Biological Activities and Secondary Metabolites from *Sophora tonkinensis* and Its Endophytic Fungi

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Abstract: The roots of *Sophora tonkinensis* Gagnep., a traditional Chinese medicine, is known as Shan Dou Gen in the Miao ethnopharmacy. A large number of previous studies have suggested the usage of *S. tonkinensis* in the folk treatment of lung, stomach, and throat diseases, and the roots of *S. tonkinensis* have been produced as Chinese patent medicines to treat related diseases. Existing phytochemical works reported more than 300 compounds from different parts and the endophytic fungi of *S. tonkinensis*. Some of the isolated extracts and monomer compounds from *S. tonkinensis* have been proved to exhibit diverse biological activities, including anti-tumor, anti-inflammatory, antibacterial, antiviral, and so on. The research progress on the phytochemistry and pharmacological activities of *S. tonkinensis* have been systematically summarized, which may be useful for its further research.

Keywords: *S. tonkinensis*; phytochemistry; pharmacology; review

1. Introduction

*Sophora tonkinensis* Gagnep. belongs to the *Sophora* genus of the Leguminosae family, which is widely distributed in the southwest provinces of China [1,2]. As a famous folk medicine of the Miao people, the roots of *S. tonkinensis* were known as Shan Dou Gen or Guang Dou Gen in the Miao ethnopharmacy [3,4]. The early medicinal records of Shan Dou Gen were contained in the classics “Kai Bao Ben Cao”, in which *S. tonkinensis* showed the effect of anti-sore throat diseases [5,6]. A large number of previous studies have suggested the usage of *S. tonkinensis* in the folk treatment of upper respiratory tract infection, including lung and throat diseases. Meanwhile, *S. tonkinensis* is also highly effective in the treatment of liver and skin diseases [7,8]. Moreover, the roots of *S. tonkinensis* can also be combined with other medicines to form dozens of clinical and marketing Chinese patent medicines, such as Kai Hou Jian throat spray, Shuyanqing Spray, and Watermelon Frost Spray, which is usually used for treatment of pharyngitis, tonsillitis, and aphthous ulcers [9–11]. Existing phytochemical works reported more than 300 compounds with various structural skeleton types from different parts and endophytic fungi of *S. tonkinensis*. Some of the isolated monomer compounds from *S. tonkinensis* have been proved to exhibit diverse biological activities, including anti-tumor, anti-inflammatory, antibacterial, antiviral, and so on [12–17]. Herein, the research progress on the phytochemistry and pharmacological activities of *S. tonkinensis* have been systematically summarized, which may be useful for its further research.

2. Phytochemistry

Previous studies have shown that alkaloids, flavonoids, triterpenoids, and triterpenoid saponins were the main chemical components isolated from *S. tonkinensis*. To date, 78 (1–78)
alkaloids, 115 (79–193) flavonoids, 46 (194–239) triterpenes and triterpenoid saponins, and 37 (240–276) other compounds have been isolated from S. tonkinensis, and it is worth mentioning that 40 (277–316) compounds were also isolated from the endophytic fungi produced by S. Tonkinensis (Table 1, Figure 1).

Table 1. The comprehensive list of the compounds from S. tonkinensis and its Endophytic fungus.

| NO | Compounds | Molecular Formula | Parts of Plant | References |
|----|-----------|-------------------|----------------|------------|
| 1  | Matrine   | C_{13}H_{22}N_{2}O | Roots          | [12]       |
| 2  | 5α,14β-Dihydroxymatrine | C_{13}H_{22}N_{2}O_{3} | Roots          | [12]       |
| 3  | (+)-5α-Hydroxyoxymatrine | C_{13}H_{22}N_{2}O_{3} | Roots          | [12]       |
| 4  | (+)-Oxymatrine | C_{13}H_{22}N_{2}O_{2} | Roots          | [18]       |
| 5  | (+)-5α-Hydroxymatrine ((+)-Sophoranol) | C_{13}H_{22}N_{2}O_{2} | Roots          | [12]       |
| 6  | (−)-14β-Hydroxyoxymatrine | C_{13}H_{22}N_{2}O_{3} | Roots          | [18]       |
| 7  | Sophtonseedline E | C_{17}H_{26}N_{2}O_{4} | Seeds          | [19]       |
| 8  | Sophtonseedline F | C_{17}H_{26}N_{2}O_{2}S | Seeds          | [19]       |
| 9  | Sophtonseedline G | C_{13}H_{24}N_{2}O_{3} | Seeds          | [19]       |
| 10 | Sophtonseedline H | C_{16}H_{26}N_{2}O_{2} | Seeds          | [19]       |
| 11 | (+)-9α-Hydroxymatrine | C_{13}H_{24}N_{2}O_{2} | Seeds          | [19]       |
| 12 | (+)-9α-9α-Dihydroxymatrine | C_{13}H_{24}N_{2}O_{3} | Seeds          | [19]       |
| 13 | (+)-Allmatrine (Sophoridine) | C_{15}H_{22}N_{2}O | Roots          | [20]       |
| 14 | (−)-Lehmannine | C_{15}H_{22}N_{2}O | Roots          | [20]       |
| 15 | (−)-12α-Hydroxysofocarpine | C_{15}H_{24}N_{2}O_{2} | Roots          | [20]       |
| 16 | (−)-13,14-Dehydrosofocarpidine | C_{13}H_{22}N_{2}O | Roots          | [20]       |
| 17 | (+)-5α-Hydroxysofocarpine | C_{15}H_{22}N_{2}O_{3} | Roots          | [14]       |
| 18 | (−)-12β-Hydroxysofocarpine | C_{15}H_{22}N_{2}O_{2} | Roots          | [14]       |
| 19 | (+)-Oxysopocarpine | C_{15}H_{22}N_{2}O_{2} | Roots          | [14]       |
| 20 | Sophtonseedline B | C_{13}H_{22}N_{2}O_{3} | Seeds          | [19]       |
| 21 | Sophtonseedline C | C_{13}H_{22}N_{2}O_{4} | Seeds          | [19]       |
| 22 | Sophtonseedline D | C_{17}H_{26}N_{2}O_{2}S | Seeds          | [19]       |
| 23 | (−)-5α-Hydroxysofocarpine (13,14-Dehydrosofocarpine) | C_{15}H_{22}N_{2}O_{2} | Seeds          | [19]       |
| 24 | (−)-9α-Hydroxysofocarpine | C_{15}H_{22}N_{2}O_{2} | Seeds          | [19]       |
| 25 | (−)-14β-Acetoxyatrine | C_{17}H_{26}N_{2}O_{3} | Leaves         | [21]       |
| 26 | (+)-14α-Acetoxyatrine | C_{17}H_{26}N_{2}O_{3} | Leaves         | [21]       |
| 27 | (−)-14β-Hydroxyatrine | C_{15}H_{24}N_{2}O_{2} | Leaves         | [21]       |
| 28 | (+)-14α-Hydroxyatrine | C_{15}H_{24}N_{2}O_{2} | Leaves         | [21]       |
| 29 | Sophtonseedline I | C_{17}H_{26}N_{2}O_{4} | Seeds          | [19]       |
| 30 | 6,7-Dehydro-matrine | C_{15}H_{22}N_{2}O | Seeds          | [19]       |
| 31 | 5-Hydroxy-6,7-dehydro-matrine | C_{15}H_{22}N_{2}O | Seeds          | [19]       |
| 32 | (+)-13,14-Dehydrosofocarpol | C_{15}H_{22}N_{2}O | Roots          | [22]       |
| 33 | (−)-Sopocarpine | C_{15}H_{22}N_{2}O | Roots          | [12]       |
| 34 | (+)-5α-Hydroxylemannine | C_{15}H_{22}N_{2}O_{2} | Roots          | [14]       |
| 35 | 13α-Hydroxymatrine | C_{15}H_{24}N_{2}O_{2} | Roots          | [23]       |
| 36 | 13β-Hydroxymatrine | C_{15}H_{24}N_{2}O_{2} | Roots          | [23]       |
| 37 | 11,12-Dehydroallmatrine | C_{15}H_{22}N_{2}O | Roots          | [1]        |
| 38 | 11,12-Dehydroamatriline | C_{15}H_{22}N_{2}O | Roots          | [1]        |
| 39 | (+)-Matrine N-oxide | C_{15}H_{22}N_{2}O | Leaves         | [21]       |
| 40 | (+)-Soporhonal N-oxide | C_{15}H_{24}N_{2}O_{2} | Leaves         | [21]       |
| 41 | (+)-7,11-Dehydroamatrine | C_{15}H_{22}N_{2}O | Roots          | [22]       |
| 42 | Alopecurin A | C_{15}H_{22}N_{2}O_{4} | Seeds          | [19]       |
| 43 | Sophtonseedline J | C_{15}H_{20}N_{2}O_{3} | Seeds          | [19]       |
| 44 | Sophtonseedline K | C_{15}H_{20}N_{2}O_{3} | Seeds          | [19]       |
| 45 | Sophtonseedline A | C_{15}H_{22}N_{2}O_{2} | Seeds          | [19]       |
| 46 | 5,6-Dehydro-matrine | C_{15}H_{22}N_{2}O | Seeds          | [19]       |
| 47 | Isosopocarpine | C_{15}H_{22}N_{2}O | Roots          | [23]       |
| 48 | (+)-Soparamine (7β-Soparamine) | C_{15}H_{20}N_{2}O | Roots          | [14]       |
Table 1. Cont.

| NO | Compounds                        | Molecular Formula         | Parts of Plant | References |
|----|----------------------------------|---------------------------|----------------|------------|
|    | Cytisine-type alkaloids           |                           |                |            |
| 50 | (−)-Cytisine                     | C_{11}H_{14}N_{2}O        | Seeds          | [19]       |
| 51 | N-Methylcytisine                 | C_{13}H_{16}N_{2}O        | Seeds          | [19]       |
| 52 | (−)-N-Formylcytisine             | C_{12}H_{14}N_{2}O        | Seeds          | [19]       |
| 53 | N-Acetylcytisine                 | C_{13}H_{16}N_{2}O        | Seeds          | [19]       |
| 54 | (−)-N-Methylecytisine            | C_{12}H_{16}N_{2}O        | Roots          | [18]       |
| 55 | (−)-N-Hexanoylcytisine           | C_{17}H_{31}N_{2}O        | Roots          | [24]       |
| 56 | (−)-N-Ethylcytisine              | C_{15}H_{18}N_{2}O        | Roots          | [24]       |
| 57 | (−)-N-Propionylcytisine          | C_{14}H_{18}N_{2}O        | Roots          | [24]       |
| 58 | Tonkinensine A                   | C_{26}H_{30}N_{2}O_{6}    | Roots          | [25]       |
| 59 | Tonkinensine B                   | C_{26}H_{30}N_{2}O_{6}    | Roots          | [25]       |
|    |                                  |                           |                |            |
|    | Anagyrine-type alkaloids          |                           |                |            |
| 60 | 17-Oxo-a-isoparteine             | C_{15}H_{23}N_{2}O        | Leaves         | [21]       |
| 61 | (−)-Anagyrine                    | C_{15}H_{23}N_{2}O        | Roots          | [12]       |
| 62 | (−)-Thermopsine                  | C_{15}H_{23}N_{2}O        | Roots          | [12]       |
| 63 | (−)-Baptifoline                  | C_{15}H_{23}N_{2}O        | Leaves         | [21]       |
| 64 | (−)-Clathrotropine               | C_{17}H_{32}N_{2}O_{4}    | Roots          | [26]       |
| 65 | Lanatine A                       | C_{15}H_{23}N_{2}O_{3}    | Roots          | [26]       |
|    |                                  |                           |                |            |
|    | Lupine-types and other alkaloids  |                           |                |            |
| 66 | Lamprolobine                      | C_{15}H_{24}N_{2}O_{2}    | Leaves         | [21]       |
| 67 | Jussiaeine B                     | C_{16}H_{24}N_{2}O_{2}    | Roots          | [26]       |
| 68 | Jussiaeine A                     | C_{16}H_{24}N_{2}O_{2}    | Roots          | [26]       |
| 69 | Senepodine H                     | C_{15}H_{26}N_{2}O_{8}    | Roots          | [26]       |
| 70 | Cermizine C                      | C_{11}H_{21}N_{2}O_{4}    | Roots          | [26]       |
| 71 | Senepodine G                     | C_{11}H_{22}N_{2}O_{4}    | Roots          | [26]       |
| 72 | Harmine                          | C_{13}H_{12}N_{2}O_{3}    | Roots          | [1]        |
| 73 | Tonkinensine C                   | C_{16}H_{26}N_{2}O_{2}    | Roots          | [1]        |
| 74 | Perlyolyrine                     | C_{16}H_{26}N_{2}O_{2}    | Roots          | [1]        |
| 75 | 3-(4-Hydroxyphenyl)-4-(3-methoxy-4-hydroxyphenyl)-3,4-dehydroquinolizidine | C_{22}H_{25}N_{3}O        | Roots          | [26]       |
| 76 | 1-(6,7-dihydro-5H-pyrrolo[1,2-a]imidazol-3-yl)ethanone | C_{18}H_{10}N_{2}O        | Roots          | [27]       |
| 77 | Cyclo (Pro-Pro)                  | C_{16}H_{14}N_{2}O_{2}    | Roots          | [27]       |
| 78 | Nicotinic acid                   | C_{6}H_{5}NO_{2}          | Roots          | [27]       |
|    | Flavonoids                       |                           |                |            |
| 79 | 4',7-Dihydroxyflavone            | C_{15}H_{10}O_{4}         | Roots          | [28]       |
| 80 | Wogonin                          | C_{16}H_{12}O_{2}         | Roots          | [29]       |
| 81 | Luteolin                         | C_{15}H_{10}O_{4}         | Roots          | [29]       |
| 82 | Luteolin-7-glucoside             | C_{21}H_{20}O_{11}        | Roots          | [30]       |
| 83 | Baicalein 7-O-β-D-glucuronide    | C_{21}H_{18}O_{13}        | Roots          | [31]       |
| 84 | Bayin                            | C_{21}H_{18}O_{13}        | Roots          | [15]       |
| 85 | Swertisin                        | C_{22}H_{18}O_{10}        | Roots          | [31]       |
| 86 | Sophoraflavone B                 | C_{21}H_{30}O_{9}         | Roots          | [32]       |
| 87 | Sophoraflavone A                 | C_{22}H_{30}O_{10}        | Roots          | [32]       |
|    | Flavonols                        |                           |                |            |
| 88 | Quercetin                        | C_{15}H_{10}O_{7}         | Roots          | [33]       |
| 89 | Morin                            | C_{15}H_{10}O_{7}         | Roots          | [31]       |
| 90 | 6,8-Diprenylkaempferol           | C_{25}H_{26}O_{6}         | Roots          | [34]       |
| 91 | 8-C-prenylkaempferol             | C_{20}H_{18}O_{6}         | Roots          | [35]       |
| 92 | Dehydrodulcinifolin              | C_{25}H_{24}O_{6}         | Roots          | [33]       |
| 93 | Tonkinensisol                    | C_{25}H_{24}O_{6}         | Roots          | [15]       |
| 94 | Isoquerctrin                      | C_{21}H_{20}O_{12}        | Roots          | [36]       |
| 95 | Quercetin                        | C_{21}H_{20}O_{11}        | Roots          | [37]       |
| 96 | Rutin (Quercetin-3-O-β-D-rutinoside) | C_{27}H_{30}O_{16}        | Roots          | [31]       |
| 97 | Isorhamnetin-3-O-β-D-rutinoside  | C_{28}H_{32}O_{16}        | Roots          | [31]       |
| NO | Compounds                                                                 | Molecular Formula | Parts of Plant | References |
|----|---------------------------------------------------------------------------|-------------------|----------------|------------|
|    | **Isoflavones and Dihydroisoflavones**                                    |                   |                |            |
| 98 | 8,4'-Dihydroxy-7-methoxyisoflavone                                       | C_{16}H_{12}O_{5} | Roots          | [38]       |
| 99 | 5,7,2',4'-Tetrahydroxyisoflavone                                          | C_{15}H_{10}O_{6} | Roots          | [38]       |
| 100| Calycosin                                                                 | C_{16}H_{12}O_{5} | Roots          | [38]       |
| 101| 7,3'-Dihydroxy-5'-methoxyisoflavone                                       | C_{16}H_{12}O_{5} | Roots          | [38]       |
| 102| 7,4'-Dihydroxy-3'-methoxyisoflavone                                       | C_{16}H_{12}O_{5} | Roots          | [38]       |
| 103| Daidzein (7,4'-Dihydroxyisoflavone)                                       | C_{15}H_{10}O_{4} | Roots          | [38]       |
| 104| 7,3'-Dihydroxy-8,4'-dimethoxyisoflavone                                   | C_{17}H_{14}O_{6} | Roots          | [38]       |
| 105| 7,8-Dihydroxy-4'-methoxyisoflavone                                        | C_{16}H_{12}O_{5} | Roots          | [38]       |
| 106| 7,3',4'-Trihydroxyisoflavone                                              | C_{15}H_{10}O_{5} | Roots          | [38]       |
| 107| Formononetin                                                              | C_{16}H_{12}O_{5} | Roots          | [39]       |
| 108| Genistein                                                                 | C_{15}H_{10}O_{5} | Roots          | [39]       |
| 109| Wighteone                                                                 | C_{20}H_{18}O_{7} | Roots          | [40]       |
| 110| 8-Methyleftusin                                                           | C_{17}H_{14}O_{2} | Roots          | [41]       |
| 111| 7-Methoxybenosin                                                          | C_{22}H_{22}O_{4} | Roots          | [42]       |
| 112| Tectorigenin                                                              | C_{16}H_{12}O_{6} | Roots          | [43]       |
| 113| Butesuperin B                                                             | C_{26}H_{22}O_{8} | Roots          | [44]       |
| 114| Butesuperin B-7''-O-β-glucopyranoside                                     | C_{33}H_{34}O_{14} | Roots         | [44]       |
| 115| Genistin                                                                  | C_{21}H_{29}O_{10} | Roots          | [33]       |
| 116| Ononin (Formononetin-7-O-β-D-glucoside)                                   | C_{22}H_{22}O_{9} | Roots          | [33]       |
| 117| Daidzein-4''-glucoside-ramnoside                                          | C_{27}H_{30}O_{13} | Roots         | [37]       |
| 118| Sophorabioside                                                            | C_{27}H_{30}O_{14} |                  | [37]       |
|    | **Dihydroflavones**                                                       |                   |                |            |
| 119| 6,8-Diprenyl-7,4'-Dihydroxyflavanone                                      | C_{25}H_{28}O_{4} | Roots          | [45]       |
| 120| Sophorane                                                                 | C_{30}H_{36}O_{4} | Roots          | [45]       |
| 121| Glabrol                                                                    | C_{25}H_{28}O_{4} | Roots          | [45]       |
| 122| 6,8-Diprenyl-7,2',4'-trihydroxyflavanone                                  | C_{25}H_{28}O_{5} | Roots          | [45]       |
| 123| Lespeflorin B                                                              | C_{30}H_{36}O_{5} | Roots          | [33]       |
| 124| (2S)-7,4'-Dihydroxy-3''-aldehyde-8,3''-(3''-methylbut-2''-eny1) flavanone  | C_{26}H_{28}O_{5} | Roots          | [34]       |
| 125| (2S)-7,2',4'-Trihydroxy-8,3'',5''-(3''-methyl- but-2''-eny1) flavanone      | C_{30}H_{36}O_{5} | Roots          | [34]       |
| 126| Tonkinochromane J                                                          | C_{25}H_{29}O_{5} | Roots          | [46]       |
| 127| Shandougenine C                                                            | C_{30}H_{36}O_{5} | Roots          | [40]       |
| 128| Shandougenine D                                                            | C_{25}H_{29}O_{5} | Roots          | [40]       |
| 129| Sophoratonic F                                                             | C_{35}F_{14}O_{4} | Roots          | [42]       |
| 130| Lonchocarpol A                                                             | C_{25}H_{29}O_{5} | Roots          | [42]       |
| 131| 2''-Hydroxylabrol                                                           | C_{25}H_{29}O_{5} | Roots          | [47]       |
| 132| 8,5''-Diprenyl-7,2',4'-trihydroxyflavanone                                | C_{25}H_{29}O_{5} | Roots          | [45]       |
| 133| Sophoratonic A                                                             | C_{27}H_{30}O_{4} | Roots          | [42]       |
| 134| Sophoratin B                                                               | C_{30}H_{32}O_{4} | Roots          | [42]       |
| 135| Tonkinochromane I                                                           | C_{30}H_{36}O_{5} | Roots          | [35]       |
| 136| Tonkinochromane G                                                           | C_{30}H_{36}O_{5} | Roots          | [34]       |
| 137| Sophoratonic C                                                              | C_{30}H_{36}O_{5} | Roots          | [42]       |
| 138| Sophoratonic D                                                              | C_{30}H_{36}O_{5} | Roots          | [42]       |
| 139| Flemichin D                                                                | C_{25}H_{26}O_{5} | Roots          | [45]       |
| 140| 5-Dehydroxylupinofolin                                                      | C_{25}H_{26}O_{4} | Roots          | [34]       |
| 141| Lupinofolin                                                                | C_{25}H_{26}O_{5} | Roots          | [40]       |
| 142| 2-(2',4'-Dihydroxyphenyl)-8,8-dimethyl-1''-(3-methyl-2-butenyl)-8H-pyranol[2,3-d] chroman-4-one | C_{25}H_{26}O_{5} | Roots          | [48]       |
| 143| Tonkinochromane A                                                           | C_{30}H_{36}O_{4} | Roots          | [45]       |
| 144| Sophorarchromene                                                            | C_{30}H_{34}O_{4} | Roots          | [33]       |
| 145| 2-{[2-(1-Hydroxy-1-methylethyl)-7-(3-methyl-2-butenyl)-2',3-dihydrobenzofuran-5-yl]-7-hydroxy-8-(3-methyl-2-butenyl)-chroman-4-one} | C_{30}H_{36}O_{5} | Roots          | [49]       |
Table 1. Cont.

| NO | Compounds                          | Molecular Formula | Parts of Plant | References |
|----|------------------------------------|-------------------|----------------|------------|
| 146 | Sophoratonin E                     | C_{30}H_{32}O_{4}  | Roots          | [42]       |
| 147 | Tonkinochromane D                  | C_{30}H_{36}O_{5}  | Roots          | [50]       |
| 148 | Tonkinochromane E                  | C_{32}H_{42}O_{5}  | Roots          | [50]       |
| 149 | 2-[[2'-(1-Hydroxy-1-methylethyl)-7'-(3-methyl-2-butenyl)-2',3'-dihydrobenzofuran]-5'-yl]-7-hydroxy-8-(3-methyl-2-butenyl) chroman-4-one | C_{30}H_{36}O_{5}  | Whole       | [51]       |
| 150 | Euchrenone A₂                      | C_{25}H_{20}O_{5}  | Roots          | [33]       |
| 151 | Sophoratonin G                     | C_{27}H_{20}O_{4}  | Roots          | [42]       |
| 152 | Tonkinochromane K                  | C_{30}H_{36}O_{4}  | Roots          | [50]       |
| 153 | 2-[[3'-Hydroxy-2',2'-dimethyl-8'-(3-methyl-2-butenyl)]chroman-6'-yl]-7-hydroxy-8-(3-methyl-2-butenyl)-chroman-4-one | C_{30}H_{36}O_{5}  | whole       | [51]       |
| 154 | 2-[[3-Hydroxy-2',2'-dimethyl-8-(3-methyl-2-butenyl)]chroman-6-yl]-7-hydroxy-8-(3-methyl-2-butenyl)-chroman-4-one | C_{31}H_{38}O_{4}  | Roots        | [49]       |
| 155 | Tonkinochromane H                  | C_{30}H_{34}O_{4}  | Roots          | [52]       |
| 156 | Tonkinochromane B                  | C_{30}H_{36}O_{4}  | Roots          | [53]       |
| 157 | Kushenol E                         | C_{25}H_{20}O_{6}  | Roots          | [46]       |
| 158 | Naringenin 7-O-neo-hesperidoside   | C_{27}H_{32}O_{14} | Roots         | [31]       |
| 159 | Isoliquiritigenin                  | C_{15}H_{12}O_{4}  | Roots          | [47]       |
| 160 | Sophoradin                         | C_{30}H_{36}O_{4}  | Roots          | [34]       |
| 161 | Xanthohumol                        | C_{21}H_{22}O_{5}  | Roots          | [54]       |
| 162 | 7,9,2,4-Tetrahydroxy-8-isopentenyl-5-methoxychalcone | C_{21}H_{22}O_{5}  | Roots        | [54]       |
| 163 | Tonkinochromane C                  | C_{28}H_{30}O_{4}  | Roots          | [53]       |
| 164 | Tonkinochromane F                  | C_{32}H_{42}O_{5}  | Roots          | [50]       |
| 165 | Kuraridine                         | C_{26}H_{30}O_{6}  | Roots          | [54]       |
| 166 | Sophoradichromene                  | C_{30}H_{34}O_{4}  | Roots          | [42]       |
| 167 | Tonkinochromane L                  | C_{21}H_{21}O_{4}  | Roots          | [46]       |
| 168 | (−)-Maackiain                      | C_{16}H_{12}O_{5}  | Roots          | [33]       |
| 169 | Pisatin                            | C_{17}H_{14}O_{6}  | Roots          | [39]       |
| 170 | Maackiain-3-O-glucoside 6′-acetate  | C_{21}H_{22}O_{11} | Roots       | [47]       |
| 171 | (−)-Maackiain 3-sulfate            | C_{21}H_{11}O_{8}S | Roots        | [53]       |
| 172 | 6αR,11αR-1-hydroxy-4-isoprenyl-maackiain (6αR,11αR) - 2-hydroxy-3-methoxy-1-isopentenyl-maackiain | C_{22}H_{22}O_{5}  | Roots        | [47]       |
| 173 | Sophotokin                         | C_{21}H_{22}O_{4}  | Roots          | [34]       |
| 174 | (−)-Pterocarpin                    | C_{17}H_{14}O_{5}  | Seeds          | [56]       |
| 175 | Medicarpin                         | C_{16}H_{14}O_{4}  | Roots          | [39]       |
| 176 | (6αR, 11αR)-3-O-β-D-Glucopyranosylmedicarpin | C_{22}H_{34}O_{9}  | Roots        | [24]       |
| 177 | Medicarpin-3-O-glucoside 6′-acetate  | C_{21}H_{22}O_{10} | Roots       | [47]       |
| 178 | Demethylmedicarpin                 | C_{15}H_{12}O_{4}  | Roots          | [40]       |
| 179 | Homopterocarpin                    | C_{17}H_{16}O_{4}  | Roots          | [42]       |
| 180 | Dehydromaackiain                   | C_{16}H_{10}O_{5}  | Roots          | [42]       |
| 181 | Flemichapparin B                   | C_{17}H_{12}O_{5}  | Roots          | [42]       |
| 182 | Maackiaterocarpin B                | C_{21}H_{18}O_{6}  | Roots          | [57]       |
| 183 | 3-Methylmaackiaterocarpin B        | C_{22}H_{20}O_{6}  | Roots          | [47]       |
| 184 | Erybraelin D                       | C_{25}H_{26}O_{4}  | Roots          | [42]       |
| 185 | Maackiaterocarpin A                | C_{21}H_{20}O_{6}  | Roots          | [42]       |
| 186 | Medicagol                          | C_{16}H_{8}O_{6}   | Seeds          | [56]       |
| 187 | Sophoneseedlin B                   | C_{28}H_{38}O_{13} | Seeds        | [56]       |
| 188 | Sophoratonkin                      | C_{26}H_{21}O_{11} | Seeds         | [28]       |
| 189 | (−)-Trifolihirzin                 | C_{22}H_{32}O_{10} | Seeds        | [56]       |
| 190 | (−)-Trifolihirzin-6′-monooacetate  | C_{24}H_{32}O_{11} | Seeds         | [56]       |
| NO | Compounds | Molecular Formula | Parts of Plant | References |
|----|-----------|------------------|----------------|-----------|
| 192 | $7,2'$-Dihydroxy-4'-methoxy-isoflavanol | $C_{10}H_{16}O_5$ | Roots | [58] |
| (3$\beta$,4$\beta$)-4-hydroxy-7,4$'$-dimethoxysiflavan | $3'\alpha$-O-$\beta$-D-glucopyranoside | $C_{23}H_{28}O_{10}$ | Roots | [24] |
| 193 | Subprogenin | $C_{30}H_{48}O_4$ | Roots | [59] |
| 194 | Subprogenin A | $C_{30}H_{48}O_3$ | Roots | [59] |
| 195 | Subprogenin B | $C_{30}H_{48}O_3$ | Roots | [59] |
| 196 | Subprogenin C | $C_{30}H_{48}O_3$ | Roots | [59] |
| 197 | Subprogenin C methylester | $C_{31}H_{48}O_3$ | Roots | [59] |
| 198 | Subprogenin D | $C_{30}H_{48}O_3$ | Roots | [59] |
| 199 | Subprogenin D methylester | $C_{31}H_{48}O_3$ | Roots | [59] |
| 200 | Abrisapogenol H | $C_{30}H_{44}O_4$ | Roots | [59] |
| 201 | Wistariasapogenol A | $C_{30}H_{40}O_4$ | Roots | [59] |
| 202 | Melilotigenin | $C_{30}H_{46}O_4$ | Roots | [59] |
| 203 | Abrisapogenol I | $C_{30}H_{46}O_4$ | Roots | [59] |
| 204 | Sophoradiol | $C_{30}H_{50}O_3$ | Roots | [59] |
| 205 | Cantoniensisitrol | $C_{30}H_{50}O_3$ | Roots | [59] |
| 206 | Soyasapogenol B | $C_{30}H_{50}O_3$ | Roots | [59] |
| 207 | Soyasapogenol A | $C_{30}H_{50}O_3$ | Roots | [59] |
| 208 | Abrisapogenol C | $C_{30}H_{50}O_3$ | Roots | [59] |
| 209 | Abrisapogenol D | $C_{30}H_{50}O_3$ | Roots | [59] |
| 210 | Abrisapogenol E | $C_{30}H_{50}O_3$ | Roots | [59] |
| 211 | Kudzusapogenol A | $C_{30}H_{50}O_3$ | Roots | [59] |
| 212 | Abrisapogenol A | $C_{30}H_{50}O_3$ | Roots | [59] |
| 213 | Lupeol | $C_{30}H_{50}O_3$ | Roots | [60] |
| 214 | Stigmasterol | $C_{30}H_{50}O_3$ | Roots | [60] |
| 215 | $\beta$-Sitosterol | $C_{30}H_{50}O_3$ | Roots | [60] |
| 216 | Daucosterol | $C_{35}H_{60}O_6$ | Roots | [60] |
| 217 | Subproside I | $C_{48}H_{78}O_{19}$ | Roots | [61] |
| 218 | Subproside I methylester | $C_{40}H_{80}O_{19}$ | Roots | [61] |
| 219 | Subproside II | $C_{47}H_{76}O_{19}$ | Roots | [61] |
| 220 | Subproside II methylester | $C_{48}H_{78}O_{19}$ | Roots | [61] |
| 221 | Soyasaponin A$_3$ methylester | $C_{40}H_{80}O_{19}$ | Roots | [61] |
| 222 | Kuzusapogenol A methylester | $C_{40}H_{80}O_{20}$ | Roots | [61] |
| 223 | Soyasaponin I methylester | $C_{40}H_{80}O_{18}$ | Roots | [61] |
| 224 | Kuziasaponin III methylester | $C_{40}H_{80}O_{17}$ | Roots | [62] |
| 225 | Soyasaponin II methylester | $C_{46}H_{78}O_{17}$ | Roots | [62] |
| 226 | Kuziasaponin I methylester | $C_{40}H_{80}O_{17}$ | Roots | [62] |
| 227 | Kudzusaponin A$_3$ | $C_{47}H_{78}O_{19}$ | Roots | [61] |
| 228 | Soyasaponin II | $C_{47}H_{78}O_{17}$ | Roots | [61] |
| 229 | Dehydrosoyasaponin I | $C_{46}H_{78}O_{18}$ | Roots | [61] |
| 230 | Subproside VII | $C_{59}H_{86}O_{27}$ | Roots | [63] |
| 231 | Subproside VII methylester | $C_{59}H_{86}O_{27}$ | Roots | [63] |
| 232 | Subproside IV | $C_{54}H_{88}O_{23}$ | Roots | [63] |
| 233 | Subproside IV methylester | $C_{55}H_{80}O_{23}$ | Roots | [63] |
| 234 | Subproside V | $C_{54}H_{88}O_{24}$ | Roots | [63] |
| 235 | Subproside V methylester | $C_{55}H_{80}O_{24}$ | Roots | [63] |
| 236 | Subproside III | $C_{54}H_{86}O_{24}$ | Roots | [61] |
| 237 | Subproside III methylester | $C_{55}H_{88}O_{24}$ | Roots | [61] |
| 238 | Subproside VI | $C_{54}H_{88}O_{24}$ | Roots | [63] |
| 239 | Subproside VI methylester | $C_{55}H_{80}O_{24}$ | Roots | [63] |

**Other compounds**

| NO | Compounds | Molecular Formula | Parts of Plant | References |
|----|-----------|------------------|----------------|-----------|
| 240 | Tyrosol | $C_8H_{10}O_2$ | Roots | [64] |
| 241 | (3-Hydroxypropyl) phenol | $C_8H_{12}O_2$ | Roots | [64] |
| 242 | Vanillin alcohol | $C_8H_{10}O_3$ | Roots | [64] |
| 243 | (±)-4-(2-Hydroxypropyl) phenol | $C_9H_{12}O_2$ | Roots | [64] |
| 244 | 3,4,5-Trihydroxybenzoic acid | $C_7H_4O_5$ | Roots | [31] |
| NO | Compounds                                                                 | Molecular Formula | Parts of Plant | References |
|----|---------------------------------------------------------------------------|-------------------|----------------|------------|
| 245| 3,4-Dihydroxybenzoic acid                                                 | C₇H₆O₄            | Roots          | [31]       |
| 246| 4-Hydroxy-3-methoxybenzoic acid                                          | C₇H₅O₄            | Roots          | [31]       |
| 247| p-Hydroxybenzonic acid                                                   | C₇H₄O₃            | Roots          | [31]       |
| 248| Venillic acid                                                            | C₇H₄O₄            | Roots          | [41]       |
| 249| p-Methoxybenzonic acid                                                   | C₇H₄O₃            | Roots          | [27]       |
| 250| Salicylic acid                                                           | C₇H₆O₃            | Roots          | [43]       |
| 251| Benzamide                                                                | C₇H₇NO            | Roots          | [64]       |
| 252| 4-Methoxybenzamide                                                       | C₉H₁₂O₄            | Roots          | [64]       |
| 253| Docosyl caffeate                                                         | C₂₁H₂₅O₄          | Roots          | [4]        |
| 254| Maltol                                                                   | C₆H₁₀O₢            | Roots          | [41]       |
| 255| (±)-3-(p-Methoxyphenyl)-1,2-propanediol                                  | C₉H₁₂O₄            | Roots          | [64]       |
| 256| 3,4-Dimethoxybenzenecarboxylic acid methyl ester                         | C₁₃H₁₄O₄          | Roots          | [39]       |
| 257| Sophoratonin H                                                           | C₂₂H₂₆O₆          | Roots          | [42]       |
| 258| Piscidic acid monoethyl ester                                            | C₁₃H₁₆O₇           | Roots          | [41]       |
| 259| 2',4'-7-trihydroxy-6,8-bis(3-methyl-2-butenyl) flavanone                   | C₂₅H₂₈O₅          | Roots          | [40]       |
| 260| 4'-dihydroxylphenyl)-5,6-methylenedioxybenzofuran                       | C₁₅H₁₀O₅          | Roots          | [56]       |
| 261| bolusanthin IV                                                           | C₁₅H₁₂O₄          | Roots          | [40]       |
| 262| 7,2'-Dihydroxy-4',5'-methylenedioxyflavan                                | C₁₆H₁₄O₇          | Roots          | [40]       |
| 263| Shandougenine A                                                          | C₂₀H₁₈O₁₀         | Roots          | [40]       |
| 264| Shandougenine B                                                          | C₂₀H₁₈O₁₀         | Roots          | [40]       |
| 265| (−)-Syringaresinol-4,4’-di-O-β-D-glucopyranoside                         | C₂₄H₄₆O₁₈         | Roots          | [27]       |
| 266| (−)-Syringaresinol-4-O-β-D-glucopyranoside                               | C₂₈H₅₆O₁₃         | Roots          | [27]       |
| 267| (−)-Pinoresinol-4,4’-di-O-β-D-glucopyranoside                            | C₃₂H₄₂O₁₆         | Roots          | [27]       |
| 268| Pinoresin                                                                | C₂₀H₂₂O₆          | Roots          | [28]       |
| 269| Syringaresin                                                             | C₂₂H₂₆O₈           | Roots          | [28]       |
| 270| Medioresin                                                               | C₂₁H₂₄O₇          | Roots          | [28]       |
| 271| Coniferin                                                                | C₁₆H₂₂O₈          | Roots          | [27]       |
| 272| 4-Hydroxyethyl-2,6-dimethoxyphenol-1-O-β-D-glucopyranoside               | C₁₅H₂₂O₉          | Roots          | [27]       |
| 273| Syringin                                                                 | C₁₇H₂₄O₉          | Roots          | [29]       |
| 274| Sophonoseedlin A                                                         | C₂₃H₄₆O₉          | Roots          | [56]       |
| 275| (65,9R)-Roseoside                                                        | C₁₀H₉₃O₅          | Roots          | [27]       |
| 276| (−)-Secoisolariciresinol-4-O-β-D-glucopyranoside                         | C₂₅H₃₃NO₉         | Roots          | [27]       |

**Table 1. Cont.**

**Compounds produced by endophytic fungi**

| NO | Compounds                             | Molecular Formula | References |
|----|---------------------------------------|-------------------|------------|
| 277| 2-Methoxy-6-methyl-1,4-benzoquinone   | C₈H₈O₃            | Endophytic Fungus Xylaria sp. GDG-102 [65] |
| 278| 1-Methyl emodin                       | C₁₆H₁₂O₅          | Endophytic Fungus Penicillium macrosclerotiorum [66] |
| 279| Isorhodoptilometrin                   | C₁₇H₁₄O₆          | Endophytic Fungus Penicillium macrosclerotiorum [66] |
| 280| (−)-5-Carboxymellein                  | C₁₁H₁₀O₅          | Endophytic Fungus Xylaria sp. GDG-102 [65] |
| 281| (−)-5-Methylmellein                   | C₁₁H₁₂O₃          | Endophytic Fungus Xylaria sp. GDG-102 [67] |
| 282| Xylariphilone                         | C₁₁H₁₆O₄          | Endophytic Fungus Xylaria sp. GDG-102 [65] |
| NO | Compounds                                      | Molecular Formula | Parts of Plant | References |
|----|------------------------------------------------|-------------------|----------------|------------|
| 283| Xylarphthalide A                               | C_{11}H_{10}O_{6}  | Endophytic     | [65]       |
| 284| 2-Anhydromevalonic acid                        | C_{6}H_{10}O_{3}   | Fungus Xylaria sp. GDG-102 Endophytic | [65]       |
| 285| (2S,5R)-2-Ethyl-5-methylhexanedioic acid       | C_{8}H_{16}O_{4}   | Fungus Xylaria sp. GDG-102 Endophytic | [65]       |
| 286| 6-Heptanoyl-4-methoxy-2H-pyran-2-one           | C_{13}H_{18}O_{4}  | Fungus Xylaria sp. GDG-102 Endophytic | [65]       |
| 287| Xylareremophil                                 | C_{15}H_{18}O_{3}  | Fungus Xylaria sp. GDG-102 Endophytic | [68]       |
| 288| 1α,10α-Epoxy-13-hydroxyeremophil-7(11)-en-12,8-β-olide | C_{15}H_{20}O_{4} | Fungus Xylaria sp. GDG-102 Endophytic | [68]       |
| 289| 1α,10α-Epoxy-3α-hydroxyeremophil-7(11)-en-12,8-β-olide | C_{15}H_{20}O_{5} | Fungus Xylaria sp. GDG-102 Endophytic | [68]       |
| 290| Mairetolide B                                  | C_{15}H_{20}O_{4}  | Fungus Xylaria sp. GDG-102 Endophytic | [68]       |
| 291| Mairetolide G                                  | C_{15}H_{22}O_{5}  | Fungus Xylaria sp. GDG-102 Endophytic | [68]       |
| 292| 1β,10α,13-Trihydroxyeremophil-7(11)-en-12,8-olide | C_{16}H_{24}O_{4} | Fungus Xylaria sp. GDG-102 Endophytic | [65]       |
| 293| (−)-3-Carboxypropyl-7-hydroxyphthalide         | C_{12}H_{12}O_{5}  | fungus Penicillium vulpinum Endophytic | [69]       |
| 294| (−)-3-Carboxypropyl-7-hydroxyphthalide methyl ester | C_{13}H_{14}O_{3} | fungus Penicillium vulpinum Endophytic | [69]       |
| 295| Sulochrin                                     | C_{17}H_{16}O_{7}  | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
| 296| Monoacetylsterric acid                        | C_{18}H_{16}O_{9}  | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
| 297| Methyl dichloroasterrate                       | C_{18}H_{16}Cl_{2}O_{8} | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
| 298| Penicillither                                  | C_{18}H_{17}ClO_{8} | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
| 299| Methyl asterrate                               | C_{18}H_{18}O_{8}  | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
| 300| Asterric acid                                 | C_{17}H_{16}O_{8}  | fungus Penicillium macrosclerotiorum Endophytic | [66]       |
### Table 1. Cont.

| NO | Compounds                  | Molecular Formula | Parts of Plant                | References |
|----|----------------------------|-------------------|-------------------------------|------------|
|    | Compounds produced by endophytic fungi |                   |                               |            |
| 301| Xylapeptide A              | C$_{30}$H$_{45}$N$_{5}$O$_{5}$ | Fungus Xylaria sp. GDG-102 Endophytic |            |
| 302| Xylapeptide B              | C$_{29}$H$_{43}$N$_{5}$O$_{5}$ | Fungus Xylaria sp. GDG-102 Endophytic |            |
| 303| 21-Acetoxytochalasin J$_2$ | C$_{30}$H$_{37}$NO$_4$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 304| 21-Acetoxytochalasin J$_3$ | C$_{30}$H$_{39}$NO$_3$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 305| Cytochalasin J$_3$         | C$_{32}$H$_{41}$NO$_4$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 306| Cytochalasin H             | C$_{30}$H$_{38}$NO$_5$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 307| 7-Acetoxytochalasin H      | C$_{32}$H$_{41}$NO$_6$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 308| Cytochalasin J             | C$_{28}$H$_{37}$NO$_4$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 309| Geomycin A                 | C$_{35}$H$_{32}$O$_{15}$ | fungus Penicillium macrosclerotiorum Endophytic |    |
| 310| Cytochalasin E             | C$_{28}$H$_{33}$NO$_7$  | fungus Diaporthe sp.GDG-118 Endophytic |            |
| 311| Cytochalasin K             | C$_{28}$H$_{33}$NO$_7$  | fungus Xylaria sp. GDG-102 Endophytic |            |
| 312| Diaporthein B              | C$_{20}$H$_{28}$O$_6$  | fungus Xylaria sp. GDGJ-368 Endophytic |            |
| 313| Piliformic                 | C$_{11}$H$_{18}$O$_4$  | fungus Xylaria sp. GDGJ-368 Endophytic |            |
| 314| Cytochalasin C             | C$_{30}$H$_{37}$NO$_6$  | fungus Xylaria sp. GDGJ-368 Endophytic |            |
| 315| Cytochalasin D             | C$_{30}$H$_{37}$NO$_6$  | fungus Xylaria sp. GDGJ-368 Endophytic |            |
| 316| (22E)-ergosta-6,22-diene-3β,5β,8α-triol | C$_{28}$H$_{46}$O$_3$  | fungus Xylaria sp. GDGJ-368 Endophytic |            |
302 Xylapeptide B C_{29}H_{43}N_{5}O_{5} Endophytic Fungus Xylaria sp. GDG-102

303 21-Acetoxycytochalasin J C_{30}H_{37}NO_{4} Endophytic fungus Diaporthe sp. GDG-118 [70]

304 21-Acetoxycytochalasin J C_{30}H_{39}NO_{3} Endophytic fungus Diaporthe sp. GDG-118 [71]

305 Cytochalasin J C_{32}H_{41}NO_{4} Endophytic fungus Diaporthe sp. GDG-118 [71]

306 Cytochalasin H C_{30}H_{39}NO_{5} Endophytic fungus Diaporthe sp. GDG-118 [71]

307 7-Acetoxycytochalasin H C_{32}H_{41}NO_{6} Endophytic fungus Diaporthe sp. GDG-118 [71]

308 Cytochalasin J C_{28}H_{37}NO_{4} Endophytic fungus Diaporthe sp. GDG-118 [71]

309 Geomycin A C_{35}H_{32}O_{15} Endophytic fungus Penicillium macrosclerotiorum [66]

310 Cytochalasin E C_{28}H_{33}NO_{7} Endophytic fungus Diaporthe sp. GDG-118 [71]

311 Cytochalasin K C_{28}H_{33}NO_{7} Endophytic fungus Xylaria sp. GDG-102 [65]

312 Diaporthein B C_{20}H_{28}O_{6} Endophytic fungus Xylaria sp. GDG-368 [72]

313 Piliformic C_{11}H_{18}O_{4} Endophytic fungus Xylaria sp. GDG-368 [72]

314 Cytochalasin C C_{30}H_{37}NO_{6} Endophytic fungus Xylaria sp. GDG-368 [72]

315 Cytochalasin D C_{30}H_{37}NO_{6} Endophytic fungus Xylaria sp. GDG-368 [72]

316 (22E)-ergosta-6, 22-diene-3β, 5β, 8α-triol C_{28}H_{46}O_{3} Endophytic fungus Xylaria sp. GDG-368 [72]

Figure 1. Cont.
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79 R₃ = R₄ = R₅ = R₆ = R₈ = H, R₂ = R₇ = OH
80 R₃ = R₂ = R₃ = R₄ = R₆ = H, R₅ = R₇ = OH, R₈ = OMe
81 R₃ = R₄ = R₅ = R₆ = R₈ = H, R₂ = OMe, R₇ = OH
82 R₁ = R₂ = R₃ = OH, R₃ = R₄ = R₆ = R₇ = H, R₈ = O-glu

88 R₁ = R₂ = R₃ = R₄ = R₅ = R₇ = OH, R₅ = R₆ = R₈ = H
89 R₁ = R₂ = R₅ = R₆ = H, R₃ = R₄ = R₇ = OH
90 R₁ = R₃ = R₄ = H, R₂ = R₅ = R₇ = OH, R₄ = R₈ = isoprenyl
91 R₁ = R₃ = R₄ = R₆ = H, R₂ = R₅ = R₇ = OH, R₈ = isoprenyl
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2.1. Alkaloids

The alkaloids isolated in *S. tonkinensis* were mainly quinolizidine-type alkaloids [73]. To date, 78 alkaloids have been identified and isolated, of which 49 (1–49) are matrine type alkaloids. Sophtonseedline A (46) was isolated from the seeds of *S. tonkinensis*, which featured an unprecedented 5/6/6/6 tetracyclic skeleton [19]. Meanwhile, tonkinensines...
A (58) and B (59) with the rare multi group bridging structures were isolated from *S. tonkinensis* also [25].

2.2. Flavonoids

Flavonoids generically referred to the compounds with C6-C3-C6 structure skeleton. The flavonoids were rich in *S. tonkinensis*, and more than 115 flavonoids have been reported as far as we know. Their structural types can be classified as flavonoids (79-87), flavonols (88–97), isoflavones and dihydroisoflavones (98–118), dihydroflavones (119–158), chalcones and dihydrochalcones (159–167), pterostanes (168–191), and flavanols (192–193). Interestingly, tonkinochromanes A (143) and B (156) may ring-fused in the isoprenyl substituents [33]. Meanwhile, sophoraflavones A (87) and B (86) were the rare 5-deoxyflavonoids from the roots of *S. tonkinensis* [32]. Among the eighteen flavonoids identified using UPLC-ESI-LTQ/MS methods, formononetin (107), quercetin (88), rutin (96), isoquercitrin (94), and quercitrin (95) were suggested as the major quality markers of *S. tonkinensis* roots [37].

2.3. Triterpenoids and Triterpenoid Saponins

As far as we know, more than 46 (194–239) triterpenoids and triterpenoid saponins have been isolated from *S. tonkinensis*. Isolated triterpenoids are mainly of the oleanane type with carbonyl substitution at position C-22 [30,74]. Compared with flavonoids and alkaloids, the triterpenoids and triterpenoid saponins of *S. tonkinensis* were rarely reported [59,61,62].

2.4. Other Compounds

In addition to alkaloids, flavonoids, and triterpenoids, a total of 37 (240–276) phenolic acids, sterols, and other compounds were reported from *S. tonkinensis*. Two new 2-arylbenzofuran dimers, shandougenines A (263) and B (264), were isolated from the roots of *S. tonkinensis*. It is noteworthy that shandougenine A (263) has the unique dimeric 2-Arylbenzofuran with a C-3\-C-5 bond, and shandougenine B (264) was the natural dimeric 2-arylbenzofuran with a novel C-3/C-3 bond [40]. Meanwhile, a new propenyl phenylacetone was also isolated from *S. tonkinensis* and named sophoratonin H (257) [42].

2.5. Compounds Produced by Endophytic Fungi

The endophytic fungus *Xylaria* sp.GDG-102, *Penicillium macrosclerotiorum*, *Penicillium vulpinum*, *Diaporthe* sp.GDG-118, and *Xylaria* sp. GDGJ-368 [65,66,69,71] were isolated from *S. tonkinensis*, and some compounds produced by these endophytic fungi were interesting. More than 40 (277–316) compounds have been isolated from its endophytic fungi. Xylapeptide A (301) identified from the associated fungus *Xylaria* sp. GDG-102 was the first example of cyclopentapeptide with an L-Pip of terrestrial origin [70].

3. Pharmacological Activities

3.1. Anti-Inflammatory Effect

Reported studies have shown the anti-inflammatory activities of *S. tonkinensis* (Table 2) [45,75]. Some novel compounds, including 12,13-dehydrosophoridine (16) from *S. tonkinensis*, showed significant activity against inflammatory cytokines TNF-α and IL-6 on LPS-induced RAW264.7 macrophages [23]. Moreover, 6,8-diprenyl-7,4’-dihydroxyflavanone (DDF) (119) inhibited the production of NO and the expression of TNF-α, IL-1β, and IL-6 [45]. Meanwhile, the compounds 2’-hydroxyglabrol (131), glabrol (121), maackiain (168), and bolusanthin IV (261) showed strong inhibitory effects on IL-6 [47]. Sophotokin (174) dose-dependently inhibited the lipopolysaccharide (LPS)-stimulated production of NO, TNF-α, PGE₂, and IL-1β in microglial cells [34]. Moreover, the orally administered roots extract of *S. tonkinensis* attenuated the total leukocytes, eosinophil infiltration, and IL-5 level in BAL fluids [76]. Another study also showed *S. tonkinensis* were able to reduce TNF-α, NO, and IL-6 contents in rat paw edema induced by carrageenan [77].
reduce TNF-α
Reduce TNF-α

Reduced the hyperplasia of goblet cell
Reduced the hyperplasia of goblet cell

Inhibit xylene induced auricle swelling in mice
Inhibit xylene induced auricle swelling in mice

Inhibit crotone oil induced ear swelling in mice
Inhibit crotone oil induced ear swelling in mice

Anti-tumor activity
Anti-tumor activity

Table 2. The comprehensive list of the pharmacological activities from S. tonkinensis.

| Detail | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|--------|---------------------|------------------|---------------------------|------------|
|        |                     | Anti-inflammatory activity |                           |            |
|        | (−)-Anagyrine (61)  | In vitro         | 50 μM                     | [12]       |
|        | Sophocarpine (34)   | In vitro         | 50 μM                     | [12]       |
|        | 14β-Hydroxymatrine (28) | In vitro         | 50 μM                     | [12]       |
|        | 7β-Sophoramine (49) | In vitro         | 50 μM                     | [12]       |
|        | Matrine (1)         | In vivo          | 50 μM                     | [12]       |
|        | (−)-5α-Hydroxymatrine (5) | In vivo         | 50 μM                     | [12]       |
|        | 12,13-Dehydrosoophoridine (16) | In vitro         | 50 μM                     | [23]       |
|        | 13α-Hydroxymatrine (36) | In vitro         | 50 μM                     | [23]       |
|        | 13β-Hydroxymatrine (37) | In vitro         | 50 μM                     | [23]       |
|        | Isophocarpine (48)  | In vitro         | 50 μM                     | [23]       |
|        | Sophoridine (13)    | In vitro         | 50 μM                     | [23]       |
|        | Water extract of roots | In vivo          | 0.3 g/kg                  | [75]       |
|        | Sophoratokhin (189) | In vitro         | IC50 = 33.0 μM            | [28]       |
|        | Maackiain (168)     | In vitro         | IC50 = 27.0 μM            | [28]       |
|        | Sophorone (120)     | In vitro         | IC50 = 28.1 μM            | [28]       |
|        | Sophorocarvone (144) | In vitro         | IC50 = 13.6 μM            | [28]       |
|        | Tonkinocromone A (143) | In vitro         | 20 μM                     | [45]       |
|        | Flemichin D (139)   | In vitro         | 20 μM                     | [45]       |
|        | 6,8-Diprenyl-7,4′-dihydroxyflavanone (119) | In vitro         | IC50 = 12.21 μM     | [45]       |
|        | Water extract of roots | In vivo          | 100 mg/kg                 | [13]       |
|        | 2′-Hydroxyglabrol (131) | In vitro         | IC50 = 1.62 μM            | [47]       |
|        | Glabrol (121)       | In vitro         | IC50 = 0.73 μM            | [47]       |
|        | Maackiain (168)     | In vitro         | IC50 = 3.01 μM            | [47]       |
|        | Bolusanthin IV (261) | In vitro         | IC50 = 4.02 μM            | [47]       |
|        | Ethanol extract of roots | In vivo          | 100 mg/kg                 | [7]        |
|        | (−)-Anagyrine (61)  | In vitro         | 50 μM                     | [12]       |
|        | Sophocarpine (34)   | In vitro         | 50 μM                     | [12]       |
|        | 14β-Hydroxymatrine (28) | In vitro         | 50 μM                     | [12]       |
|        | 7β-Sophoramine (49) | In vitro         | 50 μM                     | [12]       |
|        | Matrine (1)         | In vivo          | 50 μM                     | [12]       |
|        | (−)-5α-Hydroxymatrine (3) | In vivo         | 50 μM                     | [12]       |
|        | (+)-5α-Hydroxymatrine (5) | In vivo         | 50 μM                     | [12]       |
|        | 12,13-Dehydrosoophoridine (16) | In vitro         | 50 μM                     | [23]       |
|        | 13α-Hydroxymatrine (36) | In vitro         | 50 μM                     | [23]       |
|        | 13β-Hydroxymatrine (37) | In vitro         | 50 μM                     | [23]       |
|        | Isophocarpine (48)  | In vitro         | 50 μM                     | [23]       |
|        | Sophoridine (13)    | In vitro         | 50 μM                     | [23]       |
|        | Water extract of roots | In vivo          | 0.3 g/kg                  | [75]       |
|        | 50% (v/v) ethanol-water mixture | In vivo          | 100 mg/kg                | [76]       |
|        | 50% (v/v) ethanol-water mixture | In vivo          | 100 mg/kg                | [76]       |
|        | 50% (v/v) ethanol-water mixture | In vivo          | 0.3 g/kg                 | [75]       |
|        | Oxymatrine (4)      | In vivo          | 40 mg/kg                  | [78]       |
|        | (−)-Cytisine (50)   | In vivo          | 40 mg/kg                  | [78]       |
|        | 5. tonkinensis particles | In vivo          | 1.75 g/kg                | [79]       |
|        | Matrine (1)         | In vivo          | 40 mg/kg                  | [78]       |
|        | Sophoridine (13)    | In vivo          | 30 mg/kg                  | [78]       |
|        | Sophocarpine (34)   | In vivo          | 40 mg/kg                  | [78]       |
|        | 5. tonkinensis particles | In vivo          | 3.5 g/kg                 | [79]       |
|        | Water extract of roots | In vivo          | 0.35–1.12 g/kg           | [80]       |
|        | Ethanol extract of roots | In vivo          | 0.35–1.12 g/kg           | [80]       |
|        | Water extract of roots | In vivo          | 0.39 g/kg                | [81]       |
|        | (−)-N-hexanoxyctisine (55) | In vitro         | IC50 = 31.64 μM      | [24]       |
|        | (−)-N-Formycytisine (52) | In vitro         | IC50 = 22.05 μM      | [24]       |
|        | 6αR, 11αR-Maackiain (168) | In vitro         | IC50 = 24.58 μM      | [24]       |
|        | Water extracts of roots | In vitro         | 6.3 μg/μL                | [92]       |
|        | 1-(6,7-Dihydronaphthalene-1,2-dilimida-3-yl) ethylene (76) | In vitro         | IC50 = 23.05 ± 0.46 μM   | [27]       |
| Detail | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|--------|-------------------|-----------------|---------------------------|------------|
| **Anti-tumor activity** | | | | |
| Inhibit HL-60 | Tonkinensiolis (93) | In vitro | IC<sub>50</sub> = 36.48 ± 0.04 μg/mL | [15] |
| | Sophoranol (5) | In vitro | 1.00 ± 0.34 μg/mL | [83] |
| | 13,14-Dehydroxy-13,14-Dihydroxy-13,14-Demethoxyisoflavone (24) | In vitro | 9.18 ± 0.05 μM | [1] |
| | Tonkinensine C (73) | In vitro | IC<sub>50</sub> = 10.4 ± 0.6 μM | [1] |
| | Periloxine (74) | In vitro | IC<sub>50</sub> = 48.9 ± 5.2 μM | [1] |
| Inhibit HepG2 | Alkaloids | In vitro | IC<sub>50</sub> = 9.04 g/L | [84] |
| | Non-alkaloids extract of roots | In vitro | IC<sub>50</sub> = 0.98 g/L | [84] |
| | Water extracts of roots | In vitro | 6.5 µg/mL | [82] |
| | Sophoramine (120) | In vitro | IC<sub>50</sub> = 18.49 ± 0.05 μM | [85] |
| | Matrine (1) | In vitro | IC<sub>50</sub> = 60.81 ± 0.04 μM | [85] |
| Inhibit SH-SY5Y | Oxytremine (4) | In vitro | IC<sub>50</sub> = 42.56 ± 0.55 μM | [85] |
| | (−)-Trifolirhizin (190) | In vitro | IC<sub>50</sub> = 72.11 ± 0.67 μM | [85] |
| | (−)-Maackiain (168) | In vitro | IC<sub>50</sub> = 65.62 ± 0.67 μM | [85] |
| Inhibit B16-BL6 | Chloroform extract of roots | In vitro | 25 ± 0.14 μM/L | [87] |
| Inhibit U937 | Tonkinensine B (59) | In vitro | IC<sub>50</sub> = 3.8 ± 0.19 μM | [25] |
| Inhibit HeLa | Tonkinensine B (59) | In vitro | IC<sub>50</sub> = 48.9 ± 0.5 μM | [25] |
| Inhibit MDA-MB-231 | Water extract of roots | In vitro | 6.5 µg/μL | [82] |
| Inhibit ESC solid tumor cell | Total alkaloids of roots | In vivo | 100 mg/kg | [89] |
| Inhibit H<sub>22</sub> ascites tumor cells | Total alkaloids of roots | In vivo | 100 mg/kg | [89] |
| Inhibit S<sub>180</sub> solid tumor cell | Total alkaloids of roots | In vivo | 75 mg/kg | [89] |
| Inhibit BV2 glioma cell lines | Sophotokin (174) | In vitro | 10 µM | [34] |
| | Maackiain (168) | In vitro | 10 µM | [34] |
| | Medicarpin (176) | In vitro | 10 µM | [34] |
| Inhibit Hep3B and KG-1 cells | Water extract of roots | In vitro | 6.5 µg/μL | [82] |
| Decrease the number of cancer nodules in tumor tissue and reduce AFP in serum | Alkaloids extract of roots | In vivo | 0.036 g/kg | [90] |

**Effects on the liver**

| Protect HepG2 cell against acetaminophen (APAP)-induced damage | 4-Methoxybenzamide (252) | In vitro | 10 µmol/L | [64] |
| | 7,3'-Dihydroxy-8,4'-dimethoxyisoflavone (104) | In vitro | 10 µmol/L | [64] |
| | 7,4'-Dihydroxy-3'-methoxyisoflavone (102) | In vitro | 10 µmol/L | [64] |
| | (±)-3-(p-Methoxyphenyl)-1,2-propanediol (255) | In vitro | 10 µmol/L | [64] |
| Enhance L-02 hepatocytes | Matrine (1) | In vivo and vitro | 10 µM | [91] |
| | Oxytremine (4) | In vivo and vitro | 10 µM | [91] |

**Effects on the liver**

| Increase SOD and GSH | Non-alkaloids extract of roots | In vivo | 400 mg/kg | [13] |
| | Water extract of roots | In vivo | 400 mg/kg | [13] |
| | Water extract of roots | In vivo | 0.59 ± 0.04 μM | [92] |
| | Water extract of roots | In vivo | 25 µg/mL | [91] |
| | Matrine (1) | In vivo | 10 µM | [91] |
| Increase ALT and AST | Oxytremine (4) | In vivo | 10 µM | [91] |
| | Oxytremine (4) | In vivo | 60 mg/kg | [93] |
| | Sophorcarpine (34) | In vivo | 60 mg/kg | [93] |
| | Oxytremine (4) | In vivo | 120 mg/kg | [94] |
| Reduce immune liver injury | STRP1 (Polysaccharide part) | In vivo | 200 mg/kg | [95] |
| | STRP2 (Polysaccharide part) | In vivo | 200 mg/kg | [95] |

**Reduce immune liver injury**

| Inhibit acetaminophen-induced hepatic oxidative damage in mice | Formononetin-7-O-β-D-glucoside (116) | In vitro | IC<sub>50</sub> = (7.82 ± 0.28) × 10<sup>−4</sup> mol/L | [43] |
| | Tectorigenin (112) | In vitro | IC<sub>50</sub> = (3.73 ± 0.45) × 10<sup>−4</sup> mol/L | [43] |
| | 8-Prenyleanomeric (91) | In vitro | IC<sub>50</sub> = (1.58 ± 0.31) × 10<sup>−4</sup> mol/L | [43] |
### Table 2. Cont.

| Details | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|---------|--------------------|------------------|---------------------------|------------|
| Reduce AST and ALT | Oxymatrine (4) | In vivo | 120 mg/kg | [93] |
| | Sophocarpine (34) | In vivo | 120 mg/kg | [93] |
| | Water extract of roots | In vivo | 0.25 g/kg | [96] |
| | Non-alkaloid extract of roots | In vivo | 100 mg/kg | [13] |
| Reduce AST | Water extract of roots | In vivo | 200 mg/kg | [13] |
| Reduce ALT | Water extract of roots | In vivo | 200 mg/kg | [13] |
| Anti-viral activity | (−)-12β-Hydroxyoxysophocarpine (18) | In vitro | IC₅₀ = 26.62 μM | [14] |
| | (−)-9a-Hydroxyoxysophocarpine (25) | In vitro | IC₅₀ = 197.22 μM | [14] |
| | (+)-Sophoralin (5) | In vitro | IC₅₀ = 252.18 μM | [14] |
| | (−)-14β-Hydroxymatrine (28) | In vitro | IC₅₀ = 184.14 μM | [14] |
| | 3-(4-Hydroxyphenyl)-4-(3-methoxy-4-hydroxyphenyl)-3,4-dehydroquinoilizidine (75) | In vitro | IC₅₀ = 64.0 μM | [26] |
| Anti-Coxsackie virus B3 | Cermizine C (70) | In vitro | IC₅₀ = 3.42 μM | [26] |
| | Jussaetine A (68) | In vitro | IC₅₀ = 4.66 μM | [26] |
| | Jussaetine B (67) | In vitro | IC₅₀ = 3.21 μM | [26] |
| | (+)-5x-Hydroxyoxysophocarpine (17) | In vitro | IC₅₀ = 0.12 μM | [26] |
| | (−)-12β-Hydroxyoxysophocarpine (18) | In vitro | IC₅₀ = 0.23 μM | [26] |
| | (−)−Clathrotropine (64) | In vitro | IC₅₀ = 1.60 μM | [26] |
| | Sophonseedlin B (188) | In vitro | 100 μg/mL | [56] |
| | (−)-Triflorihizin (190) | In vitro | 100 μg/mL | [56] |
| Anti-tobacco mosaic virus (TMV) | Sophonseedline D (23) | In vitro | 100 μg/mL | [19] |
| | Sophonseedline F (8) | In vitro | 100 μg/mL | [19] |
| | (−)-N-Formylcystine (52) | In vitro | 100 μg/mL | [19] |
| | Alkaloid extracts of seeds | In vitro | 0.5 mg/mL | [9] |
| | Methanol extracts of seeds | In vitro | 0.5 mg/mL | [9] |
| | (+)-Oxysophocarpine (20) | In vitro | 0.4 μmol/mL | [20] |
| | (−)-Sophocarpine (34) | In vitro | 0.4 μmol/mL | [20] |
| | (−)-Lehmannine (14) | In vitro | 0.4 μmol/mL | [20] |
| Anti-hepatitis B virus (HBV) | Methanol extracts of plant | In vitro | EC₅₀ = 27.5 ± 1.1 μg/mL | [97] |
| | (+)-12α-Hydroxyoxysophocarpine (15) | In vitro | IC₅₀ = 84.70 μM | [14] |
| Inhibited influenza virus A/Hanfang/359/95 | (+)-12β-Hydroxyoxysophocarpine (19) | In vitro | IC₅₀ = 242.46 μM | [14] |
| | (−)-Sophoramine (49) | In vitro | IC₅₀ = 63.07 μM | [14] |
| Anti-oxidant capacity | Chloroform extract of roots | In vitro | EC₅₀ = 1.08 mg/mL | [98] |
| | Ethyl acetate extract of roots | In vitro | EC₅₀ = 0.55 mg/mL | [98] |
| | N-butanol extract of roots | In vitro | EC₅₀ = 0.66 mg/mL | [98] |
| | Ethanol extract of roots | In vitro | EC₅₀ = 3.08 mg/mL | [98] |
| | Shandougenines A (263) | In vitro | IC₅₀ = 0.532 ± 0.076 mM | [40] |
| | Shandougenines B (264) | In vitro | IC₅₀ = 0.18 ± 0.032 mM | [40] |
| | Bolusanthin IV (261) | In vitro | IC₅₀ = 0.3 ± 0.025 mM | [40] |
| ABTS free radical scavenging ability | 2-(2′,4′-Dihydroxyphenyl)-5,6-methylenedioxybenzofuran (260) | In vitro | IC₅₀ = 0.726 ± 0.041 mM | [40] |
| | Shandougenine C (127) | In vitro | IC₅₀ = 0.382 ± 0.055 mM | [40] |
| | Shandougenine D (128) | In vitro | IC₅₀ = 0.341 ± 0.058 mM | [40] |
| | Deoxymedecarpin (179) | In vitro | IC₅₀ = 0.503 ± 0.036 mM | [40] |
| | Ethyl acetate extract of roots | In vitro | 0.5 mg/mL | [98] |
| | Ethanol extract of roots | In vitro | 0.5 mg/mL | [98] |
| | Chloroform extract of roots | In vitro | 0.5 mg/mL | [98] |
| | N-butanol extract of roots | In vitro | 0.5 mg/mL | [98] |
| | Water extract of aerial parts | In vitro | IC₅₀ = 0.1434 g/L | [17] |
| | N-butyl alcohol extract of aerial parts | In vitro | IC₅₀ = 0.0724 g/L | [17] |
| | Ethyl acetate extract of aerial parts | In vitro | IC₅₀ = 0.0693 g/L | [17] |
| | Dichloromethane of aerial parts | In vitro | IC₅₀ = 0.0494 g/L | [17] |
| | Petroleum ether extract of aerial parts | In vitro | IC₅₀ = 0.1218 g/L | [17] |
| Detail | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|--------|--------------------|----------------|--------------------------|------------|
| **Anti-oxidant capacity** |                      |                |                          |            |
| Scavenging of DPPH radicals | Ethyl acetate extract of roots | In vitro | 0.5 mg/mL [98] |            |
| | STRP1 (Polysaccharide part) | In vitro | 1.0 mg/mL [95] |            |
| | STRP2 (Polysaccharide part) | In vitro | 1.0 mg/mL [95] |            |
| | Tonkinensisol (93) | In vitro | IC₅₀ = 0.616 ± 0.021 mM [40] |            |
| | Bolusanthin IV (261) | In vitro | IC₅₀ = 0.502 ± 0.101 mM [40] |            |
| | 2-(2',4'-Dihydroxyphenyl)-5,6-methylenedioxybenzofuran (260) | In vitro | IC₅₀ = 0.527 ± 0.054 mM [40] |            |
| | Shandougenines A (263) | In vitro | IC₅₀ = 1.213 ± 0.101 mM [40] |            |
| | Shandougenines B (264) | In vitro | IC₅₀ = 0.327 ± 0.022 mM [40] |            |
| | WRSP-A2b (Polysaccharide part) | In vitro | IC₅₀ = 19.95 ± 0.25 mg/mL [99] |            |
| | WRSP-A3a (Polysaccharide part) | In vitro | IC₅₀ = 5.99 ± 0.20 mg/mL | [99] |
| Reducing power | Chloroform extract of roots | In vitro | EC₅₀ = 0.60 mg/mL [98] |            |
| | Ethyl acetate extract of roots | In vitro | EC₅₀ = 0.64 mg/mL [98] |            |
| | N-butanol extract of roots | In vitro | EC₅₀ = 0.51 mg/mL [98] |            |
| | Ethanol extract of roots | In vitro | EC₅₀ = 0.84 mg/mL [98] |            |
| | Chloroform extract of roots | In vitro | EC₅₀ = 1.33 mg/mL [98] |            |
| | Ethyl acetate extract of roots | In vitro | EC₅₀ = 2.80 mg/mL [98] |            |
| | N-butanol extract of roots | In vitro | EC₅₀ = 5.00 mg/mL [98] |            |
| | WRSP-A2b (Polysaccharide part) | In vitro | IC₅₀ = 19.78 ± 0.47 mg/mL | [99] |
| Hydroxyl radical scavenging ability | WRSP-A3a (Polysaccharide part) | In vitro | IC₅₀ = 8.38 ± 0.18 mg/mL | [99] |
| | WRSP-A2b (Polysaccharide part) | In vitro | IC₅₀ = 4.24 ± 0.11 mg/mL | [99] |
| | WRSP-A3a (Polysaccharide part) | In vitro | IC₅₀ = 1.94 ± 0.05 mg/mL | [99] |
| **Superoxide anion radical scavenging ability** | Hydroalcoholic extract from the roots | Mice (i.g.) | LD₅₀ = 9.802 ± 2.0067 g/kg | [100] |
| | (-) - Cytisine (50) | Mice (i.g.) | LD₅₀ = 48.16 mg/kg | [101] |
| | Water extract of roots | Mice (i.g.) | LD₅₀ = 17.469 g/kg | [102] |
| | 90% Ethanol extract of roots | Mice (i.g.) | LD₅₀ = 13.399 g/kg | [102] |
| | Alkaloids of roots | Mice (i.g.) | LD₅₀ = 27.135 g/kg | [102] |
| | Water and 70% Ethanol extract mixture of roots | Mice (i.g.) | MTD = 36 g/kg | [103] |
| | All-component of of roots | Mice (i.g.) | MTD = 10.68 g/kg | [102] |
| **Toxicity** | Sophoranone (120) | Zebrafish (p.o.) | LC₅₀ = 22.45 µmol/L | [104] |
| | Sophoranone (120) | Zebrafish (p.o.) | 3.86 µmol/L | [104] |
| | Dealkalized water extract of roots | Zebrafish (p.o.) | LC₅₀ = 1009.1 µg/mL | [105] |
| | Ethanol sedimentation extract of roots | Zebrafish (p.o.) | LC₅₀ = 4367.6 µg/mL | [105] |
| | N-Butyl ethanol extract of roots | Zebrafish (p.o.) | MNLC = 700.0 µg/mL | [105] |
| | Sophoranone (120) | Zebrafish (p.o.) | 11.59 µmol/L | [104] |
| | Diethyl ether extract of roots | Zebrafish (p.o.) | LC₅₀ = 93.6 µg/mL | [105] |
| | N-Butyl ethanol extract of roots | Zebrafish (p.o.) | LC₅₀ = 538.3 µg/mL | [105] |
### Table 2. Cont.

| Detail | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|--------|-------------------|------------------|---------------------------|------------|
| Toxicity | | | | |
| | Dichloromethane extract of roots | Zebrafish (p.o.) | MNLC = 450.0 µg/mL | [105] |
| | Sophoranone (120) | Zebrafish (p.o.) | 1.29 µmol/L | [104] |
| | Sophoranone (120) | Zebrafish (p.o.) | 15.57 µmol/L | [104] |
| Other pharmacological activities | | | | |
| Inhibit *Pseudomonas aeruginosa* | 2',4',7-Trihydroxy-6,8-bis(3-methyl-2-butenyl) flavanone | In vitro | MIC = 125.0 µg/mL | [16] |
| | Genistin (115) | In vitro | MIC = 15.6 µg/mL | [16] |
| | 2-Methoxy-6-methyl-1,4-benzoquinone (277) | In vitro | MIC = 3.125 µg/mL | [65] |
| | Xylaripholine (282) | In vitro | MIC = 12.5 µg/mL | [65] |
| Inhibit *Bacillus megaterium* | Xylarphaltalide A (283) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Carboxylmellein (280) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Methylmellein (281) | In vitro | MIC = 25 µg/mL | [67] |
| | Lanatine A (65) | In vitro | MIC = 1.0 g/L | [26] |
| | Jussiaeiines A (68) | In vitro | MIC = 3.2 g/L | [26] |
| | Jussiaeiines B (67) | In vitro | MIC = 0.8 g/L | [26] |
| Inhibit *Escherichia coli* | 21-Acetoxycytocatalasin J (304) | In vitro | MIC = 12.5 µg/mL | [71] |
| | 2-(2',4',7-Trihydroxy)-5,6-dioxomethylbenzofuran | In vitro | MIC = 31.3 µg/mL | [16] |
| | Xylarphaltalide A (283) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Methylmellein (281) | In vitro | MIC = 25 µg/mL | [67] |
| | 6-Heptanoyl-4-methoxy-2H-pyran-2-one (286) | In vitro | MIC = 50 µg/mL | [106] |
| | 3-(4-Hydroxyphenyl)-1-(3-methyl-4-hydroxyphenyl)-3,4-dehydroquinolizidine (75) | In vitro | MIC = 8.0 g/L | [26] |
| | Cermizines C (70) | In vitro | MIC = 3.5 g/L | [26] |
| | Jussiaeiines B (67) | In vitro | MIC = 6.0 g/L | [26] |
| | Cytochalasin K (311) | In vitro | MIC = 12.5 µg/mL | [65] |
| Inhibit *Staphylococcus aureus* | 6-Heptanoyl-4-methoxy-2H-pyran-2-one (286) | In vitro | MIC = 50 µg/mL | [106] |
| | (−)-N-methyleytisine (54) | In vitro | MIC = 12.0 g/L | [26] |
| | Xylarphaltalide A (283) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Carboxylmellein (280) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Methylmellein (281) | In vitro | MIC = 12.5 µg/mL | [67] |
| | Cytochalasin K (311) | In vitro | MIC = 12.5 µg/mL | [65] |
| | 2',4',7-Trihydroxy-6,8-bis(3-methyl-2-butenyl) flavanone (259) | In vitro | MIC = 62.5 µg/mL | [16] |
| | Ethyl acetate extract of roots | In vitro | MIC = 0.313 mg/mL | [98] |
| | Xylarphaltalide A (283) | In vitro | MIC = 25 µg/mL | [67] |
| | (−)-5-Methylmellein (281) | In vitro | MIC = 25 µg/mL | [67] |
| Inhibit *Shigella dysenteriae* | (−)-3-Carboxypropyl-7-hydroxyphthalalide (293) | In vitro | MIC = 12.5 µg/mL | [69] |
| Inhibit *Proteus vulgaris* | Xylareremophil (287) | In vitro | MIC = 25 µg/mL | [68] |
| | Mairetolid G (291) | In vitro | MIC = 25 µg/mL | [68] |
| Inhibit *Micrococcus luteus* | Mairetolid G (291) | In vitro | MIC = 50 µg/mL | [68] |
| | Xylareremophil (287) | In vitro | MIC = 25 µg/mL | [68] |
| | Mairetolid B (290) | In vitro | MIC = 100 µg/mL | [68] |
| Inhibit *Micrococcus lysodeikticus* | Mairetolid G (291) | In vitro | MIC = 100 µg/mL | [68] |
| | Xylareremophil (287) | In vitro | MIC = 100 µg/mL | [68] |
3.2. Anti-Tumor Effect

The anti-tumor effect was one of the most reported activities of *S. tonkinensis* (Table 2). The chloroform extracts of *S. tonkinensis* have been discovered its inhibitory effect on cell viability and clonal growth in a dose-dependent manner [87]. Meanwhile, the extracts of *S. tonkinensis* also have been reported the inhibit ability target the proliferation, adhesion, invasion, and metastasis of mouse melanoma cells [86]. The anticancer activities of compounds have also been reported [38]. The natural compounds from *S. tonkinensis* also have been reported the inhibit ability target the proliferation, adhesion, invasion, and metastasis of mouse melanoma cells [86].

### 3.3. Hepatoprotective

The components of *S. tonkinensis* were reported significant protective effects against immune induced liver injury (Table 2). Previous works suggested that the nonalkaloid constituents of *S. tonkinensis* obviously reduced the alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum, malondialdehyde (MDA), and nitric oxide (NO), as well as increased the superoxide dismutase (SOD) and glutathione (GSH) in mice with immune-induced liver injury [13]. The water extract of *S. tonkinensis* alleviated hepatic inflammation, liver fibrosis, and hepatic lipids accumulation [91]. Compounds matrine (1)

| Detail                          | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|---------------------------------|--------------------|------------------|---------------------------|------------|
| Moderate activities against Aphis fabae | Matrine (1) | In vitro | IC\(_50\) = 31.7 ± 1.2 µg/mL | [76] |
| Decreased fasting blood glucose levels | Ethyl acetate extract of roots | In vivo | 60 mg/kg | [33] |
| alleviate insulin resistance | Matrine (1) | In vivo | 10 mg/kg | [108] |
| 50 % (v/v) Ethanol–water mixture | In vivo | IC\(_50\) = 5.68 ± 0.25 µg/mL | [76] |
| Inhibit butyrylcholinesterase | Ethanol extract of roots | In vitro | IC\(_50\) = 15.169 ± 0.214 µg/mL | [76] |

### Table 2. Cont.

| Other pharmacological activities | Extracts/Compounds | In Vivo/In Vitro | Active Concentration/Dose | References |
|---------------------------------|--------------------|------------------|---------------------------|------------|
| Inhibit *Bacillus subtilis* | Xylapeptide A (301) | In vitro | MIC = 12.5 µg/mL | [70] |
| Inhibit *Bacillus anthracis* | Methanol extract of roots | In vitro | EC\(_50\) = 1.169 mg/mL | [107] |
| Inhibit *Colletotrichum capsici* | Cytochalasin H (306) | In vitro | MIC = 12.5 µg/mL | [71] |
| Inhibit *Alternaria oleracea* | Cytochalasin H (306) | In vitro | MIC = 12.5 µg/mL | [71] |
| Inhibit *Pestalotiopsis theae* | Cytochalasin H (306) | In vitro | MIC = 12.5 µg/mL | [71] |
| Inhibit *Enterobacter aerogenes* | (-)-3-Carboxypropyl-7-hydroxyphthalalide methyl ester (294) | In vitro | MIC = 12.5 µg/mL | [69] |
| Inhibit *Enterobacter aerogenes* | (-)-3-Carboxypropyl-7-hydroxyphthalalide (293) | In vitro | MIC = 12.5 µg/mL | [69] |
| Inhibit *Colletotrichum gloeosporioides* | Methanol extract of roots | In vitro | EC\(_50\) = 1.214 mg/mL | [107] |
| Inhibit *Fusarium solani* | Methanol extract of roots | In vitro | EC\(_50\) = 1.169 mg/mL | [107] |
| Inhibit *Ceratocystis paradoxa* | Cytochalasin H (306) | In vitro | MIC = 25 µg/mL | [71] |
| Inhibit *Bacillus cereus* | Xylapeptide A (301) | In vitro | MIC = 12.5 µg/mL | [70] |
| Moderate activities against *Aphis fabae* | Matrine (1) | In vivo | LC\(_50\) = 38.29 mg/L | [19] |
| Decreased fasting blood glucose levels | Ethyl acetate extract of roots | In vivo | 60 mg/kg | [33] |
| alleviate insulin resistance | Matrine (1) | In vivo | 10 mg/kg | [108] |
| 50 % (v/v) Ethanol–water mixture | In vivo | IC\(_50\) = 1.61 ± 0.31 µg/mL | [76] |
| Inhibit 5-lipoxygenase | Sophorane (120) | In vitro | IC\(_50\) = 1.6 µM | [76] |
| Inhibit thromboxane synthase | 50 % (v/v) Ethanol–water mixture | In vitro | IC\(_50\) = 5.56 µg/mL | [76] |
and oxymatrine (4) may be the main components contributing to the lipid-lowering activity of the water extract of *S. tonkinensis* [91]. Meanwhile, two purified polysaccharide fractions (STRP1 and STRP2) from the roots of *S. tonkinensis* have been reported to attenuate hepatic oxidative damage in vivo [95]. In addition, some compounds, including sophocarpine (34) from *S. tonkinensis* have been reported to significantly improve liver injury in mice [93].

### 3.4. Anti-Viral Activity

The compounds isolated from *S. tonkinensis* (Table 2), such as 3-(4-Hydroxyphenyl)-4-(3-methoxy-4-hydroxyphenyl)-3,4-dehydroquinolizidine (75), cermizine C (70), jussiaeine A (68), jussiaeine B (67), (+)-5α-hydroxyoxysophocarpine (17), (−)-12β-hydroxyoxysophocarpine (18), and (−)-clathrotropine (64), have reported the anti-coxsackie virus B3 (CVB3) activities with IC$_{50}$ values ranging from 0.12~6.40 μmol/L [26]. The compounds sophtonseedline B (188) and (−)-trifolirhizin (190) from *S. tonkinensis* exhibited anti-tobacco mosaic virus (TMV) activities with the inhibition rates of 69.62% and 68.72%, respectively, at a concentration of 100 μg/mL [56]. The other compounds, including sophtonseedline D (23), sophtonseedline F (8), and (−)-N-formylcytisine (52), have been reported to have anti-TMV activities as well [19]. In addition to TMV, compounds (+)-oxysophocarpine (20), (−)-sophocarpine (34), and (−)-13,14-Dehydrosoforidine (16) have showed anti-HBV activities [20].

### 3.5. Anti-Antioxidant Activities

The antioxidant activities of chloroform, ethyl acetate, *N*-butanol, and ethanol extracts of *S. tonkinensis* have been tested (Table 2). The results of DPPH, ABTS, and OH radical scavenging assay showed that all extracts exhibited antioxidant activities [98]. Some compounds from *S. tonkinensis* exhibited antioxidant activities. It is noteworthy that shandougenine A (263), shandougenine C (127), shandougenine D (128), and 7,4′-Dihydroxyisoflavone (103) showed stronger superoxide anion radical scavenging capacity than the known flavanone luteloin. Shandougenines B (264) showed DPPH free radical and ABTS cation radical scavenging capacity. Shandougenine A (263), shandougenine C (127), shandougenine D (128), bolusanthin IV (261), 2-(2′,4′-Dihydroxyphenyl)-5,6-methylenedioxybenzofuran (260), and demethylmedicarpin (179) were reported parallel ABTS cation radical scavenging capacity to the positive control [40].

### 3.6. Toxicity

The roots of *S. tonkinensis* were the famous toxic Miao drug (Table 2) and were named Shan Dou Gen or Guang Dou Gen [4,110]. The aqueous and alcoholic parts of *S. tonkinensis* caused obvious liver damage in mice, which could result in both the alteration of liver function and the organelle damage of hepatocytes [111,112]. Meanwhile, the extracts of *S. tonkinensis* exhibited pulmonary toxicity, which may trigger pulmonary cancer, dyspnea, and oxidative stress [113]. The obvious toxicity of sophoranone (120) to *zebrafish* was mainly characterized as hepatotoxicity, neurotoxicity, cardiovascular toxicity, and nephrotoxicity in the acute toxicity model [104]. Besides, the alkaloids matrine (1), oxymatrine (4), cytisine (50), and sophocarpine (34) of *S. tonkinensis* showed significant cardiotoxicity [114].

### 3.7. Other Pharmacological Activities

The extracts of *S. tonkinensis* have the ability to reduce blood glucose and resist microbial activities (Table 2, Figure 2). Cytochalasin E (310) and H (306) inhibit a variety of plant pathogens [71]. The flavonoid-rich extracts of *S. tonkinensis* administrated orally to mice significantly increased sensibility to insulin, as well as reduced fasting blood-glucose levels [33]. Moreover, matrine (1) from *S. tonkinensis* could improve glucose metabolism and increased insulin secretion in diabetic mice, which may be used as a potential drug for diabetes treatment [108]. Methanol extracts of *S. tonkinensis* exhibited antidiarrheal activities [115]. Moreover, diverse anti-microbial activities of compounds from *S. tonkinensis* and its endophytic fungi have been reported [26,67].
Anti-inflammatory
Anti-tumor
Hepatoprotective
Hypoglycemic
Anti-viral

S. tonkinensis

Anti-bacterial
Anti-oxidant
Toxicity
Other activities

Figure 2. The biological activities of S. tonkinensis.

4. Conclusion and Future Prospective

In this review, we provide a detailed summary of the medicinal chemistry, pharmacological activities, and related toxicity research of S. tonkinensis. Structurally, more than 300 compounds have been isolated from S. tonkinensis and its endophytic fungi, including alkaloids, triterpenes and triterpenoid saponins, flavonoids, and so on. Some of the star molecules, including matrine (1) and oxymatrine (4), were documented to exhibit well biological activities [110]. For its pharmacological research, previous studies suggested the usage of S. tonkinensis in the folk treatment of upper respiratory tract infection diseases. It is generally believed that the alkaloid components of S. tonkinensis were the main active substances in the roots of S. tonkinensis [116]. Interestingly, the extracts of S. tonkinensis have been reported for hepatotoxicity, while the other related studies showed the opposite hepatoprotective effects. The in-depth toxicological or structure-activity relationship study may be worth for further research. Moreover, the roots of S. tonkinensis combined with other medicines form dozens of marketing Chinese patent medicine for the treatments of pharyngitis, tonsillitis, and aphthous ulcers [9–11]. However, it is rare for its prescription pharmacological research in the treatment of upper respiratory tract diseases, especially works on the drug combination mechanism, which may need to be further developed.

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