Abstract: Mosquito-borne diseases are a large problem in Vietnam as elsewhere. Due to environmental concerns regarding the use of synthetic insecticides as well as developing insecticidal resistance, there is a need for environmentally-benign alternative mosquito control agents. In addition, resistance of pathogenic microorganisms to antibiotics is an increasing problem. As part of a program to identify essential oils as alternative larvicidal and antimicrobial agents, the leaf, stem, and rhizome essential oils of several \textit{Zingiber} species, obtained from wild-growing specimens in northern Vietnam, were acquired by hydrodistillation and investigated using gas chromatography. The mosquito larvicidal activities of the essential oils were assessed against \textit{Culex quinquefasciatus}, \textit{Aedes albopictus}, and \textit{Ae. aegypti}, and for antibacterial activity against a selection of Gram-positive and Gram-negative bacteria, and for activity against \textit{Candida albicans}. \textit{Zingiber} essential oils rich in \(\alpha\)-pinene and \(\beta\)-pinene showed the best larvicidal activity. \textit{Zingiber nudicarpum} rhizome essential oil showed excellent antibacterial activity against \textit{Enterococcus faecalis}, \textit{Staphylococcus aureus}, and \textit{Bacillus cereus}, with minimum inhibitory concentrations (MIC) of 2, 8, and 1 \(\mu\)g/mL, respectively. However, the major components, \(\alpha\)-pinene and \(\beta\)-pinene, cannot explain the antibacterial activities obtained.

Keywords: ginger; \textit{Aedes aegypti}; \textit{Aedes albopictus}; \textit{Culex quinquefasciatus}; antibacterial; antifungal

1. Introduction

Vietnam is located in the tropics of Southeast Asia, and several mosquito-borne diseases are endemic, including Japanese encephalitis [1], dengue fever [2], and Zika [3]. \textit{Culex} species are considered to be important vectors of Japanese encephalitis virus (JEV), including \textit{Culex quinquefasciatus}...
Say (Diptera: Culicidae) [4], but other mosquito genera may also serve as competent vectors of the virus [5,6]. Dengue fever is hyperendemic to Vietnam with all four serotypes of the virus in circulation, resulting in periodic acute epidemics of both dengue fever and dengue hemorrhagic fever [7,8]. Aedes aegypti (L.) and Aedes albopictus (Skuse) (Diptera: Culicidae) mosquitoes are the principal vectors of dengue fever virus (DFV) in Vietnam [9]. Zika virus (ZIKV) first appeared in Vietnam in 2016, where the primary transmission vector is Aedes mosquitoes [10]. Exacerbating this problem is the increasing insecticide resistance in Aedes [11–13] and Culex mosquitoes [14,15].

As observed throughout the world, antimicrobial resistance is an increasing problem in Vietnam [16]. Particularly noteworthy are antibiotic-resistant organisms in hospital settings, including Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa [17], Streptococcus pneumoniae, Haemophilus influenzae [18], Escherichia coli, and Staphylococcus aureus [19].

Zingiber Mill. is a species-rich genus within the subfamily Zingiberoidae of Zingiberaceae, which are native to Southeast Asia [20]. The Plant List currently has 146 accepted names for Zingiber species [21]. The phytochemistry, particularly essential oil chemistry, and the pharmacology of Zingiber have been reviewed [22]. Currently, at least thirty-six species of Zingiber have been reported in Vietnam [23–25].

There is a need to discover new and alternative insect-control agents and antimicrobial agents. In this work, essential oils from seven species of Zingiber growing in Vietnam were collected and analyzed by gas chromatographic methods. Six species were screened for mosquito larvicidal activity and antibacterial and antifungal activity.

Zingiber cornubracteatum Tribouin & K. Larsen was first recorded in northern Thailand (Mae Hong Son) [26], but has since been collected in northern Vietnam (Thanh Hoa, Nghe An, and Quang Binh provinces) [25]. There have been no reports on the phytochemistry of this plant. Zingiber neotruncatum T.L. Wu, K. Larsen & Turland has been recorded from southern and western Yunnan province, China [27] and Nghe An province, Vietnam [28]. There have been no previous reports on the essential oil of this species. Zingiber nitens M.F. Newman is known from Bolikhamsai Province, Laos [29], and Nghe An Province, Vietnam [30]. The essential oil composition of Z. nitens from Vietnam has been previously published [31]. Zingiber nudicarpum D. Fang has been recorded in Guangxi Province, China [27], Laos [32], and Vietnam [33]. The essential oil composition of Z. nudicarpum from Vietnam has been previously published [34]. Zingiber ottensii Valeton is native to Southeast Asia, including Thailand, Indonesia, Malaysia, Laos, Myanmar, and Vietnam [35,36]. Essential oil compositions of Z. ottensii have been reported from Malaysia [37,38], Thailand [39,40], and Indonesia [41]. Zingiber recurvatum S.Q. Tong & Y.M. Xia has been recorded in southern Yunnan Province, China [42], northern Laos [32], and Vietnam [43,44]. There are apparently no reports on the volatile phytochemistry of this plant. Zingiber vuquangensis Lý N.S., Lê T.H., Trinh T.H., Nguyên V.H., Dô N.D. is a new species, only recently recorded in Vietnam [45]. The essential oil composition of Z. vuquangensis has been reported [46].

2. Results and Discussion

2.1. Essential Oil Compositions

The Zingiber plant tissues (leaves, stems, or rhizomes) were collected from north-central Vietnam and the plant tissues subjected to hydrodistillation to obtain the respective essential oils (Table 1, Figure 1). Gas chromatographic–mass spectral (GC-MS) and gas chromatographic–flame ionization detection (GC-FID) were used to analyze the essential oil compositions, which are compiled in Table 2.
Figure 1. Distribution map of Zingiber species from the north-central Vietnam. (A): *Zingiber cornubraceatum* Triboun & K. Larsen (red squares); *Z. neotruncatum* Triboun & K. Larsen (blue triangle), *Z. nitens* M.F. Newman (orange circle), *Z. nudicarpum* D.Fang (green stars). (B): *Zingiber ottensii* Valeton (red square), *Z. recurvatum* S.Q. Tong & Y.M. Xia (blue circle), *Z. vuquangensis* Ly N.S., Le T.H., Trinh T.H., Nguyen V.H., Do N.D. (orange star).
Table 1. Plant collection and hydrodistillation details of *Zingiber* species from north-central Vietnam.

| Zingiber Species       | Vietnamese Name          | Collection Site Coordinates; Elevation | Collection Month Year | Voucher Number | Plant Part | % Yield (v/w) |
|------------------------|--------------------------|----------------------------------------|------------------------|----------------|------------|---------------|
| *Zingiber cornubracatum* Triboun & K. Larsen | Gừng lá bac ca | Khe Kem water fall, Phú Mát National Park 19°58’14” N, 104°48’20” E; 280 m | September 2019 | 830 | Leaf, Rhizome | 0.12, 0.15 |
|                        |                          | Xuân Lý commune, Như Thanh District, Bến En National Park 19°39’09” N, 105°30’24” E; 80 m | October 2019 | 832 | Leaf, Stems, Rhizome | 0.14, 0.10, 0.17 |
|                        |                          | Tri Lệ commune, Quế Phong District, Phú Hoạt Nature Reserve 19°38’57” N, 104°40’55” E; 660 m | September 2018 | 735 | Leaf, Rhizome | 0.10, 0.12 |
| *Zingiber neotruncatum* T.L. Wu, K. Larsen & Turland | Gừng lá mới | Đồng Văn commune, Quế Phong district, Phú Hoạt Nature Reserve 19°53’58” N, 105°07’45” E; 315 m | October 2018 | 746 | Rhizome | 0.26 |
| *Zingiber nitens* M.F. Newman | Gừng lá sáng bông | Vũ Quang National Park 18°17’13” N, 105°26’12” E; 180 m | September 2018 | 738 | Leaf, Stems | 0.21, 0.45 |
| *Zingiber nudicarpum* D.Fang | Gừng quả tran | Thống Thu commune, Quế Phong district, Phú Hoạt Nature Reserve 19°49’5” N, 104°35’35” E; 460 m | April 2019 | 760 | Leaf, Stems, Rhizome | 0.12, 0.08, 0.15 |
|                        |                          | Nam Đông District, Thua Thiên Huế province 16°13’44” N, 107°53’54” E; 350 m | April 2018 | 778 | Leaf, Stems | 0.15, 0.10 |
|                        |                          | Nam Đông District, Thua Thiên Huế province 16°13’9” N, 107°43’28” E; 110 m | July 2019 | 777 | Leaf, Stems, Rhizome | 0.14, 0.09, 0.18 |
| *Zingiber ottensii* Valeton | Gừng otten | Tri Lệ commune, Quế Phong district, Phú Hoạt Nature Reserve 19°39’05” N, 105°40’59” E; 640 m | April 2019 | 772 | Leaf, Roots | 0.18, 0.25 |
| *Zingiber recurvatum* S.Q. Tong & Y.M. Xia | Gừng lá bac cong | Tri Lệ commune, Quế Phong district, Phú Hoạt Nature Reserve 19°39’37” N, 104°40’29” E; 640 m | July 2019 | 792 | Leaf, Rhizome | 0.14, 0.19 |
| *Zingiber vuquangensis* Ly N.S., Le T.H., Trinh T.H., Nguyen V.H., Do N.D. | Gừng vu quang | Nam Nhông commune, Quế Phong district, Phú Hoạt Nature Reserve 19°30’31” N, 104°43’13” E; 590 m | April 2019 | 771 | Leaf, Stems, Rhizome | 0.15, 0.10, 0.14 |
Table 2. Chemical compositions of essential oils of *Zingiber* species from north-central Vietnam.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                      | Z. ornabracatum (Pu Hoat) Leaf | Z. ornabracatum (Pu Hoat) Rhizome | Z. ornabracatum (Pu Ma) Leaf | Z. ornabracatum (Pu Ma) Rhizome | Z. ornabracatum (Ben En) Leaf | Z. ornabracatum (Ben En) Rhizome | Z. neotruncatum Leaf | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|------------------|----------------|--------------------------------|--------------------------------|-----------------------------------|-----------------------------|-----------------------------|-------------------------------|-------------------------------|-------------------|---------------------|----------------|----------------|----------------|----------------|
| 899              | 894            | 2-Heptanol                     | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 921              | 923            | Tricyclene                     | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | 0.9                  | ---            | ---            | ---            | ---            |
| 925              | 927            | α-Thujene                      | ---                            | ---                               | ---                         | 2.2                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 934              | 933            | α-Pinene                       | 5.1                            | 14.5                              | 2.7                         | 8.2                         | 10.1                          | 9.9                           | 9.8                | 1.9                  | 11.2          | 10.5          | 4.0           | 3.4           |
| 943              | 945            | α-Fenchene                     | ---                            | ---                               | 0.3                         | ---                         | ---                           | ---                           | ---                | 0.3                  | ---            | ---            | 0.9           | ---            |
| 951              | 953            | Camphene                       | ---                            | 1.2                               | ---                         | 3.2                         | 0.3                           | 0.3                           | 1.3                | 0.2                  | 0.3           | 40.4          | ---           | 0.3           |
| 952              | 953            | Thuja-2,4(10)diene             | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 971              | 972            | Sabinene                       | 0.8                            | 0.9                               | 0.7                         | 1.4                         | 1.4                           | 11.9                          | 0.4                | 1.7                  | 0.2            | 0.4           | 21.6          | ---            |
| 978              | 978            | β-Pinene                       | 20.1                           | 14.8                              | 18.8                        | 8.8                         | 67.3                          | 66.8                          | 33.1               | 3.1                  | 6.0            | 1.1           | 17.1          | 11.7          |
| 981              | 985            | 6-Methylhept-5-en-2-one        | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | 0.3                  | ---            | ---            | ---            | ---            |
| 988              | 991            | Myrcene                        | 0.4                            | 0.4                               | 1.8                         | 7.7                         | 1.0                           | 1.0                           | 4.2                | 0.3                  | 0.4            | 2.0           | 0.4           | 1.3           |
| 989              | 988            | Dehydro-1,8-cineole            | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 989              | 984            | 2-Pentylfuran                  | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 1002             | 998            | Octanal                        | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 1004             | 1108           | 1,3,8-p-Menthatriene           | ---                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 1006             | 1007           | α-Phellandrene                 | 0.8                            | 0.4                               | 1.1                         | 0.4                         | ---                           | ---                           | 1.6                | ---                  | 0.2            | ---            | 0.6           | ---            |
| 1008             | 1009           | δ-3-Carene                     | 0.2                            | 0.1                               | 0.2                         | 5.3                         | ---                           | ---                           | 2.1                | ---                  | ---            | ---            | ---            | ---            |
| 1016             | 1018           | α-Terpine                      | ---                            | ---                               | 0.2                         | 0.2                         | ---                           | ---                           | 0.8                | ---                  | ---            | ---            | 3.5           | ---            |
| 1018             | 1022           | m-Cymene                       | ---                            | ---                               | ---                         | 0.1                         | ---                           | ---                           | ---                | ---                  | ---            | ---            | ---            | ---            |
| 1023             | 1025           | p-Cymene                       | 0.4                            | 0.5                               | 0.3                         | 3.9                         | ---                           | ---                           | 2.7                | ---                  | ---            | ---            | 2.1           | ---            |
| 1034             | 1028           | Limonene                       | 0.6                            | 1.0                               | 1.2                         | 5.1                         | 1.2                           | 1.2                           | 3.4                | 0.2                  | 0.9            | 4.6           | 0.8           | 0.9           |
| 1035             | 1031           | β-Phellandrene                 | 0.5                            | 0.9                               | 0.8                         | 2.2                         | 0.3                           | 0.3                           | 0.5                | ---                  | 0.2            | ---            | 0.2           | 0.3           |
| 1035             | 1030           | 1,8-Cineole                    | ---                            | 10.4                              | ---                         | 6.1                         | 0.2                           | 0.2                           | 2.5                | 0.7                  | ---            | ---            | 4.3           | ---            |
| 1036             | 1034           | (Z)-β-Ocimene                  | 0.3                            | ---                               | ---                         | ---                         | ---                           | ---                           | ---                | 0.2                  | 0.9            | 0.3           | ---            | ---            |
| 1046             | 1045           | (E)-β-Ocimene                  | 0.6                            | 0.4                               | 0.4                         | 0.4                         | 0.1                           | 0.1                           | 0.8                | 1.2                  | 2.1            | 12.7          | 2.1           | 0.9           |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                          | Z. cornubracteatum (Pu Hoa) Leaf | Z. cornubracteatum (Pu Hoa) Rhizome | Z. cornubracteatum (Pu Mát) Leaf | Z. cornubracteatum (Pu Mát) Rhizome | Z. cornubracteatum (Ben En) leaf | Z. Cornubracteatum (Ben En) Rhizome | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|-------|-------|----------------------------------|----------------------------------|-----------------------------------|----------------------------------|----------------------------------|---------------------------------|----------------------------------|-------------------------------|----------------|----------------|----------------|----------------|
| 1057  | 1057  | γ-Terpinene                       | 0.3                              | 0.4                               | 0.4                              | 0.7                              | 0.2                             | 0.2                             | 2.4                           | ---             | ---            | 0.1            | ---            |
| 1067  | 1063  | 1-Octanol                         | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1068  | 1067  | cis-Linalool oxide (furanoid)     | ---                              | 0.3                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1072  | 1065  | cis-Sabinene hydrate              | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1084  | 1086  | Terpinolene                       | 0.1                              | ---                               | 0.3                              | ---                              | ---                             | 0.7                             | ---                           | ---             | 0.8            | ---            | ---            |
| 1084  | 1084  | trans-Linalool oxide (furanoid)   | ---                              | 0.3                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1087  | 1083  | Fenchone                          | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | 0.2            | ---            | ---            |
| 1088  | 1089  | p-Cymenene                        | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1099  | 1102  | Perillene                         | ---                              | ---                               | 0.3                              | 0.1                              | 0.1                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1099  | 1097  | 2-Nonanol                         | ---                              | ---                               | 0.3                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1100  | 1101  | Linalool                          | 0.5                              | 31.0                              | 11.6                             | 0.2                              | 0.2                             | 0.4                             | ---                           | ---             | 0.4            | ---            | 0.2            |
| 1100  | 1104  | Rosefuran                         | ---                              | ---                               | ---                              | 0.2                             | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1104  | 1098  | trans-Sabinene hydrate            | ---                              | 0.3                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | 0.2            |
| 1105  | 1107  | Nonanal                           | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1112  | 1116  | (E)-4,8-Dimethylnona-1,3,7-triene | ---                              | ---                               | 0.1                              | 0.2                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1118  | 1114  | endo-Fenchol                      | ---                              | ---                               | 0.3                              | ---                              | ---                             | 0.2                             | ---                           | ---             | ---            | ---            | ---            |
| 1118  | 1118  | cis-p-Menth-2-en-1-ol             | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | 0.4            | ---            | ---            |
| 1120  | 1128  | allo-Ocimene                      | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1124  | 1118  | exo-Fenchol                       | ---                              | 0.3                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1128  | 1122  | α-Campholenal                     | ---                              | ---                               | 0.1                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1135  | 1136  | trans-p-Menth-2-en-1-ol           | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | 0.3            |
| 1137  | 1135  | Nopinone                          | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1141  | 1135  | trans-Pinocarveol                 | ---                              | ---                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
| 1144  | 1140  | trans-Verbenene                   | ---                              | 0.8                               | ---                              | ---                              | ---                             | ---                             | ---                           | ---             | ---            | ---            | ---            |
Table 2. Cont.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                     | Z. cornubracteatum (Pu Hoat) Leaf | Z. cornubracteatum (Pu Hoat) Rhizome | Z. cornubracteatum (Pu Mat) Leaf | Z. cornubracteatum (Pu Mat) Rhizome | Z. cornubracteatum (Ben En) leaf | Z. cornubracteatum (Ben En) Rhizome | Z. neotruncatum | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|------------------|----------------|-----------------------------|-----------------------------------|-------------------------------------|---------------------------------|-----------------------------------|---------------------------------|-----------------------------------|----------------|----------------|------------------|----------------|------------------|
| 1146             | 1149           | Camphor                     | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1148             | 1165           | Lavandulol                  | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1159             | 1167           | Benzyl acetate              | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1162             | 1160           | Pinocarvone                 | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1167             | 1165           | iso-Neral                   | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | 0.2             | ---             | ---               | ---             | ---               |
| 1169             | 1162           | δ-Terpineol                 | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1170             | 1166           | p-Mentha-1,5-dien-8-ol      | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1171             | 1165           | Borneol                     | 3.2                               | 0.7                                 | 0.1                             | ---                               | ---                             | 0.8                               | 0.5             | ---             | ---               | ---             | ---               |
| 1180             | 1180           | Terpinen-4-ol               | 0.1                               | 0.7                                 | 0.5                             | 1.4                               | 0.1                             | ---                               | ---             | ---             | ---               | ---             | 17.1             |
| 1185             | 1179           | p-Cymen-8-ol                | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1185             | 1185           | iso-Geranial                | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | 1.1             | ---             | ---               | ---             | ---               |
| 1194             | 1195           | α-Terpineol                 | 0.6                               | 0.2                                 | 0.1                             | ---                               | ---                             | 0.9                               | 0.9             | ---             | ---               | ---             | ---               |
| 1194             | 1195           | Myrtenal                    | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1194             | 1193           | (4Z)-Decenal                | 1.0                               | 0.2                                 | 0.1                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1195             | 1194           | Myrtenol                    | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1198             | 1195           | cis-Piperitol               | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | 0.1               |
| 1205             | 1204           | Verbenone                   | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1206             | 1206           | Decanal                     | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1209             | 1207           | trans-Piperitol             | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | 0.2             | ---               |
| 1216             | 1218           | endo-Fenchyl acetate        | ---                               | ---                                 | 0.6                             | ---                               | ---                             | 0.5                               | ---             | ---             | ---               | 3.3             | ---               |
| 1217             | 1215           | trans- Carveol              | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1220             | 1217           | β-Cyclocitril               | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1222             | 1227           | Nerol                       | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1224             | 1223           | Citronellol                 | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1227             | 1232           | Thymyl methyl ether         | ---                               | ---                                 | ---                             | ---                               | ---                             | ---                               | ---             | ---             | ---               | ---             | ---               |
| 1236             | 1235           | Neral                       | ---                               | ---                                 | ---                             | ---                               | ---                             | 12.3                             | ---             | ---             | ---               | ---             | ---               |
Table 2. Cont.

| RI_{calc} | RI_{db} | Compounds                  | Z. cornubracteatum (Pu Hoa) Leaf | Z. cornubracteatum (Pu Hoa) Rhizome | Z. cornubracteatum (Pu Ma) Leaf | Z. cornubracteatum (Pu Ma) Rhizome | Z. cornubracteatum (Ben En) Leaf | Z. cornubracteatum (Ben En) Rhizome | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|-----------|---------|---------------------------|---------------------------------|-------------------------------------|-------------------------------|----------------------------------|-------------------------------|-------------------------------|-------------------------|-----------------|-----------------|-----------------|------------------|
| 1241      | 1238    | Cuminal                   | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1242      | 1239    | Carvone                   | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1248      | 1249    | Geraniol                  | ---                             | ---                                 | ---                           | 0.2                              | ---                           | ---                           | 0.3                     | ---             | ---              | ---              | ---               |
| 1265      | 1264    | Geranial                  | ---                             | ---                                 | ---                           | ---                              | ---                           | 17.0                         | ---                     | ---             | ---              | ---              | ---               |
| 1271      | 1266    | 1-Decanol                 | ---                             | ---                                 | ---                           | 0.2                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1281      | 1287    | iso-Bornyl acetate        | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1284      | 1285    | Bornyl acetate            | 0.2                             | 2.8                                 | 7.9                           | ---                              | ---                           | 2.5                           | 14.5                    | ---             | ---              | ---              | 0.3               |
| 1285      | 1291    | Safrole                   | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1293      | 1290    | Dihydroedulian IIA        | ---                             | ---                                 | ---                           | 0.2                              | ---                           | ---                           | ---                     | 0.3             | ---              | ---              | ---               |
| 1295      | 1298    | Carvacrol                 | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1295      | 1293    | Methyl myrtenate          | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1307      | 1295    | trans-Sabinyl acetate     | ---                             | ---                                 | ---                           | ---                              | ---                           | 0.2                           | ---                     | ---             | ---              | ---              | ---               |
| 1330      | 1324    | Methyl geranate           | ---                             | ---                                 | ---                           | 0.3                              | ---                           | ---                           | 0.2                     | ---             | ---              | ---              | ---               |
| 1330      | 1332    | Bicycloelemene            | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1330      | 1335    | δ-Elemene                 | 1.4                             | 1.5                                 | ---                           | 0.4                              | 0.5                           | ---                           | 0.2                     | ---             | ---              | ---              | ---               |
| 1333      | 1325    | Myrtenyl acetate          | 0.1                             | 0.5                                 | 2.0                           | 0.5                              | 0.7                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1342      | 1349    | α-Cubebene                | 0.1                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1345      | 1346    | α-Terpinyl acetate        | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1364      | 1367    | Cyclosativene             | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1364      | 1372    | iso-Ledene                | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1368      | 1373    | α-Ylangene                | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1374      | 1375    | α-Copaene                 | 0.2                             | 0.4                                 | 0.4                           | ---                              | ---                           | ---                           | 3.2                     | ---             | ---              | ---              | ---               |
| 1375      | 1380    | Geranyl acetate           | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | 0.6                     | ---             | ---              | ---              | ---               |
| 1377      | 1383    | cis-β-Elemene             | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1377      | 1365    | Eugenol                   | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| 1382      | 1382    | β-Bourbonene              | ---                             | ---                                 | ---                           | ---                              | ---                           | ---                           | ---                     | ---             | ---              | ---              | ---               |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                  | Z. cornubracteatum (PùHoà) Leaf | Z. cornubracteatum (PùHoà) Rhizome | Z. cornubracteatum (PùMà) Leaf | Z. cornubracteatum (PùMà) Rhizome | Z. cornubracteatum (Ben En) Leaf | Z. Cornubracteatum (Ben En) Rhizome | Z. neotruncaatm (Ben En) Leaf | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|-----------|-----------|------------------------|-------------------------------|--------------------------------|-----------------|-------------------------------|-------------------------------|--------------------------------|-------------------------------|----------------|----------------|----------------|----------------|
| 1386      | 1387      | β-Cubebene            | 0.4                           | ---                           | 0.5             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1387      | 1390      | <i>trans</i>-β-Elemene | 0.2                           | ---                           | 0.5             | ---                           | 3.9                           | 4.4                           | 0.7                           | ---             | 0.8             | 0.2             | 17.0            | 0.3             |
| 1400      | 1403      | Methyl eugenol        | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1403      | 1405      | Sesquithujene         | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1403      | 1408      | (Z)-Caryophyllene     | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1405      | 1406      | α-Gurjunene           | ---                           | ---                           | 0.3             | ---                           | ---                           | ---                           | 0.2                           | ---             | ---             | 0.6             | ---             |
| 1405      | 1415      | β-Maaliene            | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1415      | 1416      | <i>cis</i>-α-Bergamotene | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1419      | 1417      | (E)-Caryophyllene     | 8.9                           | 0.4                           | 13.9            | 1.7                           | 1.8                           | 2.1                           | 0.6                           | 1.5             | ---             | 28.0            | 0.7             |
| 1427      | 1432      | γ-Elemene             | 0.3                           | ---                           | ---             | 0.2                           | 0.3                           | 0.1                           | ---                           | ---             | ---             | ---             | ---             |
| 1428      | 1424      | 2,5-Dimethoxy-p-cymene | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1428      | 1430      | β-Copaene             | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1428      | 1438      | α-Maaliene            | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1431      | 1416      | α-Santalene           | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1431      | 1432      | <i>trans</i>-α-Bergamotene | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1433      | 1437      | α-Guaiene             | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1437      | 1438      | Aromadendrene         | 0.3                           | ---                           | 0.3             | 0.2                           | ---                           | ---                           | ---                           | ---             | ---             | 0.1             | ---             |
| 1440      | 1440      | (Z)-β-Farnesene       | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | 0.3             | ---             | ---             | ---             |
| 1444      | 1431      | β-Gurjunene           | 0.3                           | ---                           | 0.3             | 0.2                           | ---                           | ---                           | ---                           | 0.3             | ---             | ---             | ---             |
| 1445      | 1445      | Myltyl-4(12)-ene      | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1446      | 1453      | Geranyl acetone       | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1447      | 1453      | <i>trans</i>-Muurola-3,5-diene | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1450      | 1452      | (E)-β-Farnesene       | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1452      | 1457      | Prezizaene            | ---                           | ---                           | ---             | ---                           | ---                           | ---                           | ---                           | ---             | ---             | ---             | ---             |
| 1454      | 1454      | α-Humulene            | 0.7                           | ---                           | 1.0             | 0.3                           | 0.2                           | 0.3                           | ---                           | ---             | ---             | 3.0             | 3.8             |
| RI\textsubscript{calc} | RI\textsubscript{db} | Compounds                              | Z. cornubracteatum (Pu Hoa) Leaf | Z. cornubracteatum (Pu Hoa) Rhizome | Z. cornubracteatum (Pu Māo) Leaf | Z. cornubracteatum (Pu Māo) Rhizome | Z. cornubracteatum (Ben En) leaf | Z. cornubracteatum (Ben En) Rhizome | Z. cornubracteatum (Ben En) Stem | Z. neotruncatum Rhizome | Z. nitens leaf | Z. nitens Rhizome | Z. ottensis Leaf | Z. ottensis Rhizome |
|----------------------|----------------------|----------------------------------------|---------------------------------|------------------------------------|-----------------------------------|-----------------------------------|---------------------------------|-----------------------------------|----------------------------------|----------------|----------------|----------------|----------------|----------------|
| 1458 1457            | 1460 1461            | \textit{allo-}Aromadendrene            | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1460 1461            | 1470 1472            | \textit{cis-}Cadina-1(6),4-diene       | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1470 1472            | 1471 1476            | \textit{trans-}Cadina-1(6),4-diene     | ---                             | ---                                | 0.7                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1471 1476            | 1471 1475            | \textit{β}-Chamigrene                  | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1471 1475            | 1472 1482            | \textit{γ}-Gurjunene                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1472 1482            | 1473 1478            | \textit{γ}-Curcumene                   | ---                             | ---                                | 0.3                                | ---                                | 0.5                              | 0.1                                | ---                               | --- | --- | --- | --- | --- |
| 1473 1478            | 1474 1476            | \textit{γ}-Muurolone                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1474 1476            | 1477 1482            | \textit{α}-Amorphene                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1477 1482            | 1477 1479            | \textit{αr-}Curcumene                  | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1477 1479            | 1477 1487            | \textit{(E)}\textit{-}β-Ionone         | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1477 1487            | 1478 1483            | \textit{trans-}β-Bergamotene           | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1478 1483            | 1479 1464            | \textit{9-epi-(E)}-Caryophyllene       | 0.4                             | ---                                | 0.8                                | ---                                | 0.1                              | 0.2                                | ---                               | 0.2 | 0.2 | --- | --- | --- |
| 1479 1464            | 1480 1480            | Germacrene D                          | 1.6                             | ---                                | 13.7                               | 0.8                                | 0.7                              | 0.8                                | 0.2                               | --- | 2.5 | --- | --- | --- |
| 1480 1480            | 1481 1488            | \textit{δ}-Selinene                    | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1481 1488            | 1482 1492            | \textit{cis-}β-Guaiene                 | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1482 1492            | 1483 1487            | Aristolochene                          | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1483 1487            | 1488 1492            | \textit{β}-Selinene                    | 0.3                             | ---                                | 0.4                                | ---                                | 0.5                              | 0.6                                | ---                               | 0.8 | --- | --- | --- | --- |
| 1488 1492            | 1489 1496            | Valencene                              | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1489 1496            | 1490 1490            | \textit{γ}-Amorphene                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1490 1490            | 1491 1493            | \textit{α}-Zingiberene                  | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | 17.4 | 1.6 | --- | --- | --- |
| 1491 1493            | 1494 1498            | \textit{α}-Selinene                    | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1494 1498            | 1494 1497            | Bicyclogermacrene                      | 7.4                             | ---                                | 18.9                               | 0.5                                | 2.7                              | 3.0                                | 0.4                               | 1.5 | 1.2 | --- | --- | --- |
| 1494 1497            | 1496 1500            | \textit{α}-Muurolone                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1496 1500            | 1496 1506            | \textit{α}-Bulnesene                   | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| 1496 1506            | 1497 1502            | \textit{trans-}β-Guaiene               | ---                             | ---                                | ---                                | ---                                | ---                              | ---                                | ---                               | --- | --- | --- | --- | --- |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                  | Z. cornubracteatum (Pu Hoat) Leaf | Z. cornubracteatum (Pu Hoat) Rhizome | Z. cornubracteatum (Pu Ma) Leaf | Z. cornubracteatum (Pu Ma) Rhizome | Z. Cornubracteatum (Ben En) Leaf | Z. Cornubracteatum (Ben En) Rhizome | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|-----------|-----------|--------------------------|----------------------------------|------------------------------------|-------------------------------|---------------------------------|-------------------------------|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1500      | 1500      | 1p-Pentadecane           | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 0.2             | ---             | ---             | ---             | ---             |
| 1501      | 1505      | (E,E)-α-Farnesene        | ---                              | ---                                | 0.9                           | 0.2                             | 0.5                            | 0.6                             | 0.2                             | ---             | ---             | 1.1             | ---             | ---             |
| 1501      | 1495      | γ-Amorphene              | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 0.9             | 0.2             | 0.5             | 0.6             | ---             |
| 1502      | 1496      | Viridiflorene            | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1503      | 1509      | β-Curcumene              | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1506      | 1508      | β-Bisabolene             | ---                              | ---                                | 0.2                           | ---                             | ---                            | ---                             | ---                             | 0.2             | 1.2             | 3.7             | 0.2             | ---             |
| 1511      | 1512      | γ-Cadinene               | 0.3                              | ---                                | 0.5                           | ---                             | ---                            | ---                             | ---                             | 0.2             | ---             | ---             | ---             | ---             |
| 1511      | 1511      | δ-Amorphene              | ---                              | ---                                | 0.4                           | ---                             | ---                            | 0.2                             | ---                             | 0.2             | ---             | ---             | ---             | ---             |
| 1513      | 1519      | Cubebol                  | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1516      | 1518      | δ-Cadinene               | 0.6                              | -                                  | 0.9                           | 0.2                             | 0.2                            | 0.2                             | ---                             | ---             | ---             | ---             | 2.2             | ---             |
| 1517      | 1520      | 7-epi-α-Selinene         | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1517      | 1521      | Zonarene                 | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1519      | 1521      | trans-Calamenene         | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1520      | 1528      | (E)-γ-Bisabolene         | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 0.2             | ---             | ---             | ---             | ---             |
| 1523      | 1521      | Eugenyl acetate          | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 0.2             | 0.2             | 0.1             | ---             | ---             |
| 1524      | 1521      | β-Sesquiphellandrene     | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 10.1            | 0.6             | ---             | ---             | ---             |
| 1529      | 1528      | cis-Calamene             | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | 10.1            | 0.6             | ---             | ---             | ---             |
| 1530      | 1536      | trans-Cadina-1,4-diene   | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1535      | 1537      | α-Cadinene               | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1539      | 1544      | α-Calacorene             | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1546      | 1549      | α-Elemol                 | 0.2                              | ---                                | 0.2                           | ---                             | ---                            | ---                             | ---                             | 0.2             | 0.2             | 0.4             | ---             | ---             |
| 1557      | 1559      | Germanacrene B           | 0.3                              | ---                                | 0.5                           | ---                             | 0.2                            | 0.3                             | 0.3                             | ---             | ---             | ---             | ---             | ---             |
| 1558      | 1561      | (E)-Nerolidol            | 23.0                             | ---                                | 2.7                           | 8.4                             | 0.9                            | 1.1                             | 0.3                             | 0.1             | 10.0            | 1.1             | 0.5             | ---             |
| 1560      | 1564      | β-Calacorene             | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| 1564      | 1568      | Palustrol                | ---                              | ---                                | ---                           | ---                             | ---                            | ---                             | ---                             | ---             | ---             | ---             | ---             | ---             |
| $RI_{calc}$ | $RI_{db}$ | Compounds | $Z.\ cornubracteatum$ (Pu Hoà) Leaf | $Z.\ cornubracteatum$ (Pu Hoà) Rhizome | $Z.\ cornubracteatum$ (Pù Mát) Leaf | $Z.\ cornubracteatum$ (Pù Mát) Rhizome | $Z.\ cornubracteatum$ (Ben En) leaf | $Z.\ cornubracteatum$ (Ben En) Stem | $Z.\ neotruncatum$ Rhizome | $Z.\ nitens$ Leaf | $Z.\ nitens$ Rhizome | $Z.\ ottensii$ Leaf | $Z.\ ottensii$ Rhizome |
|------------|----------|-----------|---------------------|-------------------|-------------------|-------------------|---------------|-----------------|-----------------|----------------|----------------|----------------|----------------|
| 1568       | 1571     | Maaliol   | ---                 | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1570       | 1573     | (3E,7E)-4,8,12-Trimethyltrideca-1,3,7,11-tetraene | ---                  | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1575       | 1576     | Spathulenol | 2.5                 | ---               | 1.4               | ---               | ---            | 0.1             | ---             | ---             | 0.4             | 0.6             | 0.2             |
| 1575       | 1582     | Neryl isovalerate | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1575       | 1574     | Germacrene D-4-ol | 0.2                | ---               | ---               | ---               | ---            | ---             | 0.9             | ---             | ---             | ---             | ---             |
| 1582       | 1577     | Caryophyllene oxide | 2.2                | ---               | 2.0               | 0.6               | ---            | 0.2             | 0.3             | 0.3             | ---             | 0.1             | 1.2             |
| 1582       | 1582     | ar-Turmerol | ---                | ---               | ---               | ---               | ---            | ---             | 0.2             | ---             | ---             | ---             | ---             |
| 1583       | 1570     | Dendrolasin | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1583       | 1585     | epi-Globulol | ---                | ---               | ---               | ---               | ---            | ---             | 0.2             | ---             | ---             | ---             | ---             |
| 1587       | 1590     | Globulol   | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1590       | 1581     | Clovenol   | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1592       | 1594     | Salvial-4(14)en-1-one | ---             | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1593       | 1592     | Viridiflorol | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1593       | 1593     | Scapanol 8 | ---                | ---               | 0.3               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1594       | 1600     | Guaiol     | 0.5                | ---               | 0.2               | ---               | 0.1            | 0.2             | 0.3             | ---             | ---             | ---             | ---             |
| 1594       | 1601     | trans-β-Elemene | ---                | ---               | ---               | ---               | 0.1            | 0.2             | 1.2             | ---             | ---             | ---             | ---             |
| 1596       | 1599     | Cubeban-11-ol | ---                 | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1599       | 1592     | Humulene epoxide I | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | 1.2             |
| 1600       | 1609     | Rosifoliol | ---                | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1604       | 1607     | 5,7-di-epi-Eudesmol | ---              | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1604       | 1602     | Ledol     | 0.3                | ---               | 0.3               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1613       | 1618     | 1,10-di-epi-Cubenol | ---              | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1616       | 1613     | Humulene epoxide II | ---               | ---               | ---               | ---               | 0.2            | ---             | ---             | ---             | ---             | ---             | ---             |
| 1616       | 1611     | Zingiberenol | ---               | ---               | ---               | ---               | 7.2            | 0.2             | ---             | ---             | ---             | ---             | ---             |
| 1618       | 1623     | Humulane-1,6-dien-3-ol | ---               | ---               | ---               | ---               | ---            | ---             | ---             | ---             | ---             | ---             | ---             |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds | Z. cornubracteatum (Pu Hoà) Leaf | Z. cornubracteatum (Pu Hoà) Rhizome | Z. cornubracteatum (Pu Mát) Leaf | Z. cornubracteatum (Pu Mát) Rhizome | Z. Cornubracteatum (Ben En) leaf | Z. Cornubracteatum (Ben En) Rhizome | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|-------|-------|-----------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------|-----------------|-----------------|-------------|-------------|-------------|-------------|-------------|
| 1620  | 1622  | 1622  | 10-epi-γ-Eudesmol | --- | --- | 0.3 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1625  | 1631  | 1625  | 1-epi-Cubenol | --- | --- | 0.2 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1627  | 1618  | 1627  | epi-Cedrol | --- | --- | 0.4 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1628  | 1628  | 1628  | Alismol | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1630  | 1630  | 1630  | γ-Eudesmol | --- | 0.2 | --- | --- | --- | --- | --- | --- | --- | --- | 0.2 |
| 1632  | 1631  | 1632  | Caryophylla-4(12),8(13)-dien-5x-ol | --- | --- | --- | --- | 3.3 | 0.2 | --- | --- | --- | --- | --- |
| 1640  | 1638  | 1640  | α-Acorenol | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1642  | 1644  | 1642  | Caryophylla-4(12),8(13)-dien-5β-ol | 0.9 | --- | 0.2 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1644  | 1643  | 1644  | Caryophylla-4(12),8(13)-dien-5β-ol | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1651  | 1649  | 1651  | τ-Cadinol | --- | 0.3 | --- | --- | --- | --- | --- | --- | --- | --- | 0.3 |
| 1652  | 1652  | 1652  | 1,2-Diacetoxy-4-allylbenzene | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1653  | 1652  | 1653  | α-Eudesmol | 0.5 | --- | 1.0 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1654  | 1652  | 1654  | α-Eudesmol | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 1655  | 1658  | 1655  | α-Eudesmol | --- | --- | 0.2 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1656  | 1658  | 1656  | α-Eudesmol | --- | --- | 0.3 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1657  | 1658  | 1657  | α-Eudesmol | --- | --- | 0.5 | --- | --- | --- | --- | --- | --- | --- | --- |
| 1662  | 1658  | 1662  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1668  | 1668  | 1668  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1670  | 1670  | 1670  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1671  | 1676  | 1671  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1679  | 1681  | 1679  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1681  | 1685  | 1681  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1684  | 1685  | 1684  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
| 1685  | 1685  | 1685  | neo-Intermedeol | 0.5 | --- | 1.0 | 0.1 | --- | --- | 0.4 | 0.3 | --- | --- | --- |
Table 2. Cont.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds | Z. cornubracteatum (Pu Hoà) Leaf | Z. cornubracteatum (Pu Hoà) Rhizome | Z. cornubracteatum (Pu Má) Leaf | Z. cornubracteatum (Pu Má) Rhizome | Z. cornubracteatum (Ben En) leaf | Z. cornubracteatum (Ben En) Stem | Z. Cornubracteatum Rhizome | Z. neotruncatum Rhizome | Z. nitens Leaf | Z. nitens Rhizome | Z. ottensii Leaf | Z. ottensii Rhizome |
|------------------|----------------|-----------|----------------------------------|-------------------------------------|---------------------------------|----------------------------------|-------------------------------|-------------------------------|-------------------|-----------------|----------------|----------------|----------------|----------------|----------------|
| 1684             | 1683           | epi-α-Bisabolol | ---                               | ---                                 | ---                             | 0.1                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1690             | 1693           | Germacrone     | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1691             | 1694           | Germacr-4(15),5,10(14)-trien-1β-ol | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1696             | 1689           | 6α-Hydroxygermacra-1(10),4-diene | ---                               | ---                                 | ---                             | ---                              | ---                           | 0.7                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1701             | 1698           | (Z,6Z)-Farnesol | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1702             | 1690           | (Z)-trans-α-Bergamotol | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1707             | 1714           | Nootkatol      | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1713             | 1713           | Pentadecanal   | 0.2                               | ---                                 | ---                             | ---                              | ---                           | 0.2                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1738             | 1740           | Mint sulfide   | 1.5                               | ---                                 | 1.9                             | ---                              | 0.1                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1739             | 1732           | Zerumbone      | ---                               | ---                                 | ---                             | ---                              | ---                           | 12.5                          | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1761             | 1759           | Benzyl benzoate | ---                               | ---                                 | ---                             | ---                              | ---                           | 0.3                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1774             | 1760           | (Z)-Lanceol    | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | 0.3               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1799             | 1809           | Ambrial        | 0.1                               | ---                                 | 0.9                             | ---                              | 3.6                           | ---                           | 0.3               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1838             | 1838           | Phytone        | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1848             | 1845           | 6,10,14-Trimethylpentadecan-2-one | 1.1                               | ---                                 | 0.1                             | ---                              | 0.2                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 1862             | 1864           | Benzyl salicylate | ---                               | ---                                 | ---                             | ---                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 2002             | ---            | (E)-15,16-Bisnorlabda-8(17),11-dien-13-one | ---                               | ---                                 | ---                             | 0.3                              | ---                           | ---                           | ---               | ---             | ---             | ---             | ---             | ---             | ---             |
| 2104             | 2105           | (E)-Phytol     | ---                               | ---                                 | 0.3                             | ---                              | 0.3                           | ---                           | ---               | 0.2             | ---             | ---             | ---             | ---             | ---             |

|                  |                | Monoterpe hydrocarbons | 30.2 | 35.1 | 29.1 | 49.3 | 81.9 | 81.2 | 77.8 | 7.3 | 23.0 | 75.3 | 25.3 | 54.1 |
|                  |                | Oxygenated monoterpenoids | 1.9  | 51.4 | 0.0  | 30.8 | 0.5  | 0.5  | 7.3  | 7.3 | 4.0  | 18.8 | 0.4  | 18.8 |
|                  |                | Sesquiterpe hydrocarbons | 24.0 | 0.4  | 57.2 | 4.0  | 11.8 | 13.7 | 2.9  | 14.0 | 3.6  | 40.4 | 3.1  | 60.5 |
|                  |                | Oxygenated sesquiterpenoids | 31.2 | 0.0  | 9.9  | 10.1 | 3.1  | 1.9  | 16.1 | 1.1 | 29.0 | 1.8  | 2.6  | 15.9 |
|                  |                | Others | 2.9  | 0.0  | 2.3  | 1.9  | 0.4  | 0.9  | 4.0  | 0.5  | 0.0  | 0.0  | 1.0  | 0.1  |
|                  |                | Total identified | 90.2 | 86.9 | 98.5 | 96.1 | 95.7 | 98.2 | 95.1 | 97.2 | 92.8 | 99.0 | 89.4 | 99.7 |
| RI\_calc | RI\_db | Compounds          | Z. nudicarpum (Pu Hoat) leaf | Z. nudicarpum (Pu Hoat) stem | Z. nudicarpum (Nam Động) leaf | Z. nudicarpum (Nam Động) stem | Z. nudicarpum (Bạch Mã) leaf | Z. nudicarpum (Bạch Mã) stem | Z. recurvatum rhizome | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|---------|--------|-------------------|------------------------------|------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------------------------|----------------------|---------------------|------------------------|
| 899     | 894    | 2-Heptanol        | ---                          | ---                          | 0.2                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 921     | 923    | Tricyclene        | ---                          | ---                          | ---                         | tr                          | tr                          | tr                          | ---                    | ---                  | ---                  | ---                    |
| 925     | 927    | α-Thujene         | 0.1                         | 0.1                          | 0.8                         | 0.1                         | tr                          | 0.1                         | 0.3                   | 0.3                  | ---                  | ---                    |
| 934     | 933    | α-Pinene          | 10.9                        | 18.7                         | 5.0                         | 10.6                        | 4.0                         | 6.5                         | 6.1                   | 16.3                 | 1.9                  | 11.3                   |
| 943     | 945    | α-Fenchene        | ---                         | ---                          | 0.1                         | 0.3                         | 0.3                         | 0.5                         | 0.2                   | ---                  | ---                  | ---                    |
| 951     | 953    | Camphene          | 1.6                         | 1.3                          | 0.1                         | 0.3                         | 2.1                         | 0.6                         | 0.8                   | 0.4                  | 1.9                  | 0.2                    |
| 952     | 953    | Thuja-2,4(10)diene | ---                         | ---                          | ---                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 971     | 972    | Sabinene          | ---                         | 1.4                          | 2.3                         | 0.1                         | tr                          | 0.2                         | 0.1                   | 1.2                  | 0.3                  | 1.0                    |
| 978     | 978    | β-Pinene          | 34.0                        | 0.5                          | 58.3                        | 26.6                        | 9.0                         | 9.8                         | 0.7                   | 5.6                  | 71.6                 | 47.3                   |
| 981     | 985    | 6-Methylhept-5-en-2-one | ---                         | ---                          | 0.1                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 988     | 991    | Myrcene           | 0.8                         | 0.9                          | 0.8                         | 0.4                         | 0.6                         | 0.7                         | 1.2                   | 1.0                  | 2.1                  | 0.5                    |
| 998     | 998    | Dehydro-1,8-cineole | ---                         | ---                          | 0.1                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 998     | 998    | 2-Pentylfuran     | ---                         | ---                          | ---                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 1002    | 1002   | Octanal           | ---                         | ---                          | ---                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 1004    | 1108   | 1,3,8-P Menthatriene | ---                         | ---                          | ---                         | ---                         | ---                         | ---                         | ---                    | ---                  | ---                  | ---                    |
| 1006    | 1007   | α-Phellandrene    | ---                         | ---                          | 0.1                         | 0.2                         | 0.9                         | 0.6                         | 0.2                   | 0.6                  | ---                  | ---                    |
| 1008    | 1009   | δ-3 Carene        | ---                         | 0.2                          | ---                         | 0.2                         | 3.1                         | 3.7                         | 1.8                   | 1.5                  | ---                  | ---                    |
| 1016    | 1018   | α-Terpinene       | 0.1                         | ---                          | 0.2                         | tr                          | tr                          | 0.1                         | ---                    | ---                  | 0.1                  | ---                    |
| 1018    | 1022   | m-Cymene          | ---                         | ---                          | ---                         | tr                          | ---                         | ---                         | tr                     | ---                  | ---                  | ---                    |
| 1023    | 1025   | p-Cymene          | 0.2                         | 0.4                          | 0.4                         | 6.0                         | 0.9                         | 0.2                         | 0.1                   | 0.6                  | ---                  | ---                    |
| 1034    | 1028   | Limonene          | 1.5                         | 1.8                          | 2.0                         | 2.1                         | 1.8                         | 1.7                         | 6.0                   | 1.8                  | 2.4                  | 0.9                    |
| 1035    | 1031   | β-Phellandrene    | 0.2                         | 0.4                          | 0.2                         | ---                         | 0.7                         | 0.3                         | 0.3                   | 0.3                  | 0.6                  | 0.3                    |
| 1035    | 1030   | 1,8-Cineole       | 0.9                         | 0.3                          | 0.9                         | 21.2                        | 6.8                         | tr                          | ---                    | 0.6                  | ---                  | ---                    |
| 1036    | 1034   | (Z)-β-Ocimene     | ---                         | ---                          | ---                         | 0.1                         | 0.2                         | 0.2                         | ---                    | ---                  | ---                  | ---                    |
| 1046    | 1045   | (E)-β-Ocimene     | ---                         | 0.7                          | tr                          | 0.1                         | ---                         | 0.1                         | 0.2                   | 0.6                  | 0.4                  | ---                    |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds | *Z. nudiarcum* (Pu Hoà) leaf | *Z. nudiarcum* (Pu Hoà) stem | *Z. nudiarcum* (Nam Đòng) leaf | *Z. nudiarcum* (Nam Đòng) stem | *Z. nudiarcum* (Bạch Mã) leaf | *Z. nudiarcum* (Bạch Mã) stem | *Z. recurvatum* leaf | *Z. recurvatum* rhizome | *Z. vuquangensis* leaf | *Z. vuquangensis* stem | *Z. vuquangensis* rhizome |
|-------|-------|----------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| 1057  | 1057  | γ-Terpinene | 0.5                         | ---                         | 0.3                         | 0.8                         | 0.1                         | 0.4                         | 0.1                         | 0.1                         | 0.6                         | ---                         | ---                         | 0.4                         |
| 1067  | 1063  | 1-Octanol   | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1068  | 1067  | *cis*-Linalool oxide (furanoid) | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1072  | 1065  | *cis*-Sabinine hydrate | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1084  | 1086  | Terpinolene | 0.1                         | ---                         | 0.3                         | 0.2                         | 0.1                         | 0.3                         | 0.1                         | 0.1                         | 0.4                         | ---                         | ---                         | 0.4                         |
| 1084  | 1084  | *trans*-Linalool oxide (furanoid) | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1087  | 1083  | Fenchone    | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1088  | 1089  | *p*-Cymenene | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1099  | 1102  | Perillene   | ---                         | ---                         | ---                         | ---                         | 0.1                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1099  | 1097  | 2-Nonanol   | ---                         | ---                         | ---                         | ---                         | 0.1                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1100  | 1101  | Linalool    | 2.4                         | 11.0                        | 0.5                         | 0.6                         | 0.3                         | 0.5                         | 0.7                         | 1.0                         | ---                         | 3.7                         | ---                         | ---                         |
| 1100  | 1104  | Rosefuran   | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1104  | 1098  | *trans*-Sabinine hydrate | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1105  | 1107  | Nonanal     | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1112  | 1116  | *(E)-4,8-Dimethylnona-1,3,7-triene* | 0.1                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1118  | 1114  | *endo*-Fenchol | ---                         | ---                         | ---                         | ---                         | ---                         | 0.1                         | 0.7                         | ---                         | ---                         | ---                         | 0.2                         | ---                         | ---                         |
| 1118  | 1118  | *cis*-p-Menth-2-en-1-ol | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1120  | 1128  | *allo*-Ocimene | 0.3                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1124  | 1118  | *exo*-Fenchol | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1128  | 1122  | α-Campholenal | ---                         | ---                         | ---                         | ---                         | ---                         | 0.2                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1135  | 1136  | *trans*-p-Menth-2-en-1-ol | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1137  | 1135  | Nopinone    | ---                         | ---                         | ---                         | ---                         | 0.1                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1141  | 1135  | *trans*-Pinocarveol | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1144  | 1140  | *trans*-Verbenol | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         | ---                         |
| 1146  | 1149  | Camphor     | ---                         | ---                         | ---                         | ---                         | 0.1                         | 0.3                         | 0.1                         | 0.1                         | 0.6                         | ---                         | ---                         | ---                         | ---                         |
| \( R_I \)_{calc} | \( R_I \)_{db} | Compounds                  | \( Z. \) nudicarpum (Pu Hoâ€™t) leaf | \( Z. \) nudicarpum (Pu Hoâ€™t) stem | \( Z. \) nudicarpum (Nam Dong) leaf | \( Z. \) nudicarpum (Nam Dong) stem | \( Z. \) recurvatum (Nam Dong) rhizome | \( Z. \) recurvatum rhizome | \( Z. \) vuquangensis leaf | \( Z. \) vuquangensis stem | \( Z. \) vuquangensis rhizome |
|-------|-------|-----------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1148  | 1165  | Lvandulol       | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1159  | 1167  | Benzyl acetate  | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1162  | 1160  | Pinocarvone     | ---                             | ---                             | 0.2                             | tr                              | 1.5                             | 0.2                             | ---                             | ---                             | ---                             |
| 1167  | 1165  | iso-Neral       | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1169  | 1162  | \( \delta \)Terpineol | ---                             | ---                             | 0.1                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1170  | 1166  | \( p \)-Mentha-1,5-dien-8-ol | ---                             | ---                             | 0.6                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1171  | 1165  | Borneol         | 0.2                             | 0.6                             | ---                             | tr                              | 0.2                             | 4.0                             | ---                             | ---                             | ---                             |
| 1180  | 1180  | Terpinen-4-ol   | ---                             | 0.2                             | ---                             | 0.1                             | 0.4                             | 0.4                             | 0.1                             | 0.1                             | 0.1                             |
| 1185  | 1179  | \( p \)-Cymen-8-ol | ---                             | ---                             | tr                              | 0.3                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1185  | 1185  | iso-Geranial    | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1194  | 1195  | \( \alpha \)-Terpineol | ---                             | 0.2                             | ---                             | 0.1                             | 0.1                             | ---                             | 1.6                             | ---                             | ---                             |
| 1194  | 1195  | Myrtenol        | 0.2                             | 0.3                             | 0.1                             | 2.6                             | ---                             | ---                             | ---                             | 0.1                             | 0.2                             |
| 1194  | 1194  | (4Z)- Decenal   | ---                             | ---                             | 0.1                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1198  | 1195  | Myrtenol        | ---                             | ---                             | ---                             | 0.9                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1202  | 1204  | cis-Piperitol   | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1206  | 1204  | Verbenone       | ---                             | ---                             | ---                             | 0.3                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1206  | 1206  | Decanal         | ---                             | ---                             | 0.1                             | ---                             | ---                             | ---                             | 0.1                             | ---                             | 0.2                             |
| 1209  | 1207  | trans-Piperitol | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1216  | 1218  | \( endo \)-Fenchyl acetate | ---                             | ---                             | 0.1                             | tr                              | 0.5                             | 6.5                             | ---                             | ---                             | 0.2                             |
| 1217  | 1215  | trans-Carveol   | ---                             | ---                             | ---                             | 0.2                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1220  | 1217  | \( \beta \)-Cyclocitral | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1222  | 1227  | Nerol           | ---                             | ---                             | 0.1                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1224  | 1223  | Citronellol     | ---                             | ---                             | ---                             | 0.3                             | ---                             | 0.4                             | ---                             | ---                             | ---                             |
| 1227  | 1232  | Thymyl methyl ether | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| 1236  | 1235  | Neral           | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             | ---                             |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                              | Z. nucicarpum (Pu Hoat) leaf | Z. nucicarpum (Pu Hoat) stem | Z. nucicarpum (Nam Dong) leaf | Z. nucicarpum (Nam Dong) stem | Z. nucicarpum (Bach Ma) leaf | Z. recurvatum rhizome | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|---------------|---------------|----------------------------------------|------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|------------------------|---------------------|---------------------|---------------------|
| 1241          | 1238          | Cuminal                                | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1242          | 1239          | Carvone                                | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1248          | 1249          | Geraniol                               | ---                          | ---                         | 0.2                         | ---                         | ---                         | ---                     | 0.3                  | ---                  | ---                  |
| 1265          | 1264          | Geranial                               | ---                          | ---                         | 0.2                         | tr                          | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1271          | 1266          | 1-Decanol                              | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1281          | 1287          | iso-Bornyl acetate                     | ---                          | ---                         | ---                         | tr                          | ---                         | ---                     | 0.2                  | ---                  | ---                  |
| 1284          | 1285          | Bornyl acetate                         | ---                          | 0.3                         | ---                         | 0.4                         | 1.2                         | 0.2                    | 1.1                  | ---                  | 10.4                |
| 1285          | 1291          | Safrrole                               | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1293          | 1290          | Dihydroedulan IIA                      | ---                          | ---                         | 1.1                         | ---                         | ---                         | ---                     | 2.6                  | 0.8                 | 0.1                 |
| 1295          | 1298          | Carvacrol                              | ---                          | ---                         | 0.3                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1295          | 1293          | Methyl myrtenate                        | ---                          | ---                         | 0.1                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1307          | 1295          | trans-Sabinyl acetate                  | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1330          | 1324          | Methyl geranate                         | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1330          | 1332          | Bicycloelemene                          | ---                          | ---                         | 0.2                         | ---                         | 1.1                         | 0.5                    | ---                  | ---                  | ---                  |
| 1330          | 1335          | δ-Elemene                              | 0.2                          | 1.1                         | ---                         | ---                         | 0.9                         | 0.4                    | ---                  | ---                  | 2.6                 |
| 1333          | 1325          | Myrtenyl acetate                       | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1342          | 1349          | α-Cubebene                             | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | 0.7                  | 0.4                 | ---                  |
| 1345          | 1346          | α-Terpinyl acetate                     | ---                          | ---                         | 0.1                         | ---                         | 1.3                         | ---                     | ---                  | ---                  | ---                  |
| 1364          | 1367          | Cyclosativene                          | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1364          | 1372          | iso-Ledene                             | ---                          | ---                         | tr                          | 0.2                         | 0.1                         | ---                     | ---                  | ---                  | ---                  |
| 1368          | 1373          | α-Ylangene                             | ---                          | ---                         | tr                           | 0.2                         | 0.1                         | ---                     | ---                  | ---                  | ---                  |
| 1374          | 1375          | α-Copaene                              | ---                          | 0.1                         | ---                         | 3.1                         | 0.7                         | 3.2                    | 1.5                  | ---                  | 0.2                 |
| 1375          | 1380          | Geranyl acetate                        | ---                          | ---                         | 0.2                         | ---                         | 0.2                         | ---                     | 0.5                  | ---                  | ---                  |
| 1377          | 1383          | cis-β-Elemene                          | ---                          | ---                         | 0.2                         | 0.2                         | ---                         | ---                     | ---                  | ---                  | ---                  |
| 1377          | 1365          | Eugenol                                | ---                          | ---                         | ---                         | ---                         | ---                         | ---                     | ---                  | ---                  | ---                  |
Table 2. Cont.

| RI_{calc} | RI_{db} | Compounds          | \( Z. \) nudi\_carpum (Pu \_Ho\_t) leaf | \( Z. \) nudi\_carpum (Pu \_Ho\_t) stem | \( Z. \) nudi\_carpum (Nam \_Dong\_t) leaf | \( Z. \) nudi\_carpum (Nam \_Dong\_t) stem | \( Z. \) nudi\_carpum (B\_ach \_Ma\) leaf | \( Z. \) nudi\_carpum (B\_ach \_Ma\) stem | \( Z. \) recur\_trum \_trhizone leaf | \( Z. \) recur\_trum \_trhizone stem | \( Z. \) vuqu\_ang\_ensis leaf | \( Z. \) vuqu\_ang\_ensis stem |
|-----------|---------|--------------------|----------------------------------------|----------------------------------------|----------------------------------|---------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 1382      | 1382    | \( \beta \)-Bourbonene                        | ---                                   | ---                                   | 0.4                              | 0.1                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1386      | 1387    | \( \beta \)-Cubebene                           | ---                                   | ---                                   | 1.7                              | 0.6                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1387      | 1390    | \( trans-\beta \)-Elemene                      | 1.1                                   | 1.1                                   | 0.4                              | 2.3                             | 0.4                  | 0.8                  | 4.7                  | 3.7                  | ---                  | 0.8                  |
| 1400      |         | Methyl eugenol                                 | ---                                   | ---                                   | 0.1                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1402      |         | Sesquithujene                                   | ---                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1403      | 1405    | \( Z \)-Caryophyllene                           | ---                                   | ---                                   | 0.1                              | ---                             | ---                  | 0.1                  | ---                  | 0.3                  | ---                  | ---                  |
| 1405      | 1406    | \( \alpha \)-Gurjunene                          | ---                                   | ---                                   | 0.1                              | ---                             | ---                  | 0.1                  | ---                  | 0.3                  | ---                  | ---                  |
| 1405      | 1407    | \( \beta \)-Maaliene                            | ---                                   | ---                                   | 0.1                              | ---                             | ---                  | 0.1                  | ---                  | 0.3                  | ---                  | ---                  |
| 1405      | 1408    | \( cis-\alpha \)-Bergamotene                    | ---                                   | 0.4                                   | 0.2                              | ---                             | ---                  | 0.1                  | 0.1                  | ---                  | 0.2                  | 0.3                  |
| 1419      | 1417    | \( E \)-Caryophyllene                           | 13.9                                  | 52.6                                  | 1.9                              | 24.3                            | 1.6                  | 4.9                  | 6.4                  | 6.3                  | 1.7                 | 11.3                |
| 1422      | 1423    | \( \gamma \)-Elemene                            | ---                                   | ---                                   | 0.3                              | 0.7                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1426      | 1427    | \( 2,5 \)-Dimethoxy-\( p \)-cymene              | 0.1                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1428      | 1429    | \( \beta \)-Copaene                             | ---                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1429      | 1430    | \( \alpha \)-Maaliene                           | ---                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1430      | 1431    | \( \alpha \)-Santalene                          | ---                                   | 0.1                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1431      | 1432    | \( trans-\alpha \)-Bergamotene                  | 0.2                                   | 0.1                                   | ---                              | ---                             | 0.3                  | 0.1                  | ---                  | ---                  | ---                  | ---                  |
| 1433      | 1434    | \( \alpha \)-Guaiane                            | ---                                   | ---                                   | ---                              | 0.2                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1437      | 1439    | Aromadendrene                                   | 0.2                                   | 0.2                                   | 0.1                              | ---                             | 0.6                  | 0.5                  | ---                  | 0.2                  | 0.4                  | 0.4                  |
| 1440      | 1441    | \( Z \)-\( \beta \)-Farnesene                  | 0.2                                   | 0.2                                   | ---                              | ---                             | ---                  | ---                  | ---                  | 1.1                 | ---                  | 0.5                  |
| 1444      | 1445    | \( \beta \)-Gurjunene                           | ---                                   | 0.1                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | 0.9                 | 0.2                  |
| 1444      | 1446    | Myltayl-\( 4 \)-(12)-ene                        | ---                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1446      | 1447    | Geranyl acetone                                 | ---                                   | 0.3                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| 1447      | 1448    | \( trans \)-Muurola-3,5-diene                   | ---                                   | ---                                   | ---                              | 0.1                             | 0.4                  | 0.2                  | 0.1                  | ---                  | ---                  | ---                  |
| 1450      | 1451    | \( E \)-\( \beta \)-Farnesene                  | ---                                   | 0.3                                   | 0.2                              | ---                             | 0.1                  | 0.3                  | 0.2                  | ---                  | ---                  | ---                  |
| 1451      | 1452    | Prezizaene                                      | ---                                   | ---                                   | ---                              | ---                             | ---                  | 0.4                  | ---                  | ---                  | ---                  | ---                  |
| 1454      | 1455    | \( \alpha \)-Humulene                            | 2.1                                   | 5.9                                   | 0.3                              | 3.2                             | 1.1                  | 4.8                  | 6.4                  | 8.8                  | 0.2                 | 6.9                  |
| 1455      | 1456    | \( Z \)-\( \alpha \)-Humulene                  | ---                                   | ---                                   | ---                              | ---                             | ---                  | ---                  | ---                  | ---                  | ---                  | ---                  |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                  | Z. n. (Pu Hoat) leaf | Z. n. (Pu Hoat) stem | Z. n. (Nam Dong) leaf | Z. n. (Nam Dong) stem | Z. n. (Bach Ma) leaf | Z. n. (Bach Ma) stem | Z. recurvatum rhizome | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|-----------------|----------------|---------------------------|----------------------|----------------------|-----------------------|-----------------------|---------------------|---------------------|-----------------------|---------------------|---------------------|-----------------------|
| 1458            | 1457           | allo-Aromadendrene        | ---                  | ---                  | 0.9                   | 0.7                   | 0.3                 | 1.9                 | 0.1                   | ---                 | ---                 | ---                   |
| 1460            | 1461           | cis-Cadina-1(6),4-diene   | ---                  | ---                  | ---                   | ---                   | ---                 | 0.4                 | 0.2                   | ---                 | ---                 | ---                   |
| 1470            | 1472           | trans-Cadina-1(6),4-diene | ---                  | ---                  | 0.1                   | 0.1                   | ---                 | ---                 | ---                   | ---                 | ---                 | ---                   |
| 1471            | 1476           | β-Chamigrene              | ---                  | ---                  | 0.1                   | ---                   | ---                 | ---                 | ---                   | 0.6                 | 2.6                 | 0.7                   |
| 1471            | 1475           | γ-Gurjunene               | ---                  | ---                  | ---                   | ---                   | ---                 | ---                 | ---                   | 1.5                 | ---                 | ---                   |
| 1471            | 1472           | β-Curcumene               | ---                  | ---                  | ---                   | ---                   | ---                 | ---                 | ---                   | 1.4                 | 2.8                 | 0.8                   |
| 1471            | 1474           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1475           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1476           | Selina-4,11-diene         | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1477           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1478           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1479           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1480           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1481           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1482           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1483           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1484           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1485           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1486           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1487           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1488           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1489           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1490           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1491           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1492           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1493           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1494           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1495           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1496           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
| 1471            | 1497           | γ-Murolene                | 0.2                  | 0.3                  | 0.3                   | 0.3                   | 0.3                 | 0.4                 | 0.4                   | ---                 | ---                 | ---                   |
Table 2. Cont.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds            | Z. modestum (Pu Hoat) leaf | Z. modestum (Pu Hoat) stem | Z. modestum (Nam Dong) leaf | Z. modestum (Nam Dong) stem | Z. modestum (Bach Ma) leaf | Z. modestum (Bach Ma) stem | Z. recurvatum rhizome | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|-----------------|---------------|----------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------|-----------------------|
| 1497            | 1502          | trans-β-Guaiene      | ---                        | ---                        | ---                        | ---                        | ---                        | ---                        | ---                  | ---                  | ---                  | ---                   |
| 1500            | 1500          | n-Pentadecane        | ---                        | ---                        | ---                        | ---                        | ---                        | ---                        | ---                  | ---                  | ---                  | ---                   |
| 1501            | 1505          | (E,E)-α-Farnesene    | 1.6                        | 0.7                        | 0.4                        | 0.3                        | 0.3                        | 0.1                        | 0.5                  | 1.0                  | 0.4                  | ---                   |
| 1502            | 1495          | γ-Amorphene          | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1503            | 1509          | β-Curcumene          | 0.1                        | 0.2                        | 0.4                        | 0.6                        | 0.7                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1506            | 1508          | β-Bisabolene         | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1511            | 1512          | γ-Cadinene           | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1511            | 1511          | δ-Amorphene          | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1513            | 1519          | Cubebol              | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1516            | 1518          | δ-Cadinene           | 0.6                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1517            | 1520          | 7-epi-α-Selinene     | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1517            | 1521          | Zonarene             | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1519            | 1521          | trans-Calamenene     | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1520            | 1528          | (E)-γ-Bisabolene     | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1523            | 1521          | Eugenyl acetate      | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1524            | 1521          | β-Sesquiphellandrene | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1529            | 1528          | cis-Calamene         | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1530            | 1536          | trans-Cadin-1,4-diene | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1535            | 1537          | α-Cadinene           | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1539            | 1544          | α-Calacorene         | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1546            | 1549          | α-Elemol             | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1557            | 1559          | Germacrene B         | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1558            | 1561          | (E)-Nerolidol        | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| 1560            | 1564          | β-Calacorene         | 0.1                        | 0.2                        | 0.4                        | 0.1                        | 0.6                        | 0.2                        | 1.4                  | 2.0                  | 0.4                  | ---                   |
| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                                      | Z. nudicarpum (Phu Hoat) leaf | Z. nudicarpum (Phu Hoat) stem | Z. nudicarpum (Nam Dong) leaf | Z. nudicarpum (Nam Dong) stem | Z. nudicarpum (Bach Ma) leaf | Z. recurvatum rhizome | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|------|------|---------------------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|--------------------------|---------------------|---------------------|---------------------|---------------------|
| 1564 | 1568 | Palustrol                                    | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1568 | 1571 | Maaliol                                      | ---                          | ---                          | ---                          | 0.2                          | tr                           | 0.1                      | ---                  | ---                  | ---                  | ---                  |
| 1570 | 1573 | (3E,7E)-4,8,12-Trimethyltrideca-1,3,7,11-tetraene | ---                          | ---                          | ---                          | 0.1                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1575 | 1576 | Spathulenol                                  | 0.9                          | 0.7                          | 0.1                          | 2.1                          | tr                           | 0.2                      | 1.2                  | 0.9                  | 0.2                  | 1.3                  |
| 1575 | 1582 | Neryl isovalerate                            | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1575 | 1574 | Germacrene D-4-ol                            | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1582 | 1577 | Caryophyllene oxide                          | 1.3                          | 4.4                          | 0.4                          | 3.6                          | 8.0                          | 2.4                      | tr                   | 0.3                  | 0.2                  | 4.1                  | 2.0                  | 4.5                  | 1.6                  |
| 1582 | 1582 | ar-Turmerol                                  | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1583 | 1570 | Dendrolasin                                  | 0.2                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1583 | 1585 | epi-Globulol                                 | ---                          | ---                          | ---                          | 0.8                          | tr                           | 0.9                      | ---                  | ---                  | ---                  | ---                  |
| 1587 | 1590 | Globulol                                     | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1590 | 1581 | Clovenol                                     | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1592 | 1594 | Salvial-4(14)en-1-one                        | ---                          | ---                          | ---                          | 0.1                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1593 | 1592 | Viridiflorol                                 | ---                          | ---                          | ---                          | 0.2                          | ---                          | 0.5                      | 0.7                  | 1.2                  | ---                  | ---                  |
| 1593 | 1593 | Scapanol 8                                   | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1594 | 1600 | Guaiol                                       | 0.4                          | 0.6                          | 0.1                          | ---                          | 0.2                          | 0.5                      | ---                  | 0.2                  | ---                  | ---                  | 0.7                  |
| 1594 | 1601 | trans-β-Elemenone                            | ---                          | ---                          | ---                          | ---                          | tr                           | 0.4                      | ---                  | ---                  | ---                  | ---                  |
| 1596 | 1599 | Cubeban-11-ol                                | ---                          | ---                          | ---                          | 0.1                          | ---                          | ---                      | ---                  | ---                  | ---                  | 0.3                  |
| 1599 | 1592 | Humulene epoxide I                           | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | 0.4                  | 0.9                  |
| 1600 | 1609 | Rosifoliol                                   | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1604 | 1607 | 5,7-di-epi-Eudesmol                          | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | 0.2                  | 0.4                  | ---                  | ---                  |
| 1604 | 1602 | Ledol                                        | ---                          | ---                          | ---                          | ---                          | ---                          | ---                      | ---                  | ---                  | 0.2                  | ---                  |
| 1613 | 1618 | 1,10-di-epi-Cubenol                          | ---                          | ---                          | ---                          | 0.2                          | 0.7                          | ---                      | ---                  | ---                  | ---                  | ---                  |
| 1616 | 1613 | Humulene epoxide II                          | 0.2                          | 0.8                          | ---                          | 0.4                          | 1.8                          | 1.3                      | tr                   | 0.2                  | 2.8                  | ---                  | 0.6                  | 0.6                  |
Table 2. Cont.

| RI<sub>calc</sub> | RI<sub>db</sub> | Compounds                      | Z. nudicarpum (Pu Hoà) leaf | Z. nudicarpum (Pu Hoà) stem | Z. nudicarpum (Nam Đông) leaf | Z. nudicarpum (Nam Đông) stem | Z. nudicarpum (Bạch Ma) leaf | Z. recurvatum rhizome | Z. recurvatum leaf | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|------------------|----------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------------|----------------------|-----------------------|-----------------------|------------------------|
| 1616             | 1611           | Zingiberenol                  | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | 0.3                  | ---                   | ---                   | ---                    |
| 1618             | 1623           | Humulane-1,6-dien-3-ol        | ---                          | ---                          | ---                          | ---                          | ---                          | 8.2                    | 9.9                  | ---                   | ---                   | ---                    |
| 1620             | 1622           | 10-epi-γ-Eudesmol             | ---                          | ---                          | ---                          | ---                          | tr                           | 0.4                    | ---                   | 2.9                   | ---                   | ---                    |
| 1625             | 1631           | 1-epi-Cubenol                 | 0.2                          | 0.3                          | ---                          | 0.2                          | 0.3                          | 1.3                    | ---                   | ---                   | ---                   | ---                    |
| 1627             | 1618           | epi-Cedrol                    | ---                          | ---                          | 0.2                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1628             | 1622           | Alismol                       | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1630             | 1630           | γ-Eudesmol                    | ---                          | ---                          | ---                          | 0.3                          | 1.7                          | 0.5                    | 0.7                  | ---                   | ---                   | ---                    |
| 1632             | 1631           | Caryophylla-4(12),8(13)-dien-5x-ol | ---                          | ---                          | 0.7                          | 0.1                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1634             | 1632           | α-Acorenol                    | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1636             | 1639           | Caryophylla-4(12),8(13)-dien-5β-ol | ---                          | ---                          | 0.9                          | 0.3                          | 0.4                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1640             | 1638           | τ-Cadinol                     | 0.9                          | 2.2                          | 0.1                          | 0.3                          | ---                          | ---                    | ---                   | ---                   | ---                   | 1.7                    |
| 1640             | 1643           | Cubenol                       | ---                          | ---                          | 0.1                          | 0.3                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1642             | 1644           | τ-Murrolo                     | ---                          | ---                          | 0.2                          | 0.1                          | 0.4                          | ---                    | ---                   | 0.2                   | 0.6                   | ---                    |
| 1645             | 1644           | α-Mururolo (= α-Cadinol)      | 0.2                          | ---                          | 0.1                          | tr                           | 0.1                          | 0.2                    | 0.7                  | ---                   | ---                   | ---                    |
| 1651             | 1649           | β-Eudesmol                    | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1652             | 1652           | α-Cadinol                     | 0.5                          | 0.5                          | 0.7                          | tr                           | 1.3                          | 1.0                    | 1.7                  | 0.3                   | 0.2                   | 2.0                    |
| 1652             | 1647           | 1,2-Diacetoxy-4-allylbenzene  | 0.1                          | 1.9                          | ---                          | ---                          | ---                          | ---                    | ---                   | 1.0                   | ---                   | ---                    |
| 1653             | 1652           | α-Eudesmol                    | ---                          | ---                          | 0.6                          | 1.1                          | ---                          | ---                    | ---                   | ---                   | 1.0                   | ---                    |
| 1657             | 1658           | Selin-11-en-4x-ol             | ---                          | ---                          | 0.2                          | tr                           | 0.5                          | ---                    | ---                   | ---                   | 0.2                   | 2.6                    |
| 1662             | 1658           | neo-Intermedeol               | 0.7                          | 1.2                          | 0.2                          | 0.5                          | 4.4                          | 0.2                    | 0.6                  | 0.2                   | 0.4                   | 2.6                    |
| 1668             | 1668           | 14-Hydroxy-9-epi-(E)-caryophyllene | ---                          | 0.6                          | 0.6                          | 0.3                          | 0.5                          | ---                    | ---                   | 0.4                   | 0.2                   | 1.0                    |
| 1670             | 1675           | Cadalene                      | ---                          | ---                          | ---                          | ---                          | 0.1                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1671             | 1676           | Mustakone                     | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
| 1679             | 1681           | γ-Bicyclofarnesal             | 0.9                          | 0.6                          | ---                          | ---                          | ---                          | ---                    | 1.2                   | ---                   | 0.6                   | 0.4                    |
| 1681             | 1685           | α-Bisabolol                   | ---                          | ---                          | ---                          | ---                          | ---                          | ---                    | ---                   | ---                   | ---                   | ---                    |
Table 2. Cont.

| RI_{calc} | RI_{db} | Compounds                                      | Z. multicarpum (Pù Hoàt) leaf | Z. multicarpum (Pù Hoàt) stem | Z. multicarpum (Nam Đông) leaf | Z. multicarpum (Nam Đông) stem | Z. multicarpum (Bạch Ma) leaf | Z. multicarpum (Bạch Ma) stem | Z. recurvatum | Z. vuquangensis leaf | Z. vuquangensis stem | Z. vuquangensis rhizome |
|---------|---------|------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|---------------|------------------|------------------|---------------------|
| 1684    | 1685    | Germacra-4(15),5,10(14)-trien-1α-ol             | ---                           | ---                           | 0.1                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1684    | 1685    | epi-α-Bisabolol                                 | ---                           | ---                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1690    | 1693    | Germacrone                                      | ---                           | ---                           | 0.2                           | 1.6                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1691    | 1694    | Germacra-4(15),5,10(14)-trien-1β-ol             | ---                           | ---                           | 0.1                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1696    | 1689    | 6α-Hydroxygermacra-1(10),4-diene                | ---                           | ---                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1701    | 1698    | (Z,Z,6Z)-Farnesol                               | ---                           | ---                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1702    | 1690    | (Z)-trans-α-Bergamotol                          | ---                           | 0.3                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1707    | 1714    | Nootkatol                                       | ---                           | ---                           | 0.1                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1713    | 1713    | Pentadecanal                                    | ---                           | ---                           | 0.1                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1738    | 1740    | Mint sulfide                                    | ---                           | ---                           | 0.1                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1739    | 1732    | Zerumbone                                       | ---                           | ---                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | ---              | ---                  |
| 1761    | 1759    | Benzyl benzoate                                 | ---                           | ---                           | 0.2                           | ---                           | 2.5                           | 3.0                           | ---            | 0.3              | ---              | 0.9                  |
| 1774    | 1760    | (Z)-Lanceol                                     | ---                           | ---                           | 0.1                           | ---                           | 0.2                           | 3.9                           | ---            | ---              | ---              | ---                  |
| 1799    | 1809    | Ambsial                                         | ---                           | ---                           | 0.2                           | ---                           | 0.5                           | ---                           | ---            | 0.3              | ---              | 0.9                  |
| 1838    | 1838    | Phytone                                         | ---                           | ---                           | 0.7                           | ---                           | ---                           | ---                           | ---            | 0.2              | ---              | 0.2                  |
| 1848    | 1845    | 6,10,14-Trimethylpentadecan-2-one               | ---                           | ---                           | ---                           | ---                           | 0.5                           | 0.8                           | ---            | ---              | 0.3              | ---                  |
| 1862    | 1864    | Benzyl salicylate                               | ---                           | ---                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | 0.3              | ---                  |
| 2002    | ---     | (E)-15,16-Bisnorlabda-8(17),11-dien-13-one      | ---                           | 0.8                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | 0.3              | ---                  |
| 2104    | 2105    | (E)-Phytol                                      | ---                           | 0.2                           | ---                           | ---                           | ---                           | ---                           | ---            | ---              | 0.2              | 0.6                  |
|         |         | Monoterpenes hydrocarbons                       | 50.3                          | 0.5                           | 84.8                          | 39.4                          | 29.6                          | 23.9                          | 16.0           | 23.4             | 94.2             | 18.3                |
|         |         | Oxygenated monoterpenoids                       | 3.8                           | 12.0                          | 1.7                           | 2.0                           | 34.8                          | 25.3                          | 1.1             | 2.9              | 0.1              | 16.2                |
|         |         | Sesquiterpene hydrocarbons                     | 32.9                          | 65.1                          | 4.0                           | 41.4                          | 20.0                          | 28.5                          | 63.3            | 46.6             | 4.7              | 31.0                |
|         |         | Oxygenated sesquiterpenoids                    | 6.6                           | 13.9                          | 1.6                           | 11.6                          | 14.0                          | 21.3                          | 14.8            | 22.2             | 0.9              | 21.6                |
|         |         | Others                                          | 0.2                           | 2.9                           | 0.0                           | 4.0                           | 0.8                           | 0.5                           | 3.1             | 4.1              | 0.2              | 2.3                 |
|         |         | Total identified                                | 93.8                          | 94.4                          | 92.1                          | 98.4                          | 99.2                          | 99.5                          | 98.3            | 99.2             | 100.0            | 89.4                |

RI_{calc} = Retention Indices determined with respect to a homologous series of n-alkanes on an HP-5ms column; RI_{db} = Retention Indices from the databases (NIST 17 and Wiley version 10); tr = trace (< 0.05%).
The rhizome essential oils of *Z. cornubracteatum* were predominantly composed of monoterpenoid hydrocarbons and oxygenated monoterpenoids. The major components were α-pinene (8.2–14.5%), β-pinene (8.8–33.1%), limonene (1.0–5.1%), 1,8-cineole (2.5–10.4%), and linalool (0.4–31.0%). Both α-pinene and β-pinene were major components in the leaf essential oils of *Z. cornubracteatum* (2.7–10.1% and 18.8–67.3%, respectively). However, sesquiterpene hydrocarbons, including (E)-caryophyllene (1.8–13.9%), germacrene D (0.7–13.7%), bicyclogermacrene (2.7–18.9%), as well as the sesquiterpenoid (E)-nerolidol (0.9–23.0%), were also abundant in the leaf essential oils.

The leaf essential oils of *Z. nudicarpum* were also rich in α-pinene (5.0–10.9%), β-pinene (0.7–34.0%), in addition to the sesquiterpene hydrocarbons (E)-caryophyllene (6.4–24.3%), α-humulene (2.1–6.4%), germacrene D (0.6–6.5%), and bicyclogermacrene (3.3–16.1%). The leaf essential oil of *Z. nudicarpum* from Pù Hoạt Nature Reserve previously reported also showed α- and β-pinenes (2.4% and 11.7%, respectively) [34]. Important differences are apparent between the previously reported essential oil and those from the present study. The previous report found no (E)-caryophyllene or germacrene D, but large concentrations of cedrol (14.8%) and β-eudesmol (13.8%), which were not observed in this current study. Interestingly, the stem essential oils of *Z. nudicarpum* showed wide variation in monoterpenoid hydrocarbon concentrations, with the sample from Pù Hoạt Nature Reserve showing only low concentrations of monoterpenoid hydrocarbons compared to samples from Nam Đong or Bạch Mâ National Park. For example, the concentrations were: α-pinene (0.0, 10.6, 6.1%), β-pinene (0.5, 9.0, 5.6%), p-cymene (0.0, 6.0, 0.1%), and limonene (0.0, 2.1, 6.0%). The Pù Hoạt stem essential oil had a high concentration of (E)-caryophyllene (52.6%). The rhizome essential oil from Pù Hoạt Nature Reserve had α-pinene (18.7%) and β-pinene (58.3%) as dominant constituents, and is qualitatively similar to a sample earlier reported from that collection site [34]. α-Pinene and β-pinene concentrations were lower in the rhizome essential oil sample from Nam Đong (4.0% and 9.8%, respectively).

The most abundant constituents in the rhizome essential oil of *Z. neotruncatum* were perillene (51.3%), neral (12.3%), and geranial (17.0%). Perillene is a major component of *Perilla frutescens* (perillene chemotype) [47] and *Elsholtzia polystachya* (perillene chemotype) [48], but has been found in *Zingiber officinalis* rhizome oil (0.1–0.6%) [49,50] and *Z. zerumbet* leaf oil (1.2%) [51]. Neral and geranial are also major components of *Z. officinale* rhizome oil [49,50].

Camphene (40.4%) dominated the rhizome essential oil composition of *Z. nitens*, followed by bornyl acetate (14.5%), (E)-β-ocimene (12.7%), and α-pinene (10.5%). In comparison, the rhizome essential oil of *Z. nitens* from Pù Mát National Park previously reported contained bornyl acetate (11.8%), (E)-β-ocimene (1.1%), and α-pinene (7.3%), along with β-pinene (21.0%), and δ-elemene (12.8%) [31]. In contrast, the leaf essential oil of *Z. nitens* was composed largely of α-zingiberene (17.4%), α-pinene (11.2%), β-sesquiphellandrene (10.1%), (E)-nerolidol (10.0%), zingiberenol (7.2%), β-pinene (6.0%), and ar-curcumene (5.2%). The previously reported *Z. nitens* leaf essential oil was devoid of α-zingiberene, β-sesquiphellandrene, zingiberenol, and ar-curcumene, but contained large concentrations of δ-elemene (17.0%) and ledol (8.1%), which were not observed in the present sample. In addition, concentrations of trans-β-elemene, germacrene D, and bicyclogermacrene were high in the previous report (8.8%, 8.2%, and 8.3%, respectively), but low in the present sample (0.8%, 0.7%, and 1.5%, respectively). The variations in chemical constituents can likely be attributed to the different geographical collection sites as well as climatic factors. The Pù Mát sample was collected in May, 2014 (beginning of the rainy season), while the sample from Vù Quang National Park (this work) was collected in September, 2018 (height of the rainy season).

The essential oil from the leaves of *Z. ottensii* had abundant sesquiterpene hydrocarbons, including (E)-caryophyllene (28.0%) and trans-β-elemene (17.0%), along with the monoterpenoid β-pinene (17.1%). (E)-Caryophyllene (19.6%) and trans-β-elemene (12.3%) were also found to be key constituents in *Z. ottensii* leaf oil from Bandung, West Java, Indonesia [41]. However, zerumbone was a major component (11.4%) in the leaf oil from Indonesia, but was not detected in the sample from Vietnam. The rhizome essential oil from Vietnam had monoterpenes as the major components, such as
sabinene (21.6%), β-pinene (11.7%), γ-terpinene (5.5%), and terpinen-4-ol (17.1%), in addition to the sesquiterpenoid zerumbone (12.5%). Rhizome essential oils of Z. ottensii from other geographical locations have been reported; the major components are presented in Table 3. A hierarchical cluster analysis using the eight major constituents (Figure 2) reveals the similarities between these rhizome essential oils. The clusters are largely defined by the zerumbone concentrations.

**Table 3.** Comparison of the major components of Zingiber ottensii rhizome essential oils from different geographical locations.

| Major Components       | Collection Location          |
|------------------------|-----------------------------|
|                        | Johor, Malaysia [37]        |
|                        | Petchaburi, Thailand [39]   |
|                        | Sabah, Malaysia [38]        |
|                        | Chiang Mai, Thailand [40]   |
|                        | Bandung, Thailand [41]      |
|                        | Pù Hoạt Nature Reserve, Vietnam (This Work) |
| Sabinene               | 7.2                         |
|                        | 6.5                         |
|                        | 4.1                         |
|                        | 21.1                        |
|                        | 8.6                         |
|                        | 21.6                        |
| β-Pinene               | 5.1                         |
|                        | 4.3                         |
|                        | 1.3                         |
|                        | 6.8                         |
|                        | 3.5                         |
|                        | 11.7                        |
| p-Cymene               | 0.0                         |
|                        | 6.9                         |
|                        | 0.0                         |
|                        | 0.0                         |
|                        | 2.1                         |
| 1,8-Cineole            | 3.3                         |
|                        | 1.2                         |
|                        | 0.6                         |
|                        | 3.9                         |
|                        | 5.8                         |
|                        | 4.3                         |
| γ-Terpinene            | 5.1                         |
|                        | 0.2                         |
|                        | 0.4                         |
|                        | 4.7                         |
|                        | 4.8                         |
|                        | 5.5                         |
| Terpinen-4-ol          | 16.8                        |
|                        | 11.2                        |
|                        | 3.2                         |
|                        | 19.7                        |
|                        | 16.6                        |
|                        | 17.1                        |
| α-Humulene             | 10.9                        |
|                        | 5.6                         |
|                        | 18.3                        |
|                        | 15.6                        |
|                        | 3.3                         |
|                        | 3.8                         |
| Zerumbone              | 25.6                        |
|                        | 40.1                        |
|                        | 36.7                        |
|                        | 0.0                         |
|                        | 14.2                        |
|                        | 12.5                        |

**Figure 2.** Dendrogram obtained from agglomerative hierarchical cluster analysis of the rhizome essential oils from Zingiber ottensii from different geographical locations.

The monoterpenes α-pinene (16.3%) and β-pinene (71.6%) dominated the leaf essential oil composition of Z. recurvatum. The major components in the rhizome essential oil of Z. recurvatum were (E)-caryophyllene (11.3%), bornyl acetate (10.4%), α-humulene (6.9%), and bicyclogermacrene (5.1%).

**Zingiber vuquangensis** leaf and rhizome essential oils were both rich in α-pinene (11.3% and 9.8%, respectively) and β-pinene (38.5% and 45.0%, respectively). The sesquiterpene hydrocarbons trans-β-elemene (5.9% and 10.0%), and (E)-caryophyllene (12.2% and 14.4%) were major components in the leaf and stem essential oils, respectively. The leaf, stem, and rhizome essential oils from Z. vuquangensis from Vu Quang National Park, Ha Tinh Province, Vietnam, have been previously published [46]. A comparison of the major components is summarized in Table 4. Although there are qualitative similarities in the essential oil compositions from these two collections (α-pinene, β-pinene, and (E)-caryophyllene are major components), there are some notable differences. Bornyl acetate and zerumbone were major components in the rhizome essential oil from the Vu Quang collection, but were
not observed in the Pù Hoát sample; trans-β-elemene was observed in relatively small concentrations in the sample from Vu Quang, but was a major component in the leaf and stem essential oils from Pù Hoát. The differences in chemical composition can be attributed to the geographical locations of the two collections and/or the season when the samples were collected. The Vu Quang sample was collected in August, 2014 (rainy season), while the Pù Hoát sample was collected in April, 2019 (dry season).

Table 4. Major components in the leaf, stem, and rhizome essential oils of *Zingiber vuquangensis*.

| Major Components | Vu Quang National Park [46] | Pù Hoát Nature Reserve |
|------------------|-----------------------------|------------------------|
|                  | Leaf | Stem | Rhizome | Leaf | Stem | Rhizome |
| α-Pinene         | 6.9  | 5.2  | 2.2     | 11.3 | 0.5  | 9.8     |
| β-Pinene         | 24.7 | 26.1 | 8.0     | 38.5 | 3.1  | 45.0 |
| Bornyl acetate   | 2.5  | 0.0  | 20.9    | 0.0  | 0.0  | 0.0     |
| trans-β-Elemene  | 0.8  | 0.5  | 0.6     | 5.9  | 10.0 | 2.5     |
| (E)-Caryophyllene| 12.3 | 13.9 | 4.5     | 12.2 | 14.4 | 2.3     |
| α-Humulene       | 7.7  | 8.2  | 9.6     | 1.1  | 1.6  | 0.5     |
| Zerumbone        | 3.0  | 3.6  | 14.1    | 0.0  | 0.0  | 0.0     |

2.2. Mosquito Larvicidal Activity

Several of the *Zingiber* essential oils (depending on availability) were assayed for insecticidal activity against larvae of *Aedes aegypti*, *Aedes albopictus*, and *Culex quinquefasciatus* mosquitoes. The 24- and 48-h larvicidal activities are presented in Table 5.

The essential oils showing the best larvicidal activity against *Ae. aegypti* were *Z. cornubracteatum* rhizome essential oil from Bến En National Park (24-h LC$_{50}$ = 17.0 µg/mL) and *Z. nudicarpum* leaf essential oil from Pù Hoát Nature Reserve (24-h LC$_{50}$ = 19.3 µg/mL). The rhizome essential oil of *Z. cornubracteatum* also demonstrated remarkable activity against *Ae. albopictus* (24-h LC$_{50}$ = 12.7 µg/mL). Both *Z. nudicarpum* leaf essential oil and rhizome essential oil were very active against *Cx. quinquefasciatus* larvae, with LC$_{50}$ values of 12.4 and 11.5 µg/mL, respectively.

Multivariate analysis of the concentrations of the major components in the essential oils that were used for larvicidal activity screening (α-pinene, sabinene, β-pinene, perillene, terpinene-4-ol, neral, geranial, bornyl acetate, (E)-caryophyllene, α-humulene, bicyclogermacrene, and zerumbone), along with their 24-h larvicidal activities, reveals the correlation between activity and composition. The agglomerative hierarchical cluster (AHC) analysis (Figure 3) shows a cluster of largely active essential oils (*Z. nudicarpum* rhizome, *Z. cornubracteatum* rhizome, and *Z. nudicarpum* leaf), along with a marginally active essential oil (*Z. ottensii* rhizome), and two less active essential oils (*Z. recurvatum* rhizome and *Z. neotruncatum* rhizome). The concentrations of β-pinene and, to some extent, α-pinene, are largely responsible for the larvicidal activities of *Zingiber* essential oils, as seen in the principal component analysis (PCA) (Figure 4). Consistent with this correlation, β-pinene has shown larvicidal activity against *Ae. Aegypti*, with LC$_{50}$ values ranging from 12.1 to 42.5 µg/mL [52]. β-Pinene has also shown larvicidal activities against *Ae. albopictus* (LC$_{50}$ of 47.33 and 42.39 µg/mL for (+)-β-pinene and (−)-β-pinene, respectively) [53] and *Cx. quinquefasciatus* (LC$_{50}$ = 19.6 µg/mL) [34]. α-Pinene and sabinene have also shown larvicidal activity against *Ae. aegypti* [52], *Ae. albopictus* [53,55,56], and *Cx. quinquefasciatus* [57,58].
Table 5. Larvicidal activities of *Zingiber* essential oils from north-central Vietnam.

| Zingiber Essential Oil | LC<sub>50</sub> (95% Confidence Levels) | LC<sub>90</sub> (95% Confidence Levels) | χ<sup>2</sup> | p |
|------------------------|----------------------------------------|----------------------------------------|----------------|----------|
| **Twenty-four-hour**    |                                        |                                        |                |          |
| *Aedes aegypti*         |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 16.97 (15.49–18.42) | 24.52 (22.65–27.31) | 1.7 × 10<sup>-6</sup> | 1.000    |
| *Z. neotruncatum* rhizome | 34.95 (32.49–37.37) | 51.49 (48.32–55.56) | 6.625          | 0.036    |
| *Z. nudicarpum* (PH) leaf | 19.30 (17.95–20.56) | 23.74 (22.40–25.40) | 0.0            | 1.000    |
| *Z. nudicarpum* (PH) rhizome | 23.44 (21.94–25.17) | 31.81 (29.07–36.31) | 1.1 × 10<sup>-3</sup> | 0.999    |
| *Z. Ottensii* rhizome | 38.16 (35.50–40.89) | 57.87 (53.60–63.62) | 3.286          | 0.193    |
| Permethrin (control) | 0.0094 (0.0082–0.0107) | 0.0211 (0.0185–0.0249) | 37.6           | 0.000    |
| *Culex quinquefasciatus* |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 12.72 (10.43–14.11) | 21.56 (19.43–25.10) | 4.6 × 10<sup>-6</sup> | 1.000    |
| *Z. neotruncatum* rhizome | 21.50 (19.71–23.52) | 31.99 (27.52–36.51) | 0.0402         | 0.980    |
| *Z. nudicarpum* (PH) leaf | 22.33 (20.78–23.86) | 31.12 (27.52–36.51) | 2.025          | 0.193    |
| *Aedes albopictus*       |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 12.32 (10.36–13.78) | 19.57 (17.61–23.23) | 9.8 × 10<sup>-6</sup> | 1.000    |
| *Z. neotruncatum* rhizome | 19.97 (18.07–21.98) | 31.24 (28.16–36.33) | 0.0528         | 0.974    |
| *Z. nudicarpum* (PH) leaf | 15.81 (13.56–18.06) | 22.22 (20.59–24.53) | 0.0            | 1.000    |
| *Culex quinquefasciatus* |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 11.48 (5.78–15.28) | 33.79 (29.71–40.16) | 1.7 × 10<sup>-6</sup> | 0.101    |
| *Z. neotruncatum* rhizome | 29.91 (27.71–32.79) | 39.59 (36.06–44.53) | 5.383          | 0.020    |
| *Z. nudicarpum* (PH) leaf | 6.687 (4.942–8.197) | 18.85 (16.52–22.30) | 0.02453        | 0.988    |
| *Aedes aegypti*         |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 16.32 (14.72–17.84) | 24.52 (22.50–27.54) | 9.8 × 10<sup>-6</sup> | 1.000    |
| *Z. neotruncatum* rhizome | 33.58 (31.39–36.00) | 42.76 (39.94–46.48) | 6.675          | 0.036    |
| *Z. nudicarpum* (PH) leaf | 12.44 (8.78–15.67) | 44.29 (39.05–51.64) | 34.20         | 0.000    |
| *Aedes albopictus*       |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 16.97 (15.76–18.32) | 22.22 (20.59–24.53) | 0.0            | 1.000    |
| *Z. neotruncatum* rhizome | 22.73 (21.09–24.63) | 31.31 (28.88–35.35) | 8.8 × 10<sup>-3</sup> | 0.996    |
| *Culex quinquefasciatus* |                                        |                                        |                |          |
| *Z. cornubracteatum* (BE) rhizome | 11.48 (5.78–15.28) | 33.79 (29.71–40.16) | 9.8 × 10<sup>-6</sup> | 1.000    |
| *Z. neotruncatum* rhizome | 29.91 (27.71–32.79) | 39.59 (36.06–44.53) | 12.57         | 0.002    |
| *Z. nudicarpum* (PH) leaf | 17.30 (15.15–19.24) | 28.94 (25.97–33.94) | 0.02453        | 0.988    |

LC<sub>50</sub> = medial lethal concentration, LC<sub>90</sub> = 90% lethal concentration, χ<sup>2</sup> and p = goodness-of-fit chi-square value and p-value, BE = Bến En National Park, PH = Pù Hoạt Nature Reserve.
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Active observations

Plants 2020quinquefasciatus have also shown larvicidal activity against Ae. Aegypti.

Similarly, the essential oil (doTERRA International) contains 4.0% β-pinene, respectively) [53], and 

Z. officinale (LC50 = 55.8 and 33.3 μg/mL), or the larvicidal activity of Z. Ottensii with LC50 values ranging from 12.1 to 42.5 μg/mL); [52,55,56], and (LC50 47.33 and 42.39 μg/mL) [52,57,58].

Ae. Albopictus (LC50 44.9 μg/mL, respectively) [61]. Finally, Z. Neotruncatum rhizome essential oil (0.8%) showed relatively marginal larvicidal activity against Cx. Quinquefasciatus larvae (LC 50 = 50.8 μg/mL), and Z. Recurvatum rhizome essential oil, with no larvicidal activity against Ae. Aegypti.

Consistent with this correlation, Z. Collinssi rhizome essential oil, with 9.0% β-pinene, respectively) [53] and Z. Cernuum essential oil larvicidal activities, as seen in the principal component biplot of PC1 and PC2 scores and loadings indicating the correlations between Zingiber essential oil major components and larvicidal activities.

Figure 3. Dendrogram obtained from agglomerative hierarchical cluster analysis of the Zingiber essential oils screened for larvicidal activity.

Figure 4. Principal component biplot of PC1 and PC2 scores and loadings indicating the correlations between Zingiber essential oil major components and larvicidal activities.
Several Zingiber essential oils have been screened for mosquito larvicidal activity. Consistent with the correlation of α- and β-pinene with Zingiber essential oil larvicidal activities, Z. nimmonii rhizome essential oil, with no α-pinene and only low β-pinene (0.8%), showed relatively marginal larvicidal activity against *Ae. aegypti* and *Cx. quinquefasciatus* (LC$_{50}$ values of 44.5 and 48.3 µg/mL, respectively) [59]. Similarly, Z. cernuum rhizome essential oil, with 1.6% α-pinene and 1.2% β-pinene, showed relatively marginal larvicidal activities against *Ae. aegypti* (LC$_{50}$ 44.9 µg/mL), *Ae. albopictus* (LC$_{50}$ 55.8 µg/mL), or *Cx. quinquefasciatus* (LC$_{50}$ 48.4 µg/mL) [60], and the larvicidal activity of Z. zerumbet rhizome essential oil (0.8% α-pinene, 0.1% β-pinene) showed larvicidal activities against *Ae. albopictus* and *Cx. quinquefasciatus* with LC$_{50}$ = 25.5 µg/mL [63].

2.3. Antimicrobial Activity

Several of the essential oils from Zingiber species were tested for antibacterial activity against a panel of Gram-positive (*Enterococcus faecalis*, *Staphylococcus aureus*, and *Bacillus cereus*), and Gram-negative (*Escherichia coli*, *Pseudomonas aeruginosa*, and *Salmonella enterica*) bacteria, and for anticandidal activity against *Candida albicans* (Table 6). The essential oils generally showed good to excellent activity against the Gram-positive organisms compared to Gram-negative. It has frequently been noted that Gram-positive bacteria demonstrate a higher susceptibility to essential oils than do Gram-negative organisms [64–66]. This phenomenon has been attributed to the existence of cell wall lipopolysaccharides in the Gram-negative bacteria, which can inhibit the hydrophobic essential oil constituents from diffusing into the cells [67,68]. *Candida albicans* was also relatively sensitive to the Zingiber essential oils.

The essential oil with the best overall antimicrobial activity was Z. nudicarpum rhizome essential oil from Pù Hoat Nature Reserve with MIC < 10 µg/mL against all three Gram-positive organisms and MIC = 16 µg/mL against *P. aeruginosa* and *C. albicans*. It is difficult to correlate essential oil composition with antimicrobial activity, however. The rhizome essential oil of Z. nudicarpum was rich in α-pinene (18.7%) and β-pinene (58.3%). The antimicrobial activities of α-pinene and β-pinene have ranged from excellent to inactive against *E. faecalis*, *S. aureus*, *B. cereus*, or *C. albicans* [69–71]. However, the presence of these two compounds as major components is not enough to impart good antimicrobial activity. The leaf essential oil of Z. recurvatum and the leaf and stem essential oils of Z. cornibracteatum from Bén En National Park were also rich in α-pinene (16.3%, 10.1%, and 9.9%, respectively) and β-pinene (71.6%, 67.3%, and 66.8%), but these essential oils showed significantly lower antimicrobial activity. There are likely synergistic and/or antagonistic effects of minor components responsible for the activities.
Table 6. Antibacterial and antifungal activities of Zingiber essential oils from north-central Vietnam.

| Zingiber Essential Oil (EO) | Enterococcus faecalis ATCC 299212 | Staphylococcus aureus ATCC 25923 | Bacillus cereus ATCC 14579 | Escherichia coli ATCC 25922 | Pseudomonas aeruginosa ATCC 27853 | Salmonella enterica ATCC 13076 | Candida albicans ATCC 10231 |
|-----------------------------|------------------------------------|---------------------------------|---------------------------|-----------------------------|---------------------------------|-------------------------------|-----------------------------|
| Z. cornubracteatum (BE) leaf EO | 128 | 128 | na | 64 | na | na | na |
| Z. cornubracteatum (BE) rhizome EO | 32 | 32 | 64 | 256 | na | na | 256 |
| Z. cornubracteatum (BE) stem EO | 128 | 128 | na | 64 | na | na | na |
| Z. cornubracteatum (PM) leaf EO | 64 | 64 | 128 | 128 | na | na | 16 |
| Z. cornubracteatum (PM) rhizome EO | 32 | 64 | 128 | 64 | 256 | na | 16 |
| Z. nudicarpum (PH) leaf EO | 32 | 16 | 16 | na | 128 | na | 16 |
| Z. nudicarpum (PH) rhizome EO | 2 | 8 | 1 | 64 | 16 | na | 16 |
| Z. ottensii leaf EO | 64 | 64 | 64 | na | 16 | na | 64 |
| Z. ottensii rhizome EO | 8 | 64 | 32 | na | na | na | 8 |
| Z. recurvatum leaf EO | 16 | 64 | 128 | na | na | na | 128 |
| Z. recurvatum rhizome EO | 16 | 128 | 64 | na | 256 | 256 | 64 |
| Z. vuquangensis leaf EO | 16 | 16 | 16 | na | na | na | 32 |
| Streptomycin nt | 256 | 256 | 128 | 32 | 256 | 128 | nt |
| Nistatin nt | nt | nt | nt | nt | nt | nt | 8 |
| Cyclohexamide nt | nt | nt | nt | nt | nt | nt | 32 |
| Z. cornubracteatum (BE) leaf EO | 45.67 | 45.67 | na | 18.78 | na | na | na |
| Z. cornubracteatum (BE) rhizome EO | 10.45 | 9.34 | 18.79 | 68.99 | na | na | 99.34 |
| Z. cornubracteatum (BE) stem EO | 46.78 | 19.78 | na | 67.89 | na | na | na |
| Z. cornubracteatum (PM) leaf EO | 20.78 | 9.34 | 45.67 | 45.67 | na | na | 5.67 |
| Z. cornubracteatum (PM) rhizome EO | 9.56 | 13.56 | 43.67 | 20.45 | 100.34 | 256 | 7.89 |
| Z. nudicarpum leaf EO | 16.33 | 8.54 | 8.57 | na | 65.44 | na | 8.67 |
| Z. nudicarpum rhizome EO | 1.33 | 4.35 | 0.567 | 33.22 | 8.66 | na | 8.99 |
| Z. ottensii leaf EO | 32.66 | 32.33 | 33.77 | na | 7.99 | na | 32.33 |
| Z. ottensii rhizome EO | 32.66 | 32.33 | 33.77 | na | 7.99 | na | 32.33 |
| Z. recurvatum leaf EO | 2.57 | 17.89 | 15.56 | na | na | na | 3.56 |
| Z. recurvatum rhizome EO | 3.99 | 13.67 | 53.89 | na | na | na | 67.74 |
| Z. vuquangensis leaf EO | 6.46 | 36.87 | 32.33 | na | 108.99 | 112.67 | 25.67 |

BE = Bến En National Park, PM = Pù Mát National Park, MIC = minimum inhibitory concentration, IC₅₀ = median inhibitory concentration, na = not active, nt = not tested.
3. Materials and Methods

3.1. Plant Material

*Zingiber* plants were collected from several locations in north-central Vietnam (Table 1, Figure 1). The fresh plant materials (leaves, stems, and/or rhizomes; 2.0 kg each) were immediately chopped and hydrodistilled using a Clevenger apparatus for 4 h to give the essential oils.

3.2. Gas Chromatographic Analysis

Gas chromatography with flame ionization detection (GC-FID) was carried out as previously described [72]: Agilent Technologies HP 7890A Plus Gas chromatograph (Santa Clara, CA, USA), flame ionization detector (FID), HP-5ms column (30 m × 0.25 mm, film thickness 0.25 µm, Agilent Technologies), H₂ carrier gas (1 mL/min), injector temperature = 250 °C, detector temperature = 260 °C, column temperature program: 60 °C (2 min hold), increase to 220 °C (4 °C/min), 220 °C (10 min hold), inlet pressure = 6.1 kPa, split mode injection (10:1) split ratio), 1.0 µL injection volume.

Gas chromatography–mass spectrometry (GC-MS) was carried out as previously described [72]: Agilent Technologies HP 7890A Plus Chromatograph (Santa Clara, CA, USA), HP-5ms (30 m × 0.25 mm, film thickness 0.25 µm) column, HP 5973 MSD mass detector, He carrier gas (1 mL/min), MS ionization voltage = 70 eV, emission current = 40 mA, acquisitions range = 35–350 amu, sampling rate = 1.0 scan/s. The GC operating conditions were the same as those used for GC-FID. The chemical components of the essential oils were identified based on their retention indices (RI) based on a series of n-alkanes, co-injection with pure compounds when available (Sigma-Aldrich, St. Louis, MO, USA) or identified essential oil components, MS library search (NIST 17 and Wiley Version 10) and by comparing with the literature MS fragmentation [73]. The relative concentrations (%) of the components were calculated based on the GC peak area (FID response) without correction factors. The measurements were carried out in triplicate.

3.3. Mosquito Larvicidal Screening

Larvae of *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus* were raised in the laboratory as previously described [74]. *Aedes aegypti* larvae were reared from eggs (Institute of Biotechnology, Vietnam Academy of Science and Technology). Adults of *Culex quinquefasciatus* and *Aedes albopictus* were collected in Hoa Khanh Nam ward, Lien Chieu district, Da Nang city (16°03′14.9″ N, 108°09′31.2″ E) and were maintained as described previously [74]. Eggs were hatched and the larvae reared as previously described [74].

Fourth instar larvae of each mosquito species were used for the larvicidal assays, which were carried out as previously described [74]: 250-mL beakers, 150 mL of water, and 20 larvae, aliquots of the *Zingiber* essential oils dissolved in EtOH (1% stock solution) were added to give final concentrations of 100, 50, 25, 12.5, 6, and 3 µg/mL; EtOH only was the negative control, permethrin was the positive control, mortality was recorded after 24 and 48 h of exposure, experiments were carried out at 25 ± 2 °C, assays were carried out in quadruplicate. The larvicidal data were subjected to log-probit analysis [75] to obtain LC₅₀ values, LC₉₀ values and 95% confidence limits using Minitab® 19.2020.1 (Minitab, LLC, State College, PA, USA).

All procedures involving vertebrates (mice, chicks) were carried out in accordance with the “Guideline for the Care and Use of Laboratory Animals” which was approved by the Medical-Biological Research Ethics Committee of Duy Tan University (DTU/REC2020/NHH01), Vietnam.

3.4. Antimicrobial Screening

Antimicrobial activity of *Zingiber* essential oils was carried out on three Gram-negative organisms, *Salmonella enterica* (ATCC 13076), *Pseudomonas aeruginosa* (ATCC 27853), and *Escherichia coli* (ATCC 25922); three Gram-positive organisms, *Bacillus cereus* (ATCC 14579), *Enterococcus faecalis* (ATCC 299212), and *Staphylococcus aureus* (ATCC 25923); and the pathogenic yeast, *Candida albicans*.
(ATCC 10231), using the microbroth dilution assay as previously described [72]. Dilutions were formulated from 16,384 to 2 μg/mL in sterile distilled water and pipetted into 96-well microplates. Bacteria were grown in tryptic soy broth or Mueller–Hinton broth (double-strength), fungi were grown in Sabouraud dextrose broth (double-strength). Bacteria and fungi were standardized to $5 \times 10^5$ CFU/mL for bacteria and $1 \times 10^3$ CFU/mL for the yeast. The final lane, containing only serial dilutions of the essential oil without bacteria or yeast, was treated as the positive control. Sterile water (no sample) and media with microorganisms were the negative controls; streptomycin was the positive antibiotic standard; cycloheximide and nystatin served as positive antifungal standards. The plates were incubated at 37 °C for 24 h and the minimum inhibitory concentrations were established as the well with the lowest concentration completely inhibiting microbial growth based on turbidity. The IC$_{50}$ values were determined spectrophotometrically (EPOCH2C spectrophotometer, BioTek Instruments, Inc Highland Park Winooski, VT, USA) and computed according to the following

\[
\% \text{ inhibition} = \frac{\text{OD}_{\text{control}}(+) - \text{OD}_{\text{test agent}}}{\text{OD}_{\text{control}}(+) - \text{OD}_{\text{control}}(-)} \times 100\%
\]

\[
\text{IC}_{50} = \text{High}_{\text{conc}} - \frac{(\text{High}_{\text{inh}}\% - 50\%) \times (\text{High}_{\text{conc}} - \text{Low}_{\text{conc}})}{(\text{High}_{\text{inh}}\% - \text{Low}_{\text{inh}}\%)}
\]

where OD = optical density, control(−) = cells with medium but no antimicrobial agent, test agent is a known concentration of antimicrobial agent, control(+) = culture medium without cells, High$_{\text{conc}}$/Low$_{\text{conc}}$ = concentration of test agent at high concentration/low concentration and High$_{\text{inh}}\%$/Low$_{\text{inh}}\%$ = % inhibition at high concentration/low concentration.

The antimicrobial assays were carried out in triplicate.

4. Conclusions

There are wide variations in essential oil compositions from the Zingiber species in this study, not only between species and tissues, as expected, but also between essential oils from the same species and tissues collected from different locations. This is an important consideration if the essential oils are to be used for agricultural or medicinal uses, but also if commercialization is considered. The monoterpenes α-pinene and β-pinene seem to be largely responsible for the mosquito larvicidal activities observed. It is worth investigating whether Zingiber or other essential oils rich in these components are viable alternatives for vector control. The presence of α-pinene and β-pinene cannot explain the antimicrobial activities of Zingiber essential oils, and synergistic or antagonistic interactions likely contribute. Nevertheless, several Zingiber essential oils have shown excellent antimicrobial activity and should be investigated further for controlling Gram-positive bacterial and yeast infections.

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