0 | 1.2 | August 2021 |
|               |                           | Leaves | 0.3 | 1.56 | August 2021 |
|               |                           | Flowers | 0.3 | 1.10 | August 2021 |
|               |                           | Stems | 0.3 | 0.35 | August 2021 |
| *B. sinuata*  | Nghia Dan District, Nghe An Province (19°20′06″ N, 105°25′59″ E). | Aerial parts | 4.0 | 0.16 | August 2021 |
| *E. sonchifolia* | Dien Lâm Commune, Pù Huơng Natural Reserve, Nghe An Province (19°26′44″ N, 104°58′40″ E). | Aerial parts | 3.0 | 0.51 | August 2021 |
| *P. hysterophorus* | Dien L詹姆斯 Commune, Pù Huơng Natural Reserve, Nghe An Province (19°16′53″ N, 104°55′16″ E). | Aerial parts | 5.0 | 0.05 | August 2021 |
| *S. africanus* | Dien L詹姆斯 Commune, Pù Huơng Natural Reserve, Nghe An Province (19°26′44″ N, 104°58′40″ E). | Aerial parts | 4.0 | 0.25 | August 2021 |
3.2. Gas Chromatography–Mass Spectral Analysis

Gas chromatography–mass spectral analyses (GC–MS) of *B. lacera*, *B. sinuata*, *E. sonchifolia*, *P. hysterophorus*, and *S. africanus* essential oils were carried out using the instrumentation and protocols previously published [36,56,63]. A Shimadzu GCMS-QP2010 Ultra, with a ZB-5 ms fused silica capillary column (60 m length, 0.25 mm diameter, 0.25 µm film thickness) was used, He carrier gas, 2.0 mL/min flow rate, injection and ion source temperatures of 260 °C, and a GC oven program of 50 to 260 °C at 2.0 °C/min. Injection volumes of 0.1 µL of 5% (w/v) samples of essential oil in CH2Cl2 were injected in split mode, with a 24.5:1 split ratio. Identification of the essential oil components was carried out with a comparison of MS fragmentation and retention indices (RI) with those available in the databases [64–67]. The peak areas were corrected for response using external standards of representative compounds from each compound class.

3.3. Mosquito Larvicidal Activity Screening

Mosquito larvicidal activity screening against *Ae. aegypti* and *Ae. albopictus* was carried out as previously described [34,56]. Quadruplicate assays using 20 fourth-instar mosquito larvae and five essential oil concentrations (100, 75, 50, 25, and 12.5 µg/mL) and a permethrin positive control. Mortality was recorded after 24 h and again after 48 h of exposure. Lethality data were subjected to log-probit analysis to obtain LC50 values, LC90 values, and 95% confidence limits using Minitab® version 19.2020.1 (Minitab, LLC, State College, PA, USA).

3.4. Diplonychus Rusticus Insecticidal Assay

Insecticidal activity against *D. rusticus* was carried out as previously described [33]. Quadruplicate assays were conducted, using 20 adult *D. rusticus*, and five essential oil concentrations (100, 75, 50, 25, and 12.5 µg/mL), with mortality recorded after 24 h and 48 h exposure times.

4. Conclusions

The essential oils of *B. sinuata*, rich in thymohydroquinone dimethyl ether, (E)-β-caryophyllene, α-pinene, and germacrene D; *P. hysterophorus*, rich in germacrene D, myrcene, and (E)-β-caryophyllene; and *S. africanus*, dominated by 1-decen-3-ol and α-pinene, all showed good mosquito larvicidal activities without toxicity to a non-target aquatic species. Based on these encouraging results, *B. sinuata*, *P. hysterophorus*, and *S. africanus* essential oils should be further investigated for use as eco-friendly botanical pesticides. Field trials and formulations are needed to enhance the environmental lifetime of the essential oils and determine whether they are a viable alternative pest-control agents in aquatic systems.

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Sample Availability: Samples of the essential oils are available from the corresponding author N.H.H.

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