Fungal Endophytes: A Potential Source of Antibacterial Compounds

Sunil K. Deshmukh 1,2,*, Laurent Dufosse 3,*, Hemraj Chhipa 4, Sanjai Saxena 2,5,*, Girish B. Mahajan 6, and Manish Kumar Gupta 7

Abstract: Antibiotic resistance is becoming a burning issue due to the frequent use of antibiotics for curing common bacterial infections, indicating that we are running out of effective antibiotics. This has been more obvious during recent corona pandemics. Similarly, enhancement of antimicrobial resistance (AMR) is strengthening the pathogenicity and virulence of infectious microbes. Endophytes have shown expression of various new many bioactive compounds with significant biological activities. Specifically, in endophytic fungi, bioactive metabolites with unique skeletons have been identified which could be helpful in the prevention of increasing antimicrobial resistance. The major classes of metabolites reported include anthraquinone, sesquiterpenoid, chromone, xanthone, phenols, quinones, quinolone, piperazine, coumarins and cyclic peptides. In the present review, we reported 451 bioactive metabolites isolated from various groups of endophytic fungi from January 2015 to April 2021 along with their antibacterial profiling, chemical structures and mode of action. In addition, we also discussed various methods including epigenetic modifications, co-culture, and OSMAC to induce silent gene clusters for the production of noble bioactive compounds in endophytic fungi.

Keywords: endophytic fungi; antibacterial compound; natural product; drug resistance; medicinal plant; AMR

1. Introduction

Over the decades since the discovery of the first antibiotics, resistance to those has been a curse that is being dragged along with every discovery of new antibiotics. This has kept all scientists, professionals, and clinical specialists working on antibiotics on their toes. The quest for new antibiotics scaffolds and repurposing of existing molecules has been persistent for the past nine decades. Getting a new and right scaffold is a herculean task, especially with the least ability to induce mutations in the target bacteria. As examined in some of the earlier reviews [1,2] there are several ways of getting new scaffolds and classes of antimicrobial bioactive compounds. In the domain of natural products, one of the most demonstrated ways is studying less explored species and genera of microbes [3–5]. Investigating unexplored ecological units on the globe synergizes with the concept of investigating the least or not explored species of microbes.

In the current review, we present the latest ways of exploring the credentials of such microbial sources, especially endophytic fungi, as a main stream of novel antimicrobial
scaffolds. Bioactive compounds are mainly responsible for the activity profiles displayed by endophytic fungi. These metabolites belong to a wide range of scaffolds such as alkaloids, benzopyranones, chinones, peptides, phenols, quinones, flavonoids, steroids, terpenoids, tetrалones, xanthones, and others. Moreover, they, in the pure form, have demonstrated abundant biological activities, including antibacterial, antifungal, anticancer, antiviral, antioxidant, immunosuppressant, anti-inflammatory, and antiparasitic properties [6–15]. Even though there are a few specialized reviews on the bioactive compounds from fungi, actinomycetes and other microbes [16,17], the amount of work done in the area is quite versatile, tenacious and significant. There is a need to comprehend these topics periodically to have its effective output for future research keeping in mind the probability of success of any newly discovered bioactive compound in clinical studies has been 0.01 to 1 % based on therapeutic area and type of scaffold. This demands that the base of such scaffolds in the ladder of clinical development should be wider. This width can be increased by exploring such less-tapped resources, the endophytic fungi.

In our previous review, we have covered antibacterials reported from endophytic fungi up to 2014 [1]. This review describes some bioactive molecules isolated from 2015 onwards to early 2021 from various endophytic fungi from terrestrial plants and designated as antibacterials. The antibacterial activity against various pathogenic organisms is listed in Table 1.

2. Antibacterials from Various Class of Endophytic Fungi

2.1. Ascomycetes

Ascomycetes are the fungi characterized by the formation of ascospores and some of the genera belonging to this class are known to produce chemically diverse metabolites. The important genera include *Diaporthe*, *Xylaria*, *Chaetomium*, *Talaromyces*, and *Paraphaeosphaeria* and are known to produce terpenoids, cytochalasins, mellein, alkaloids, polyketides, and aromatic compounds. Here we report the antibacterial from ascomycetes.

2.1.1. *Diaporthe* (Asexual State: *Phomopsis*)

The genus *Diaporthe* (asexual state: *Phomopsis*) has been thoroughly investigated for secondary metabolites that have various pathogenic, endophytic and saprobic species of temperate and tropical habitats. Two natural bisantraquinone, (+)-1,1′-bislunatin (bis) (1) and (+)-2,2′-epicytoskyrin A (epi) (2, Figure 1), were extracted from endophytic fungi, *Diaporthe* sp. GNBP-10 is associated with plant *Uncaria gambir*. Compounds (bis)- (1) and (epi)- (2) showed promising anti-tubercular activity, against *Mycobacterium tuberculosis* strains H37Rv (Mtb H37Rv) with MIC values of 0.422 and 0.844 µM, respectively. Both compounds have the ability to combat nutrient-starvation and biofilms of the Mtb model with relatively moderate activity in bacterial reduction with between 1–2 fold log reduction. Both compounds could reduce the number of Mtb infected into macrophages with 2-fold log reduction. The in-silico results via a docking study show that both compounds have a good affinity with pantothenate kinase (PanK) enzyme with a Glide score of −8.427 kcal/mol and −7.481 kcal/mol for the epi and bis compounds, respectively [18].

An endophytic fungus, *Diaporthe* sp. GDG-118, associated with *Sophora tonkinensis* collected from Hechi City (China) yielded a new compound 21-acetoxycytochalasin J3 (3, Figure 1) and inhibited the pathogens *Bacillus anthraci* and *E. coli* at 12.5 µg/mL concentration (6 mm sterile filter paper discs were impregnated with 20 µL (50 µg) of each compound) [19].

Two novel naphthalene derivatives, 1-(3-hydroxy-1-(hydroxymethyl)-2-methoxy-6-methylnaphthalen-7-yl)propan-2-one (4) and 1-(3-hydroxy-1-(hydroxymethyl)-6-methylnaphthalen-7-yl)propan-2-one (5, Figure 1), were obtained from the *Phomopsis fukushii*. Compounds 4 and 5 displayed poor anti-methicillin-resistant *Staphylococcus aureus* (anti-MRSA) activity, with zones of inhibition of 10.2 and 11.3 mm, respectively (6 mm sterile filter paper discs were impregnated with 20 µL (50 µg) of each compound) [20].
Figure 1. Structures of metabolites 1–22 isolated from Ascomycetes.

Earlier *Phomopsis fukushii* (*Diaporthe fukushii*) isolated from the rhizome of *Paris polyphylla var. yunnanensis* was the source of three new compounds namely 3-hydroxy-1-(1,8-dihydroxy-3,6-dimethoxynaphthalen-2-yl)propan-1-one (6), 3-hydroxy-1-(1,3,8-trihydroxy-6-methoxynaphthalen-2-yl)propan-1-one (7) and 3-hydroxy-1-(1,8-dihydroxy3,5-dimethoxy naphthalen-2-yl) propan-1-one (8, Figure 1). Compounds 6–8 exhibited anti-MRSA-ZR11 activity, with MIC values of 8, 4, and 4 µg/mL, respectively [21]. Later two new di-Ph ethers, 1-[2-methoxy-4-(3-methoxy-5-methylphenoxy)-6-methylphenyl]-ethanone (9) and 1-[4-(3-(hydroxymethyl)-5-methoxyphenoxy)-2-methoxy-6-methylphenyl]-ethanone (10, Figure 1), were also purified from the same fungus. Compounds 9–10 exhibited anti-MRSA activity with good inhibition (zones of 13.8 and 14.6 mm, respectively) [22].

Three new di-Ph ethers, 4-(3-methoxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-methyl phenol (11), 4-(3-hydroxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-methylphenol (12) and 4-(3-methoxy-5-methylphenoxy)-2-(3-hydroxypropyl)-6-methylphenol (13, Figure 1) were purified from *Phomopsis fukushii* associated with the rhizome of *Paris polyphylla var. yunna-
nensis. Compounds 11–13, exhibited potent anti-MRSA activity, with 20.2, 17.9 and 15.2 mm inhibition zones, respectively, when tested at 50 µg concentration in 6 mm discs [23].

Phomopsis fukushii isolated from the rhizome of Paris polyphylla var. yunnanensis yielded three new isopentylated diphenyl ethers, 1-(4-(3-methoxy-5-methylphenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (14), 1-(4-(3-hydroxymethyl)-5-methoxyphenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (15) and 1-(4-(3-hydroxy-5-(hydroxym ethyl) phenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (16, Figure 1). Compounds 14–16 displayed anti-MRSA activity with 21.8, 16.8 and 15.6 mm inhibition zones, respectively (50 µg/6 mm disc) [24].

Phomopsis fukushii isolated from the rhizome of Paris polyphylla var. yunnanensis yielded three new isopentylated diphenyl ethers, 1-(4-(3-methoxy-5-methylphenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (14), 1-(4-(3-hydroxymethyl)-5-methoxyphenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (15) and 1-(4-(3-hydroxy-5-(hydroxym ethyl) phenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (16, Figure 1). Compounds 14–16 displayed anti-MRSA activity with 21.8, 16.8 and 15.6 mm inhibition zones, respectively (50 µg/6 mm disc) [24].

Two new anthraquinones, 3-hydroxy-6-hydroxymethyl-2,5-dimethylanthraquinone (17) and 6-hydroxymethyl-3-methoxy-2,5-dimethylanthraquinone (18, Figure 1), were purified from the endophytic fungus Phomopsis sp. and displayed good anti-MRSA activity with inhibition zone diameters (IZDs) of 14.2 and 14.8 mm, respectively [25].

A new dihydroisocoumarin derivative diaporone A (19, Figure 1), was purified from Diaporthe sp. an endophyte of Pteroceltis tatarinowii. Compound 19 showed MIC at 66.7 µM against Bacillus subtilis [26].

A pair of new phenolic bisaboline-type sesquiterpenoid enantiomers (±)-phomoterp enes A and B ([±]-1) (20) along with two new isocoumarins, phomoisocoumarins C-D (21–22, Figure 1) were purified from an endophytic fungus Phomopsis prunorum (F4-3). Compounds (+)-1 (20 and 22) exhibited average antimicrobial activity against Pseudomonas syringae pv. lachrymans with MIC values of 15.6 µg/mL, and compounds (−)-1 (20 and 21) displayed poor activity with MICs of 31.2 µg/mL each. Compounds (−)-1, (+)-1, (20, 21, 22) showed antibacterial activity against Xanthomonas citri pv. phaseoli var. fuscans with MIC values of 31.2, 62.4, 31.2, and 31.2 µg/mL, respectively [27].

The fungus Diporthe vochysiae LGMF1583 isolated from Vochysia divergens yielded two new carboxamides, vochysiamides A (23), and B (24, Figure 2). Compound 24 inhibited Klebsiella pneumoniae carbapenemase-producing (KPC), MSSA, and MRSA with MIC of 0.08, 1.0, and 1.0 µg/mL, respectively, and compound 23 was active against KPC with a MIC of 1.0 µg/mL. KPC is of public health concern due to the presence of antimicrobial resistance carbapenemases [28].

An endophyte Phomopsis asparagi obtained from the rhizome of Paris polyphylla var. yunnanensis was the source of two new di-Ph ethers, 4-(3-methoxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-(hydroxymethyl)phenol (25), and 4-(3-hydroxy-5-(methylphenoxy)-2-(2-hydroxyethyl)-6-(hydroxymethyl)phenol (26, Figure 2). Compounds 25 and 26 exhibited potent anti-MRSA activity with 10.8 and 11.4 mm inhibition zones, respectively [29].

Two new naphthalene derivatives, 5-methoxy-2-methyl-7-(3-methyl-2-oxobut-3-enyl)-1-naphthaldehyde (27) and 2-(hydroxymethyl)-5-methoxy-7-(3-methyl-2-oxobut-3-enyl)-1-naphthaldehyde (28, Figure 2), were characterized from Phomopsis sp., an endophyte of Paris polyphylla var. yunnanensis. Compounds 27 and 28 displayed potent antibacterial activity with 14.5 and 15.2 mm zones of inhibition, respectively, against MRSA [30].

The endophytic fungus Diaporthe terebinthifolii LGMF907 associated with the plant Schinus terebinthifolius yielded diaporthin (29) and orthosporin (30, Figure 2). Compound 29 displayed antimicrobial activity against various pathogens like E. coli, Micrococcus luteus, MRSA, and S. aureus with 1.73, 2.47, 9.50, and 9.0 mm zones of inhibition, respectively at 100 µg/disk concentration. Compound 30 inhibited E. coli, M. luteus, MRSA, and S. aureus with 1.03, 1.53, 9.0 and 9.33 mm zones of inhibition, respectively, when tested at 100 µg/disk [31].
Figure 2. Structures of metabolites 23–37 isolated from Ascomycetes.

A pyrimidine iminomethylfuran derivative, (2Z)-2-(1,4-dihydro-2-hydroxy-1-((E)-2-mercaptop-1-(methylimino)ethyl)pyrimidine-4-ylimino)-1-(4,5-dihydro-5-methylfuran-3-yl)-3-methylbutane-1-one (31, Figure 2) was extracted from *Phomopsis/Diaporthe* sp. GJJM 16 is associated with *Vitex negundo* and inhibited *S. aureus*, and *P. aeroginosa* with MICs of 1.25 µg/mL each [32].

*Phomopsis* sp. PSU-H188 associated with *Hevea brasiliensis*, yielded the known compounds diaporthalasin (32), cytosporones B (33) and cytosporones D (34, Figure 2). Compound 32, displayed antibacterial activity against *S. aureus* and MRSA with equal MIC values of 4 µg/mL, but compound 33 inhibited *S. aureus* and MRSA with MIC values of 32 and 16 µg/mL, respectively. Compound 34 also inhibited *S. aureus* and MRSA with MIC values at higher concentrations of 64 and 32 µg/mL, respectively [33].

An endophyte, *Diaporthe terebinthifolii* GG3F6, associated with *Glycyrrhiza glabra* yielded two new hydroxylated unsaturated fatty acids namely diapolic acid A–B (35–36) and the known molecules xylarolide (37, Figure 2) and phomolide G (38, Figure 3). Compounds 35–38 inhibited *Yersinia enterocolitica* with an IC₅₀ values of 78.4, 73.4, 72.1 and 69.2 µM, respectively [34].
The compounds phomosine A (39), and phomosine C (40, Figure 3), were obtained from *Diaporthe* sp. F2934 from *Siparuna gesnerioides*. Compound 39 was found to be active against *Bordetella bronchiseptica*, *Enterococcus faecalis*, *Enterococcus cloacae*, *S. aureus*, and *Streptococcus oralis* with 10, 10, 10, 12 and 9 mm inhibition zones at 4 µg/mL concentration, respectively. Compound 40 inhibited *S. aureus*, *M. luteus*, *S. oralis*, *E. faecalis*, *E. cloacae*, and *B. bronchiseptica*, with 9, 6, 8, 8, 8 and 9 mm inhibition zones at 4 µg/mL concentration, respectively [35].

Known cytochalasins 18-methoxyctochalasin J (41), cytochalasins H (42), J (43) and alternariol (44, Figure 3) were extracted from *Phomopsis* sp., residing inside *Garcinia kola* nuts. Compounds 41–44 were found to be active against *Shigella flexneri* (MIC, 128 µg/mL...
each). Compounds 41 and 42 showed activity against S. aureus with MIC values of 128 and 256 µg/mL, respectively [36].

The fungal culture Diaporthe sp. LG23, an endophyte of Mahonia fortune, yielded some new lanostanoids, 19-nor-lanosta-5(10),6,8,24-tetraene-1α,3β,12β,22S-tetraol (45), 3β,5α,9α-trihydroxy-(22E,24R)-ergosta-7,22-dien-6-one (46), and chaxine C (47, Figure 3). Compound 45 was found to be active against S. aureus, E. coli, B. subtilis, Pseudomonas aeruginosa, and Streptococcus pyogenes, with MIC values of 5.0, 5.0, 2.0, 2.0 and 0.1 µg/mL, respectively. Compounds 46 and 47 were active against B. subtilis with MIC values of 5.0 µg/mL each [37].

The known compound, pyrrolocin A (48, Figure 3), was purified from Diaporthales sp. E6927E isolated from Ficus sphenophyllum. Pyrrolocin A (48) displayed inhibition against S. aureus and E. faecalis with MICs of 4 and 5 µg/mL, respectively [38].

2.1.2. Xylaria

The genus Xylaria comprises various endophytic species associated with both vascular and nonvascular plants. For example, ellisiamide A (49, Figure 3) was isolated from Xylaria ellisii from Vaccinium angustifolium and was chemically characterized using 1D and 2D NMR, HRMS/MS data. It showed modest inhibitory activity against E. coli (MIC, of 100 µg/mL) [39].

Xylareremophil (50), a new eremophilane sesquiterpene, along with the already reported eremophilanes mairielolides B (51) and G (52, Figure 3) were extracted from Xylaria sp. GDG-102 residing inside S. tonkinensis. Compound 50 displayed moderate activity against Proteus vulgaris and Micrococcus luteus (MIC, of 25 µg/mL each). Compound 51 was found to be active against M. luteus, with a MIC value of 50 µg/mL. Compound 52 inhibited P. vulgaris with a MIC value of 25 µg/mL and M. luteus with a MIC value of 50 µg/mL. Compounds 50–52 also displayed inhibition of B. subtilis and Micrococcus lysodeikticus with MIC values of 100 µg/mL, respectively [40].

A new compound, 6-heptanoyl-4-methoxy-2H-pyran-2-one (53, Figure 3), was purified from Xylaria sp. (GDG-102) an endophyte of S. tonkinensis and displayed antibacterial activity against E. coli as well as S. aureus (MIC, 50 µg/mL) [41].

The phthalide derivative xylophthalide A (54) and known compounds (−)-5-carboxyl mellein (55, Figure 3) and (−)-5-methylmellein (56, Figure 4) were extracted from Xylaria sp. (GDG-102) associated with S. tonkinensis. Compound 54 inhibited Bacillus anthracis, B. megaterium, B. subtilis, S. aureus, E. coli, Shigella dysenteriae and Salmonella paratyphi, with the MICs of 50, 25, 12.5, 25, 12.5, 25 and 25 µg/mL, respectively. Compound 55 showed antibacterial activity with MIC of values of 25, 25, 12.5, 25, 25, 25 and 25 µg/mL against B. anthracis, B. megaterium, B. subtilis, S. aureus, E. coli, S. dysenteriae and S. paratyphi, respectively. Compound 56 displayed antibacterial activity with MIC values of 25, 12.5, 12.5, 25, 25, 25 and 50 µg/mL against B. megaterium, B. subtilis, S. aureus, E. coli, S. dysenteriae and S. paratyphi, respectively [42].

A novel compound 3,7-dimethyl-9-(2,2,5,5-tetramethyl-1,3-dioxolan-4-yl)nona-1,6-dien-3-ol (57), and previously reported compound nalgiovensin (58, Figure 4) were purified from Xylaria sp., associated with Taxus mairei. Compound 57 exhibited strong inhibition against B. subtilis (48.1%), B. pumilus (31.6%) and S. aureus (47.1%). Compound 58 exhibited broad inhibition against S. aureus (42.1%), B. subtilis (36.8%), B. pumilus (47.1%) and E. coli (41.2%) [43].
2.1.3. Chaetomium

The genus Chaetomium has been included among the genera producing various bioactive compounds and more than 200 secondary metabolites belonging to diverse structural types such as anthraquinones, azaphilones, chaetoglobosins, chromones, depsidones, epipolythiodioxopiperazines, terpenoids, and steroids and xanthones have been recorded, making it a rich source of novel bioactive metabolites. Most of these fungal metabolites exhibited antitumor, cytotoxic, antimalarial, enzyme inhibitory, antibiotic, and other activities [44]. Here we report the antibacterial compounds isolated from the genus Chaetomium.
A new xanthoquinodin B9 (59), along with previously reported two xanthoquinodins, xanthoquinodin A1 (60) and xanthoquinodin A3 (61), and three epipolythiodioxopiperazines, chetomin (62), chaetocochin C (63) and dethiotetramethylthioc)chetomin (64, Figure 4), were obtained from C. globosum 7s-1, associated with Rhapis cochinchinensis. Xanthoquinodins 59–61 displayed potent antibacterial activity, with MIC values of 0.87, 0.44 and 0.22 µM against B. cereus, respectively. Compounds 59–61 were also found active against S. aureus and MRSA (MICs in the range of 0.87 to 1.75 µM). Epipolythiodioxopiperazines 62–64 exhibited potent activity against B. cereus, S. aureus, and MRSA (MICs in the range of 0.02 pM to 10.81 mM). Compound 62 showed the highest activity towards B. cereus, S. aureus and MRSA (MICs of 0.35 µM, 10.74 and 0.02 pM). Compounds 59–64 showed poor activity against E. coli, P. aeruginosa, and Salmonella typhimurium (MICs of 45.06 to >223.72 µM). Epipolythiodioxopiperazines 62–64 showed activity against Mycobacterium tuberculosis with MICs of 0.55, 4.06 and 8.11 µM, respectively [45].

Known compounds chaetocochin C (63), chetomin A (65) and chetomin (62, Figure 4) were extracted from Chaetomium sp. SYP-F7950 residing inside Panax notoginseng. Compounds 62, 63 and 65 displayed potent activity against B. subtilis, S. aureus, and Enterococcus faecium, with MIC values ranging from 0.12 to 19.3 µg/mL. The length of B. subtilis was increased up to 1.8-fold after treatment with compounds 62, 63 and 65. These compounds also showed good interactions with the filamentous temperature-sensitive protein Z (FtsZ) of B. subtilis in an in silico molecular docking study. These results revealed that inhibition of pathogenic B. subtilis could be achieved by combination with FtsZ and inhibition of cell division [46].

Compounds differanisole A (66), 2,6-dichloro-4-propylphenol (67) and 4,5-dimethylresorcino (68, Figure 4), were purified from Chaetomium sp. HQ-1, isolated from Astragalus chinensis. Compounds 66–68 displayed average activity against Listeria monocytogenes, S. aureus, and MRSA (MICs ranging from 16 to 128 µg/mL). Compound 66 showed a MIC of 16 µg/mL for L. monocytogenes and a MIC of 128 µg/mL for S. aureus and MRSA. Compounds 67 and 68 could suppress the growth of L. monocytogenes with MICs of 64 and 32 µg/mL, respectively [47].

A novel cytochalasan, chamiside A (69, Figure 4), was obtained from Chaetomium nigricolor F5, an endophytic fungus associated with Mahonia fortune collected from Qingdao (China) and showed inhibition of S. aureus with a MIC of 25 µg/mL [48].

A known compound, equisetin (70, Figure 4), was purified from C. globosum of Salvia miltiorrhiza. Compound 70 displayed activity against multidrug-resistant E. faecalis, E. faecium, S. aureus, and S. epidermidis with MIC values of 3.13, 6.25, 3.13, and 6.25 µg/mL, respectively [49].

Chaetomium sp. Eef-10, from Eucalyptus exserta yielded a new depsidone mollicellin O (71), along with the known compounds mollicellin H (72) and mollicellin I (73, Figure 5). Mollicellin H (72) displayed potent activity against S. aureus and S. aureus N50, with IC₅₀ values of 5.14 and 6.21 µg/mL, respectively. Mollicellin O (71) exhibited antibacterial activities against S. aureus and S. aureus N50, with IC₅₀ values of 79.44 and 76.35 µg/mL, respectively, while mollicellin I (73) exhibited activity against S. aureus and S. aureus N50 with IC₅₀ values of 70.14 and 63.15 µg/mL, respectively [50].
A new compound, 6-formamidochetomin (74, Figure 5) was isolated from Chaetomium sp. M336 an endophyte of Huperzia serrata. Compound 74 inhibited E. coli, S. aureus, S. typhimurium and E. faecalis with MIC values of 0.78 µg/mL [51].

Two known cytochalasans, chaetoglobosin A (75) and C (76, Figure 5), were purified from Chaetomium globosum, an endophyte of Nymphaea nouchali. Compound 75 inhibited B. subtilis, S. aureus, and MRSA with MIC values of 16, 32 and 32 µg/mL, respectively, and the MIC values for compound 76 were >64 µg/mL for all the microorganisms tested [52].

2.1.4. Talaromyces

An endophytic fungus Talaromyces pinophilus XL-1193 residing inside the plant Salvia miltiorrhiza yielded a new polyene, pinophol A (77, Figure 5). Pinophol A (77) exhibited low activity against Bacterium paratyphosum B with a MIC value of 50 µg/mL [53].

The compounds talaroconvolutin A (78) and talaroconvolutin B (79, Figure 5), were discovered in Talaromyces purpureogenus XL-25, an endophyte associated with Panax notoginseng. Compound 78 showed pronounced activity against B. subtilis (MIC, 1.56 µM). Compound 79 had a certain inhibitory activity against Micrococcus lysodeikticus (MIC = 0.73 µM) and Vibrio parahaemolyticus (MIC = 0.18 µM) [54].
A drimane sesquiterpenoid (1S,5S,7S,10S)-dihydroxyconfertifolin (80, Figure 5) was purified from *Talaromyces purpureogenus* residing inside the plant *Panax notoginseng*. Compound 80 inhibited *E. coli* with a MIC value of 25 µM/L [55].

A novel polyketide, talafun (81), and a new compound, N-(2′-hydroxy-3′-octadecenoyl)-9-methyl-4,8-sphingadienin (82, Figure 5), were purified from *Talaromyces funiculosus* Salicorn 58 together with some previously reported compounds, chrodrimanin A (83), and chrodrimanin B (84, Figure 6). Compound 81 exhibited potent activity against *E. coli* (MIC, 18 µM) but poor activity toward *S. aureus* (MIC, 93 µM). Compound 82 was found to be active against *Mycobacterium smegmatis*, *S. aureus*, *Micrococcus tetragenus*, and *E. coli*, with MIC values of 85, 90, 24, and 68, 93 µM, respectively. Compound 83 inhibited *S. aureus*, *M. tetragenus*, *Mycobacterium phlei*, and *E. coli* (MICs of 67, 28, 47, and 26 µM). However, compound 84 showed only moderate activity against *E. coli* with a MIC of 43 µM [56].

![Figure 6. Structures of metabolites 83–102 isolated from Ascomycetes.](image-url)
Alkaloids 85–90 (Figure 6), were extracted from Talaromyces sp. LGT-2, from Tripterygium wilfordii. Compounds 85–90 inhibited E. coli, P. aeruginosa, S. aureus, Bacillus licheniformis, and Streptococcus pneumoniae, with MIC values in the range of 0.125 to 1.0 50 µg/mL [57].

2.1.5. Minor Taxa of the Ascomycetes

The known compound euphorbol (91, Figure 6) was isolated from Rhytidhysteron sp. BZM-9, an endophyte isolated from the leaves of Leptospermum brachyandrum. Compound 91 displayed weak antibacterial activity against MRSA, with a MIC value of 62.5 µg/mL (positive control vancomycin MIC 1.25 µg/mL) [58].

A new natural product, stagonosporopsin C (92, Figure 6) was purified from an endophytic fungus, Stagonosporopsis oculihominis, isolated from Dendrobium huoshanense. Stagonosporopsin C (92) exhibited moderate inhibitory activity against S. aureus sub sp. aureus ATCC29213 with a MIC 50 value of 41.3 µM (positive control penicillin G, MIC 50 value 1.963 µM) [59].

Two new compounds eutyscoparols H-I (93, 94, Figure 6) together with the related known ones tetrahydroauroglaucin (95) and flavoglaucin (96, Figure 6), were isolated from the endophytic fungus Eutypella scoparia SCBG-8. Compounds 93–96 displayed growth inhibition against S. aureus and MRSA, with MIC values ranging from 1.25 to 6.25 µg/mL [60].

A new sesquiterpene eutyscoparin G (97, Figure 6) was purified from an endophytic fungus Eutypella scoparia SCBG-8 isolated from leaves of Leptospermum brachyandrum from the South China Botanical Garden (SCBG, Chinese Academy of Sciences, Guangzhou, China). Compound 97 exhibited antibacterial activity against S. aureus and MRSA with MIC values of 6.3 µg/mL [61].

Two new helvolic acid derivatives named saroclactone A (98), saroclactone B (99), along with the previously reported compounds helvolic acid (100), helvolinic acid (101), 6-desacetoxyhelvolic acid (102, Figure 6), and 1,2-dihydrohelvolic acid (103, Figure 7), were isolated from Sarocladium oryzae DX-THL3, associated with leaves of Oryza rufipogon Griff. Compounds 98–103 showed antibacterial activity against S. aureus with MIC values of 64, 4, 8, 1, 4 and 16 µg/mL, respectively (positive control tobramycin MIC 1 µg/mL), while compound 101 also showed antibacterial activity against B. subtilis with a MIC value of 64 µg/mL (positive control tobramycin, MIC 64 µg/mL). Compounds 98, 101, 103, showed some potent antibacterial activity against E. coli with MIC 64 µg/mL [62].

The diketopiperazine cyclo(L-Pro-L-Phe) (104, Figure 7), was purified from Paraphaeosphaeria sporulosa, associated with Fragaria x ananassa. Compound 104 displayed activity against Salmonella strains, S1 and S2, with IC 50 values of 7.2 and 7.9 µg/mL and MICs of 71.3 and 78.6 µg/mL, respectively [63].

A fungal culture of Aplosporella javeedii isolated from Orychophragmus violaceus was the source of terpescatin (105) fusaproliferin (106), 6,7,9,10-tetrahydromutolide (107) and mutolide (108, Figure 7). Compounds 105, 106, 108 showed poor activities against M. tuberculosis H37Rv and compound 107 against S. aureus, respectively, with MICs of 100 µM [64].

A new chlamydosporal derivative pleospyrone E (109, Figure 7), was extracted from Pleosporales sp. Sigfr05, residing inside the tuberous roots of Siraitia grosvenorii. Compound 109 exhibited weak inhibition against Agrobacterium tumefaciens, B. subtilis, R. solanacearum, and X. vesicatoria with the same MIC value of 100.0 µM [65].
New polyketides aplojaveediins A and F (110, 111, Figure 7) were purified from the *Aplosporella javeedii* associated with the *Orychophragmus violaceus*. Compound 110 exhibited average activity against the sensitive *Staphylococcus aureus* strain ATCC 29213, the methicillin-resistant and vancomycin-intermediate sensitive (MRSA/VISA) *S. aureus*.
strain ATCC 700699 and \textit{B. subtilis} (ATCC 169) with MICs of 50, 50 and 25 μM, respectively. Compound 111 also exhibited moderate inhibition against \textit{S. aureus} ATCC 29213 and ATCC 700699 with MICs of 25 and 50 μM, respectively [66].

A new chromone, lawsozaheer (112, Figure 7), was isolated from \textit{Paecilomyces variotii} from \textit{Lawsonia alba}. Compound 112 showed activity against \textit{S. aureus} (NCTC 6571) with 84.26% inhibition at 150 μg/mL [67].

A known polyketide, setosol (113, Figure 7), was extracted from an endophytic fungus \textit{Preussia isomera} in \textit{Panax notoginseng} from Wenshan, by using an OSMAC strategy. Compound 113 displayed potent activity against multidrug-resistant \textit{E. faecium}, methicillin-resistant \textit{S. aureus} and multidrug-resistant \textit{E. faecalis} with MIC values of 25 μg/mL [68].

A pair of enantiomeric norsesquiterpenoids, (+)- (114) and (−)-preisolactone A (115, Figure 7) featuring an unprecedented tricyclo[4.4.01,6.02,8]decane carbon scaffold were isolated from \textit{Preussia isomera}. XL-1326, obtained from the stems of \textit{Panax notoginseng}, Compounds (+)-l and (−)-l are 2 rare naturally occurring sesquiterpenoidal enantiomers. Compounds 114 and 115 exhibited potent antibacterial activity against \textit{Micrococcus luteus} and \textit{B. megaterium} with MIC values of 10.2 and 163.4 μM, respectively [69].

A new α-pyrene derivative, udagawanone A (116, Figure 7) was isolated from \textit{Neurospora udagawae} associated with \textit{Quercus macranthera}, and displayed moderate inhibition against \textit{S. aureus} (MIC = 66 μg/mL) [70].

Five chromone derivatives, including 2,6-dimethyl-5-methoxy-7-hydroxycromone (117), 6-hydroxymethylugenin (118), 6-methoxymethylugenin (119), and isoeugenitol (120), and isocoumarin congeners, 8-hydroxy-6-methoxy-3-methylisocoumarin (121, Figure 7) and diaporthin (29), were purified from \textit{Xylomelasma} sp. Samif07, an endophyte of \textit{Salvia miliitiorrhiza}. Compound 120 showed good activity against \textit{M. tuberculosis} (MIC 10.31 μg/mL). Compounds 29, 117–121 displayed inhibitory activities against \textit{B. subtilis}, \textit{Staphylococcus haemolyticus}, \textit{A. tumefaciens}, \textit{Erwinia carotovora}, and \textit{X. vesicatoria} (with MICs ranging from 25 ~ 100 μg/mL). Compounds 117 and 29 showed inhibition against only \textit{E. carotovora} (MIC, 100 μg/mL), and \textit{B. subtilis} (MIC, 50 μg/mL), respectively. Compounds 118, 119, 29 were found active against \textit{S. haemolyticus} and \textit{E. carotovora} (MIC of 75 μg/mL), whereas compound 121 exhibited stronger inhibition against \textit{B. subtilis}, \textit{A. tumefaciens}, and \textit{X. vesicatoria}, with MICs of 25, 75, and 25 μg/mL, respectively [71].

The compound (45,55,65)-5,6-epoxy-4-hydroxy-3-methoxy-5-methylcyclohex-2-en-1-one (122, Figure 7) was purified from \textit{Amphirosellinia nigrospora} JS-1675, an endophytic fungus isolated from the stem tissue of \textit{Pteris cretica}. Compound 122 showed high to moderate in vitro antibacterial activity, with MIC values ranging between 31.2 and 500 μg/mL against \textit{Pectobacterium carotovorum} subsp. \textit{Carotovorum}, \textit{Agrobacterium conjaci}, \textit{Burkholderia glumae}, \textit{Clavibacter michiganensis} subspp. \textit{michiganensis}, \textit{A. tumefaciens}, \textit{Pectobacterium chrysanthemi}, \textit{R. solanacearum}, \textit{Acidovorax avenae} subspp. \textit{cattleya}, \textit{Xanthomonas arboricola} pv. \textit{pruni}, \textit{X. euvesicatoria}, \textit{X. axonopodis} pv. \textit{Citri}, \textit{X. oryzae} pv. \textit{oryzae} [72].

Two new alkylated furan derivatives, 5-(undeca-3′,5′,7′-trien-1′-yl)furan-2-ol (123) and 5-(undeca-3′,5′,7′-trien-1′-yl)furan-2-carbonate (124, Figure 7), were isolated from \textit{Emericella} sp. XL029, an endophyte of \textit{Panax notoginseng}. Compounds 123, 124 inhibited \textit{B. subtilis}, \textit{B. cereus}, \textit{S. aureus}, \textit{B. paratyphosum} B, \textit{S. typhi}, \textit{P. aeruginosa}, \textit{E. coli}, and \textit{E. aerogenes} with MIC values ranging from 6.3 to 50 μg/mL [73].

Four new compounds, 14-hydroxytajixanthone (125), 14-hydroxytajixanthone hydrate (126, Figure 7), 14-hydroxy-15-chlorotajixanthone hydrate (127) and epitajixanthone hydrate (128), along with known compounds tajixanthone hydrate (129), 14-methoxytajixanthene-25-acetate (130), and 15-chlorotajixanthone hydrate (131), questin (132) and carnemycin B (133, Figure 8), were purified from \textit{Emericella} sp. XL029 residing inside the leaves of \textit{Panax notoginseng}. Compounds 125–127, 130, 132, 133 exhibited potent activity against \textit{M. luteus}, \textit{S. aureus}, \textit{B. megaterium}, \textit{B. anthracis}, and \textit{B. paratyphosum} B (MIC values ranging from 12.5 and 25 μg/mL). Compound 128 exhibited potent activity against \textit{M. luteus}, \textit{S. aureus}, \textit{B. megaterium}, and \textit{B. paratyphosum} B (MIC 25 μg/mL each), while compounds 129, 131 inhibited \textit{S. aureus}, \textit{B. megaterium}, and \textit{B. paratyphosum} B (MIC 25 and 12.5 μg/mL).
Compounds 125, 128, 133 displayed average activity against drug-resistant *S. aureus* (MICs 50 µg/mL each). All isolated compounds 125–133 displayed moderate activity against *P. aeruginosa*, *E. coli*, and *E. aerogenes* (MIC 50 µg/mL) [74].

An endophytic fungus *Byssochlamys spectabilis* from the plant *Edgeworthia chrysantha* yielded bysspectin C (134, Figure 8) which was active against *E. coli* and *S. aureus* with MIC values of 32 and 64 µg/mL, respectively [75].

Two new compounds, sydowianumols A (135), and B (136, Figure 8), were isolated from *Poculum pseudosydowianum* (TNS-F-57853), an endophytic fungus associated with the petiole of *Quercus crispula* var. *crispula* in Yoshiwa. Compounds 135 and 136 exhibited anti-MRSA activity, with MIC90 values of 12.5 µg/mL [76].

Six previously undescribed halogenated dihydroisocoumarins, palmaerones A–C, (137–139) and E–G (140–142, Figure 8) were purified from *Lachnum palmae*, an endophytic fungus from *Przewalskia tангутica* by exposure to a histone deacetylase inhibitor SAHA.

**Figure 8.** Structures of metabolites 127–144 isolated from Ascomycetes.
Compounds 137, 138, 140–142 were active against *B. subtilis*, with MIC values of 35, 30, 10, 50, and 55 µg/mL, respectively, while compounds 137–140, were found active against *S. aureus* with MIC values of 65, 55, 60, and 55 µg/mL, respectively [77].

The polyketide nemanifuranone A (143), a nor-dammarane triterpenoid, was isolated from *Nemania serpens*, an endophyte of *Vitis vinifera*. Additionally, a known metabolite 144, also a nor-dammarane triterpenoid (Figure 8) was isolated from the mycelium. Nemanifuranone A (143) showed modest activity against *E. coli*, with a MIC of 200 µg/mL, and significant inhibition (>75% inhibition) against *S. aureus*, *B. subtilis* and *M. luteus* at a concentration of 100–200 µg/mL. However, 144 showed significant inhibition (>75% inhibition) of *M. luteus* at a concentration of 100 µg/mL [78].

A sesquiterpene, variabilone (145, Figure 9), with a new skeleton, was isolated from the endophytic fungus *Paraconiothyrium variabile* isolated from *Cephalotaxus harringtonia*. Compound 145 behaved as a potent growth inhibitor of *B. subtilis* at an IC₅₀ of 2.13 µg/mL after 24 h [79].

A new 4-hydroxycinnamic acid derivative compound, methyl 2-\{(E)-2-[4-(formyloxy) phenyl]ethenyl\}-4-methyl-3-oxopentanoate (146), along with the known compounds (3R,6R)-4-methyl-6-(1-methylethyl)-3-phenylmethylperhydro-1,4-oxazine-2,5-dione (147), (3R,6R)-N-methyl-N-(1-hydroxy-2-methylpropyl)-phenylalanine (148), siccanol (149), sambutoxin (150, Figure 9) and fusaproliferin (106), were extracted from *Pyronema* sp. an endophyte of the *Taxus mairei*. Compounds 106, 146–150 also exhibited potential inhibitory activity, with IC₅₀s of 64, 59, 57, 84, 43 and 32 µM against *Mycobacterium marinum*, respectively [80].

Three new natural furanones, pulvinulin A (151), graminin C (152), and cis-gregatin B (153), together with the known fungal metabolite, graminin B (154, Figure 9), were isolated from *Pulvinula* sp. 11120, an endophyte of the leaves of *Cupressus arizonica*. Compounds 151–154 displayed antibacterial against *E. coli* with 12, 18, 16, and 14 mm zones of inhibition [81].

Stelliosphaerols A (155) and B (156, Figure 9), new sesquiterpene—polyol conjugates were purified from a *Stelliosphaera formicum* endophytic fungus associated with the plant *Duroia hirsuta*. Compounds 155 and 156 inhibited *S. aureus* with MIC values of 250 µg/mL [82].

Two novel polyketides, cis-4-acetoxyoxymellein (157) and 8-deoxy-6-hydroxy-cis-4-acetoxyoxymellein (158, Figure 9) were extracted from an unidentified ascomycete, associated with *Mellitotus dentatus*. Compound 157 was found to be active against *E. coli* and *B. megaterium* with 10 and 10 (partial inhibition) zones of inhibition at 0.05 mg concentration. Compound 158 displayed antibacterial activity against *E. coli* and *B. megaterium* with 9 and 9 (partial inhibition) zones of inhibition at a concentration of 0.05 mg [83].

2.2. Anamorphic Ascomycetes

Anamorphic Ascomycetes are the fungi that are the asexual form of ascomycetes. The first antibiotic penicillin-producing fungi belonged to this group. Fungi belonging to this group are prolific producers of bioactives metabolites. After the discovery of penicillin, this group is extensively screened for bioactives. Some important genera in this group are *Penicillium*, *Aspergillus*, *Fusarium*, *Pestalotiopsis*, *Phoma* and *Colletotrichum*. Here we report the antibacterials compounds from this group of fungi.
Aspergillus is one of the important fungal genera and some of the antibacterials from this genus such as aspochalasin P (159), alatinone (160), β-11-methoxycurvariline (161), and 12-keto-10,11-dehydrocurvularine (162, Figure 9) were purified from Aspergillus sp. FT1307 associated with plant Heliotropium sp. Compounds 159–162 showed weak activity against Staphylococcus aureus ATCC12600, Bacillus subtilis ATCC6633 and MRSA ATCC43300 with MICs in the range of 40 to 80 µg/mL [84].

A new polyketide, aspergillone A (163, Figure 10), was isolated from Aspergillus cristatus associated with Pinellia ternata. Aspergilline A (163) is the first example of a bicyclo[2.2.2]diazaoctane indole alkaloid where the diketopiperazine structure is constructed from tryp-
Aspergillone A (163) exhibited average antibacterial activities against *B. subtilis* and *S. aureus*, with MIC$_{50}$ values of 8.5 and 32.2 µg/mL, respectively [85].

A new quinolone derivative, (22S)-aniduquinolone A (164) and its known isomer (22R)-aniduquinolone A (165, Figure 10) were purified from the endophytic fungus *Aspergillus versicolor* strain Eich.5.2.2 from the petals of flowers of *Eichhornia crassipes*. The epimers 164/165 together exhibited significant antibacterial activity against *S. aureus*, with a MIC of 0.4 µg/mL [86].

A new diaryl ether derivative aspergillether B (166, Figure 10) was separated from *Aspergillus versicolor* residing inside the roots of *Pulicaria crispa*. Compound 166 exhibited...
significant antibacterial capacity towards *S. aureus*, *Bacillus cereus*, and *E. coli* with MICs values of 4.3, 3.7, and 3.9 µg/mL, respectively [87].

The known compound 3-O-β-D-glucopyranosyl stigmasta-5(6),24(28)-diene (167, Figure 10) was extracted from an endophytic fungus *Aspergillus ochraceus* SX-C7eus SX-C7 from *Setaginella stauntoniana* and displayed inhibitory activity against *B. subtilis* with a MIC value of 2 µg/mL [88].

A prenylated benzaldehyde derivative, dihydroauroglaucin (168, Figure 10), was isolated from *Aspergillus amstelodami* (MK215708) an endophytic fungi of *Ammi majus*, a plant indigenous to Egypt. Compound 168 showed activity against *E. coli*, *Streptococcus mutans* and *S. aureus*, with MICs of 1.95, 1.95 and 3.9 µg/mL, respectively. The highest antibiofilm activity at concentration 7.81 µg/mL against *S. aureus* and *E. coli* biofilms, at 15.63 µg/mL concentration against *S. mutans* and moderate activity (MBIC = 31.25 µg/mL) against *P. aeruginosa* biofilm was measured [89].

Two cysteine residue-containing merocytchalasans, cyschalasins A (169) and B (170, Figure 10) were isolated from *Aspergillus micronesiensis* associated with the root of *Phyllanthus glaucus*. Compounds 169 and 170 displayed anti-MRSA activity with MIC50 values of 17.5 and 10.6 µg/mL and MIC90 values of 28.4 and 14.7 µg/mL, respectively [90].

Methylsulochrin (171, Figure 10) is a diphenyl ether derivative isolated from *A. niger* associated with the stems of *Acanthus montanus*. It inhibits *Enterobacter cloacae*, *Enterobacter aerogenes* and *S. aureus* with MIC values of 7.8, 7.8 and 15.6 µg/mL, respectively [91].

A new furan derivative named 3-(5-oxo-2,5-dihydrofuran-3-yl) propanoic acid (172, Figure 10) was purified from *Aspergillus tubingensis*, an endophyte from the stems of *Decaisnea insignis*. Compound 172 inhibited *Streptococcus lactis* with MIC value of 32 µg/mL [92].

Aspergillus fumigatus, an endophyte associated with *Edgeworthia chrysantha*, was the source of pseurotin A (176) and spirotryprostatin A (177, Figure 10). Compounds 176, 177 displayed good antibacterial activity against *S. aureus* (MIC 0.39 µg/mL each). Compound 177 also showed potent antibacterial activity against *E. coli* (MIC of 0.39 µg/mL) [94].

Six compounds, fumiquinazoline J (178, Figure 10), fumiquinazoline I (179), fumiquinazoline C (180), fumiquinazoline H (181), fumiquinazoline D (182), and fumiquinazoline B (183, Figure 11) were extracted from *Aspergillus* sp., residing inside the plant *Astragalus membranaceus*. Compounds 178, 180–182 displayed potent activity against *B. subtilis*, *E. coli*, *P. aeruginosa* and *S. aureus* (MICs in the range of 0.5–8 µg/mL). Compounds 179, 183 displayed moderate activity against *B. subtilis*, *E. coli*, *P. aeruginosa* and *S. aureus* with MICs of 4–16 µg/mL [95].
Figure 11. Structures of metabolites 179–201 isolated from Anamorphic Ascomycetes.
An antibacterial polyketide named (-) palitantin (184, Figure 11) was isolated from *Aspergillus fumigatus affinis*, an endophyte of the medicinal plant *Tribulus terrestris*, which displayed antibacterial activity against *E. faecalis* UW 2689 and *S. pneumoniae* with MIC values of 64 µg/mL each [96].

A novel terpene-polyketide hybrid, i.e., a meroterpenoid, aspermerodione (185), and a new heptacyclic analog and iconin C (186, Figure 11) were purified from *Aspergillus* sp. TJ23 residing inside the plant *Hypericum perforatum*. Compound 185 showed antibacterial activity against MRSA (MIC of 32 µg/mL), whereas compound 186 showed poor anti-MRSA activity (>100 µg/mL). Aspemerodione (186) worked synergistically with the antibiotics oxacillin and piperacillin against MRSA and was found to be a potential inhibitor of PBP2a [97].

Aspergillus sp. YXf3, an endophyte residing inside the leaves of *Ginkgo biloba*, yielded some novel *p*-terphenyls named prenylterphenyllin D (187), prenylterphenyllin E (188), and 2′-O-methylprenylterphenyllin (189), along with the known compounds prenylterphenyllin (186) and prenylterphenyllin B (191, Figure 11). Compounds 187–191 displayed antibacterial activity against *X. oryzae* pv. *oryzicola* and *E. amylovora* with the same MIC values of 20 µg/mL, while compound 191 exhibited activity against *E. amylovora* with a MIC value of 10 µg/mL [98].

Nine new phenalenone derivatives, aspergillusanone D (192), aspergillusanone E (193), F (194) G (195) H (196), I (197), J (198), K (199), along with two known analogues, the aspergillusanones L (200 and 201, Figure 11) were extracted from *Aspergillus* sp. residing inside the plant *Pinellia ternata*. Compound 200 exhibited good antimicrobial activity against *P. aeruginosa*, *S. aureus*, and *B. subtilis* (MIC50 values of 1.87, 2.77, and 4.80 µg/mL). Compound 192 exhibited the antibacterial activity against *P. aeruginosa*, *S. aureus*, and *E. coli* (MIC50 of 7.83 µg/mL). Compound 194 exhibited antimicrobial activity against *P. aeruginosa* and *S. aureus*, (MIC50 of 38.47 and 29.91 µg/mL). Compound 193 was found to be selectively active against *E. coli* (MIC50 of 7.83 µg/mL). Compound 194 exhibited antimicrobial activity against *P. aeruginosa* and *S. aureus*, (MIC50 values of 26.56, 3.93 and 16.48 µg/mL). Compound 195 inhibited *P. aeruginosa*, and *S. aureus*, (MIC50 values of 24.46 and 34.66 µg/mL). Compound 196 inhibited *P. aeruginosa*, and *E. coli*, (MIC50 values of 8.59 and 5.87 µg/mL). Compound 197 selectively inhibited *P. aeruginosa*, (MIC50 of 12.0 µg/mL). Compound 198 exhibited activity against *P. aeruginosa*, *E. coli* and *S. aureus* with MIC50 values of 28.50, 5.34 and 29.87 µg/mL, respectively. Compound 199 exhibited antibacterial activity against *P. aeruginosa* and *S. aureus*, (MIC50 values of 6.55 and 21.02 µg/mL). Compound 201 inhibited *P. aeruginosa*, and *E. coli*, with MIC50 values of 19.07 and 1.88 µg/mL, respectively [99].

The compound terrein (202, Figure 12), a polyketide, was extracted from *Aspergillus terreus* JAS-2 associated with *Achyranthus aspera*. Terrein (202) exhibited antibacterial activity with an IC50 value of 20 µg/mL against *E. faecalis*, and more than 20 µg/mL against *Aeromonas hydrophila* and *S. aureus*, as the compound showed only 48% and 38.3% inhibition [100].
Figure 12. Structures of metabolites 202–220 isolated from Anamorphic Ascomycetes.

A known compound (22E,24R)-stigmasta-5,7,22-trien-3-β-ol (203, Figure 12), was purified from the Aspergillus terreus isolate of Carthamus lanatus. Compound 203 displayed potent anti-MRSA activity, with IC₅₀ values of 2.29 µM compared to ciprofloxacin (IC₅₀ 0.21 µM) [101].

A new furan derivative named 5-acetoxymethylfuran-3-carboxylic acid (204), along with the furan compound 5-hydroxymethylfuran-3-carboxylic acid (205, Figure 12), were obtained from Aspergillus flavus, isolated from Cephalotaxus fortunei. The compounds 204–205 inhibited S. aureus with MIC values of 15.6 and 31.3 µg/mL, respectively [102].

A new compound, allahabadolactone B (206), and the known compound ergosterol peroxide (207, Figure 12) were purified from Aspergillus allahabadii BCC45335 residing inside the roots of Cinnamomum subavenium. Compounds 206–207 displayed antimicrobial activity against B. cereus with IC₅₀ values of 12.50 and 3.13 µg/mL, respectively [103].
A new pyrone named 6-isovaleryl-4-methoxy-pyran-2-one (208), along with three known pyrone compounds, rubrofusarin B (209), asperpyrone A (210) and campyprone A (211, Figure 12), was purified from Aspergillus tubingensis isolated from the roots of Lyceum ruthenicum. Compound 209 possessed potent activity against E. coli with a MIC of 1.95 µg/mL while the compounds 208, 210, 211 showed poor activity against E. coli, P. aeruginosa, S. aureus and Streptococcus lactis [104].

A new cyclic pentapeptide, malformin E (212, Figure 12), was extracted from Aspergillus tamarii FR02 associated with Ficus carica. Compound 212 displayed potent activity against B. subtilis, S. aureus, P. aeruginosa, and E. coli with MIC values of 0.91, 0.45, 1.82, and 0.91 µM, respectively [105].

A new butyrolactone, aspernonilide F (213), together with a known stigmastanol derivative, (22E,24R)-stigmasta-5,7,22-trien-3-β-ol (203, Figure 12), were purified from Aspergillus terreus, an endophyte of Carthamus lanatus. Compound 203 displayed a potent anti-MRSA activity, with an IC₅₀ value of 0.96µg/mL while compound 213 displayed poor anti-MRSA activity (IC₅₀ 6.39µg/mL) [106].

The metabolites 1-(3,8-dihydroxy-4,6,6-trimethyl-6H-benzochroman-2-yloxy)propane-2-one (214), 5-hydroxy-4-(hydroxymethyl)-2H-pyran-2-one (215) and 5-hydroxy-2-oxo-2H-pyran-4-yl)methyl acetate (216, Figure 12) were purified from Aspergillus sp. (SbdD5) associated with the plant Andrographis paniculata. Compounds 214–216 displayed poor to average activity against S. aureus, E. coli, S. dysenteriae and Salmonella typhi with an inhibition zone diameter ranging from 8.1 to 12.1 mm at a concentration 500 µg/mL [107].

The compounds xanthoascin (217), prenylterphenyllin B (218) and prenylcandidusin (219, Figure 12), were extracted from Aspergillus sp. IFB-YXS, associated with the leaves of Ginkgo biloba. Compound 217 displayed antibacterial activity against X. oryzae pv. oryzae, E. amylovora, P. syringae pv. lachrymans and C. michiganense subsp. sepedonicus with MICs of 20, 10, 5.0 and 0.31 µg/mL, respectively. Compound 218 exhibited antibacterial activities with MICs of 20 µg/mL each towards X. oryzae pv. oryzae, E. amylovora, P. syringae pv. lachrymans, respectively. Compound 219 was found to be effective against X. oryzae pv. oryzae and X. oryzae pv. oryzicola (MIC of 10 and 20 µg/mL). It was observed that compound 217 can change the permeability and cause nucleic acid leakage of the cytomembrane of the phytopathogen [108].

2.2.2. Penicillium

New β-resorcyclic acid lactones, including 4-O-desmethyl-aigialomycin B (220, Figure 12), and penochro lactones C (221), and D (222, Figure 13), were purified from Penicillium ochrocholoron SWUKD.1850 from the medicinal plant Kadsura angustifolia. Compounds 220–222 exhibited moderate activities against S. aureus, B. subtilis, E. coli, and P. aeruginosa with MIC values between 9.7 and 32.0 µg/mL [109].

The compound p-hydroxybenzaldehyde (223, Figure 13), was isolated from Penicillium brefeldianum, an endophyte residing inside the root bark of Syzygium zeylanicum. Compound 223 was found to be active against S. typhi, E. coli, and B. subtilis with MIC values of 64 g/mL. p-Hydroxybenzaldehyde was also reported from Syzygium zeylanicum [110].

An endophytic fungus, Penicillium vulpinum GDGJ-91, from the roots of Sophora tonkinensis, yielded the new compound 10-demethylated andrastone A (224), and four known analogs, 15-deacetylcreathrhybridone E (225), citreohybridol (226) and andrastins A (227) and B (228, Figure 13). Compounds 224 and 227 displayed good activity against Bacillus megaterium (MIC value of 6.25 µg/mL), and compounds 225, 226, 228 showed average activity against Bacillus megaterium (MIC of 25, 12.5 and 25 µg/mL). Compound 226 showed potent antibacterial activity against B. paratyphosus B at 6.25 µg/mL, while the other compounds showed average activities against B. paratyphosus B at 12.5 or 25 µg/mL and compound 226 also exhibited moderate activities against E. coli and S. aureus with MIC values of 25 µg/mL [111].
A novel N-methoxy-1-pyridone alkaloid, chromenopyridin A (229), and the already reported compound viridicatol (230, Figure 13) were purified from Penicillium nothofagi P-6, residing inside the bark of Abies beshanzuensis. Compounds 229 and 230 exhibited antibacterial activity against S. aureus, with MIC values of 62.5 and 15.6 µg/mL, respectively [112].
ω-Hydroxyemodin (231, Figure 13) a polyhydroxy anthraquinone, was extracted from *Penicillium restrictum* (strain G85) from *Silybum marianum*. Compound 231 showed inhibition against MRSA as a quorum sensing inhibitor in both in vitro and in vivo systems [113].

Two new phthalide derivatives, (−)-3-carboxypropyl-7-hydroxyphthalalide (232) and (−)-3-carboxypropyl-7-hydroxyphthalalide methyl ester (233, Figure 13), were isolated from *Penicillium vulpinum* residing inside the plant *S. tonkinensis*. Compound 232 exhibited a medium inhibition against *Shigella dysenteriae*, *Enterobacter aerogenes*, *B. subtilis*, *B. megaterium*, and *Micrococcus luteus* with MIC value between 12.5–50 µg/mL. Compound 233 showed average activity against *E. aerogenes* with MIC value of 12.5 µg/mL, and showed poor activity against *B. subtilis*, *B. megaterium* and *M. luteus* with MIC values of 100 µg/mL [114].

Citridone E (234), a new phenylpyridone derivative, and the previously reported compound (−)-dehydrocurvularin (235, Figure 13) were purified from *Penicillium sumatrense* GZWMJZ-313 associated with the plant *Garcinia multiflora*. Compounds 234 and 235 showed antibacterial activity against *S. aureus*, *P. aeruginosa*, *Clostridium perfringens*, and *E. coli* (with MICs ranging from 32 to 64 µg/mL) [115].

Three new, 3,4,6-trisubstituted α-pyrone derivatives, namely 6-(2′R-hydroxy-3′E,5′E-diene-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (236), 6-(2′S-hydroxy-5′E-ene-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (237), and 6-(2′S-hydroxy-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (238), along with the previously reported compound trichodermin acid (239, Figure 13), were purified from *Penicillium ochrochloron* associated with *Taxus media*. Compounds 236–239 displayed antimicrobial activity with MIC values ranging from 25 to 50 µg/mL against *B. subtilis*, *B. megaterium*, *E. coli*, *Enterobacter aerogenes*, *Micrococcus luteus*, *Proteusbacillum vulgaris*, *P. aeruginosa*, *S. aureus*, *Salmonella enterica*, and *Salmonella typhi* [116].

Three new compounds, brasiliamide J-a (240), brasiliamide J-b (241) and penicilolide (242, Figure 13), as well as the known compound austin (243, Figure 14), were isolated from *Penicillium janthinellum* SYPF 7899 associated with the plant *Panax notoginseng*. Compound 240 exhibited potent activity against *B. subtilis* and *S. aureus* (MICs of 15 and 18 µg/mL). Compounds 241 and 243 showed average inhibitory activities against *B. subtilis* (MIC 35 µg/mL and 50 µg/mL, respectively) and *S. aureus* (MIC 39 µg/mL and 60 µg/mL, respectively). In addition, compound 240 also affected the length of *B. subtilis*. Similarly, coccoid cells of *S. aureus* also swelled 2-fold after treatment with compound 240. Compounds 240, 241, 242 showed high binding energies, strong H-bond interactions and hydrophobic interactions with filamentous temperature-sensitive protein Z (FtsZ) [117].

The new compounds penicimenolidyu A (244), and penicimenolidyu B (245) and the known compound rasfonin (246, Figure 14) were purified from *Penicillium cataractarum* SYPF 7131 obtained from the plant *Ginkgo biloba*. Compound 246 exhibited good antibacterial activity against *S. aureus*, with a MIC value of 10 µg/mL. Compounds 245 and 246 showed moderate inhibitory activity against *S. aureus* (MIC 65 µg/mL and 59 µg/mL). The docking results revealed that compounds 244–246 possess high binding energies, strong H-bond interactions and hydrophobic interactions with FtsZ from *S. aureus*, validating the observed antimicrobial activity [118].

A rare dichloroaromatic polyketide, 3′-methoxycitrivone (247) along with known metabolites cis-bis-(methylthio)-silvatin (248), citreovirene (249), trypacidin A (250, Figure 14) and helvolic acid (100), were obtained from endophytic *Penicillium sp.* of *Pinellia ternate*. Compound 100 displayed potent antibacterial activity against *S. aureus* and *P. aeruginosa* (MIC = 5.8 and 4.6 µg/mL) as well as mild activity against *B. subtilis* and *E. coli* (MIC = 42.2 and 75.0 µg/mL). Compounds 247 and 249 were found to have moderate antibacterial activity against *E. coli* and *S. aureus* (MIC = 62.6 and 76.6 µg/mL). Compounds 248 and 250 exhibited poor antibacterial activity against *S. aureus* with MIC values of 43.4 and 76.0 µg/mL and 250 also displayed effect against *B. subtilis* (MIC = 54.1 µg/mL) [119].
A known quinolinone alkaloids viridicatol (251, Figure 14) was obtained from *Penicillium* sp. R22 was associated with *Nerium indicum* and displayed potent antibacterial activity against *S. aureus* with MIC value of 15.6 µg/mL [120]. The novel compound penicitroamide (252, Figure 14), was purified from *Penicillium* sp. (NO. 24) isolated from the leaves of *Tapis-
cio sinensis. Compound 252 displayed potent antibacterial activity against plant pathogens, Erwinia carotovora sub sp. carotovora (Jones) Bersey, et al. with MICs at 45 µg/mL [121].

Penalidins A-C (253–255), citromycin (256), p-hydroxyphenylglyoxalaldoxime (257) and brefeldin A (258, Figure 14) were purified from the Penicillium sp. CAM64 a fungus associated with the plant Garcinia nobilis. Compounds 253–258, exhibited antibacterial activity against Vibrio cholerae SG24 (1), V. cholerae CO6, V. cholerae NB2, V. cholerae PC2, S. flexneri (MIC = 0.50–128 µg/mL). Compound 255 exhibited potent activity against V. cholerae SG24 (1), V. cholerae CO6, V. cholerae NB2, V. cholerae PC2, S. flexneri SDINT, with MIC values of 0.50, 16, 8, 0.50 and 8 µg/mL, respectively following in decreasing order of activity by compound 254 (MIC = 4–32 µg/mL), compound 257 (MIC = 8–32 µg/mL), compound 257 (MIC = 32–64 µg/mL) and compounds 256 and 258 (MIC = 64–128 µg/mL) [122].

Purpureone (259, Figure 14) was extracted from Purpureocillium lilacinum, residing inside the roots of Rauvolfia macrophylla. Compound 259 displayed antibacterial activity with the zone of inhibition of 10.6, 12.3, 13.0, 8.7, 12.3, and 10.0, mm against B. cereus, L. monocytogenes, E. coli, K. pneumoniae, P. stuartii, and P. aeruginosa (6 mm filter paper disks impregnated with 10 µL of compound) [123].

2.2.3. Fusarium

Secondary metabolites identified as 2-methoxy-6-methyl-7-acetyl-8-hydroxy-1,4-naphthalenedione (260), 5,8-dihydroxy-7-acetyl-1,4-naphthalenedione (261, Figure 14), anhydrojavanicin (262), and fusarnaphthoquinone B (263, Figure 15), were purified from Neocosmospora sp. MFLUCC17-0253 associated with Rhizophora apiculata. All three compounds showed potent antibacterial against Acidovorax citrulli (responsible for bacterial fruit blotch (BFB) a bacterial disease of Cucurbitaceae crops) with MIC values of 0.0075 mg/mL (mixture of 260, 261), 0.004 mg/mL (262), 0.025 mg/mL (263). Compounds 260–263 significantly inhibited biofilm development of Acidovorax citrulli, thus demonstrating that these metabolites can be used for biological control of bacterial fruit blotch of watermelon and melon [124].

A new aminobenzamidine derivative, namely fusaribenzamide A (264, Figure 15), was purified from Fusarium sp. of Mentha longifolia. Compound 264 displayed antibacterial activity against S. aureus and E. coli with MIC values of 62.8 and 56.4 µg/disc, respectively [125].

Two alkaloids, indol-3-acetic acid (265), bassiatin (266), a depsipeptide, beauvericin (267), two sesquiterpenoids, cycloneronadiol (268), epicycloneronadiol oxide (269), four 1,4-naphthoquinones, 5-O-methylisolaniol (270), 5-O-methyljavanicin (271), fusarubin methyl ether (272), and anhydrojavanicin (273, Figure 15) and a sesterterpene, fusaproliferin (106), were separated from the green Chinese onion-derived fungus F. proliferatum, residing inside the roots of Rauvolfia macrophylla, with MICs of 0.50, 16, 8, 0.50 and 8 µg/mL, respectively. Compounds 270–273 displayed good antibacterial activity against B. megaterium with MICs of 25 µg/mL each; compounds 265, 267, 269 displayed moderate activity with MICs of 50 µg/mL each and compound 268, displayed activity with an MIC of 12.50 µg/mL. Compounds 266, 270–272 displayed good antibacterial activity against B. subtilis, with MICs of 50 µg/mL each. Compounds 269 and 272 were found to be active against E. coli with MIC values of 50 µg/mL each and compounds 270, 271, 273 with MIC values of 25 µg/mL, respectively. Compounds 269–272 displayed antibacterial activity against Clostridium perfringens with MIC values of 50, 50, 12.5 and 50 µg/mL, respectively. Compounds 267, 106, 270–273 displayed anti-MRSA activity with MIC values of 50, 50, 12.5, 12.5, and 25µg/mL, respectively. Compounds 270–273 displayed antibacterial activity against RN4220 (MICs of 50 µg/mL each). Compounds 272, 273 showed inhibition against NewmanWT (MICs of 50 µg/mL each). Compound 266 displayed antibacterial activity against NewmanWT with a MIC value of 50 µg/mL each. [126].
Figure 15. Structures of metabolites 262–284 isolated from Anamorphic Ascomycetes.
**Fusarium** sp. TP-G1 an endophyte of *Dendrobium officinale*, was the source of the compounds trichosetin (274), beauvericin A (275), enniatin B (276), enniatin H (277), enniatin I (278), enniatin MK1688 (279), fusicaric acid (280) and dehydrofusaric acid (281, Figure 15) and beauvericin (267). Compounds 267, 274, 275, 277–279 displayed antibacterial activity against *S. aureus* and MRSA with IC₅₀ values in the range of 2–32 µg/mL. Compounds 280, 281 displayed antimicrobial activity against *Acinetobacter baumannii* with a MIC value of 64 µg/mL and 128 µg/mL, respectively. Compound 276 inhibited *S. aureus* and MRSA with IC₅₀ value of 128 µg/mL each [127].

A new spiromeroterpenoid, namely fusaritioamido A (282), together with the previously reported terpenoids asperterpenoid A (283) and agathic acid (284, Figure 15), were purified from *Fusarium* sp. YD-2 associated with the plant *Santalum album*. Compound 282 showed antibacterial activity against pathogenic *S. aureus* and *P. aeruginosa* (MIC of 6.5 µg/mL), and compound 283 showed average activity against pathogenic *Salmonella enteritidis* and *Micrococcus luteus* (MICs of 25.2 and 6.3 µg/mL). Compound 284 showed moderate activities against *B. cereus* and *M. luteus*, with MIC values of and 12.5 and 25.4 µg/mL, respectively [128].

A new aminobenzamide derivative, namely fusaritioamido B (285, Figure 16), was separated from *Fusarium chlamydosporium* an endophyte of *Anvillea garcinii* and exhibited antibacterial activity against *E. coli*, *B. cereus*, and *S. aureus* (MIC values of 3.7, 2.5 and 3.1 µg/mL) [129].

The compounds 3,6,9-trihydroxy-7-methoxy-4,4-dimethyl-1H-benzo[g]isochromene-5,10-dione (286), fusicarubin (287), 3-O-methylfusarubin (288) and javanicin (289, Figure 16) were extracted from *Fusarium solani* A2 residing inside the plant *Glycyrrhiza glabra*. Compounds 286–289 showed inhibition of *B. subtilis*, *B. cereus*, *E. coli*, *S. aureus*, *K. pneumonia*, *S. pyogenes*, and *Micrococcus luteus* (MICs in the range of < 1 to 256 µg/mL). Fusarubin (287) showed good activity against *M. tuberculosis* strain H37Rv with a MIC value of 8 µg/mL, whereas compounds 286, 288, 289 exhibited moderate activity with MIC values of 256, 64, 32 µg/mL, respectively [130].

A new benzamide derivative, furalithioamido A (290, Figure 16) was characterized from *Fusarium chlamydosporium*, an endophyte of *Anvillea garcinii*. Compound 290 had antibacterial potential towards *B. cereus*, *S. aureus*, and *E. coli* with MIC values of 3.1, 4.4, and 6.9 µg/mL, respectively [131].

The polyketide javanicin (289, Figure 16) was purified from *Fusarium* sp. associated with *Rhoeo spathacea*, and displayed activity against *M. tuberculosis* with a MIC value of 25 µg/mL and *M. phlei* with a MIC value of 50 µg/mL [132].

Helvolic acid methyl ester (291, Figure 16), a new helvolic acid derivative, together with previously reported hydrohelvolic acid (292, Figure 16), and helvolic acid (100) were isolated from a *Fusarium* sp. residing inside the plant *Ficus carica*. Compound 291 was found to be active against *B. subtilis*, *S. aureus*, *E. coli* and *P. aeruginosa* (MIC between 3.13 to 12.5, µg/mL). Compound 100 displayed activity against *B. subtilis*, *S. aureus*, *E. coli* and *P. aeruginosa* (MICs between 3.13 to 6.25 µg/mL). Compound 292 displayed activity against *B. subtilis*, *S. aureus*, *E. coli* and *P. aeruginosa* with MIC values between 3.13 to 12.5 µg/mL [133].

The compounds colletorin B (293) and 4,5-dihydroascochlorin (294, Figure 16) were purified from an endophytic *Fusarium* sp. fungus. Compounds 293 and 294 exhibited potent antibacterial activity towards *B. megaterium*, with 5 and 10 mm zones of inhibition at a concentration of 10 µg/mL [134].

The tetramic acid derivative equisetin (295, Figure 16) was isolated from a *Fusarium* sp. associated with *Opuntia dillenii*, and displayed antibacterial activity against *B. subtilis* with a MIC value of 8 and MICs of 16 µg/mL against *S. aureus* and MRSA [135].
Figure 16. Structures of metabolites 285–299 isolated from Anamorphic Ascomycetes.

2.2.4. Trichoderma

Pretrichodermamide A (296, Figure 16), a known compound, was isolated from Trichoderma harzianum, an endophyte of Zingiber officinale and displayed antimycobacterial activity towards M. tuberculosis with a MIC value of 25 µg/mL (50 µM) [136].

A new compound named koninginin W (297) and four known polyketides, namely koninginin D (298), 7-O-methylkoninginin D (299, Figure 16), koninginin T (300) and koninginin A (301, Figure 17) were isolated from the endophytic fungus Trichoderma koningiopsis YIM PH30002 of Panax notoginseng. Compounds 297, 298, 301, showed the weak activity against B. subtilis with MICs of 128 µg/mL. Compounds 297 and 299, showed weak activity against S. typhimurium, with MIC values of 64 and 128 µg/mL; Compounds 297 and 300, showed the weak activity against E. coli with MICs of 128 µg/mL. [137].
Figure 17. Structures of metabolites 300–323 isolated from Anamorphic Ascomycetes.

Five new carotane sesquiterpenes, trichocarotins I–M (302–306), which have diverse substitution patterns, and seven known related analogues including CAF-603 (307), 7β-hydroxy CAF-603 (308), trichocarotins E–H (309–312), and trichocarane A (313, Figure 17) were purified from Trichoderma virens QA-8, an endophytic fungus associated with the inner root tissue of Artemisia argyi. Compounds 302–313 displayed antibacterial activity against E. coli EMBLC-1, with MIC values ranging from 0.5 to 32 µg/mL, while 7β-hydroxy CAF-603 (308) displayed potent activity against Micrococcus luteus QDIO-3 (MIC = 0.5 µg/mL) [138].

Three new polyketides, trichodermaketone E (314), 4-epi-7-O-methylkoninginin D (315), and trichopyranone A (316), two new terpenoids, 3-hydroxyharziandione (317) and 10,11-dihydro-11-hydroxycyclonerodiol (318), together with three related known congeners, cyclonerodiol (319), 6-(3-hydroxypent-1-en-1-yl)-2H-pyran-2-one (320), and harziandione (321, Figure 17) were isolated from the endophytic fungus Trichoderma koningiopsis QA-3.
associated with the plant *Artemisia argyi*. Compounds 314, 316–318, 321 displayed potent activities against *E. coli*, with MIC values ranging from 0.5 to 64 µg/mL, while compounds 316–321 showed inhibitory activities against *M. luteus* with MIC values ranging from 1 to 16 µg/mL, compounds 314, 315, 317–321, showed inhibitory activities against *P. aeruginosa* with MIC values ranging from 4 to 16 µg/mL, and compounds 314, 318–321 showed activities against *V. parahaemolyticus* with MIC values ranging from 4 to 16 µg/mL. Among the compounds tested, compound 317 showed the strongest activity against *E. coli*, with a MIC value of 0.5 µg/mL and compound 320 showed the strongest activity against *M. luteus*, with a MIC value of 1 µg/mL, comparable to that of the positive control chloramphenicol [139].

New highly oxygenated polyketides, 15-hydroxy-1,4,5,6-tetra-epi-koninginin G (322), koninginin U (323, Figure 17) and 14-ketokoninginin B (324, Figure 18), were isolated from *Trichoderma koningiopsis* QA-3, isolated from *Artemisia argyi*. Compound 322 displayed good activity against the aquatic pathogen *Vibrio alginolyticus*, with a MIC value of 1 µg/mL. Compounds 323, 324 exhibited activity against aquatic bacteria *Vibrio harveyi* and *Edwardsiella tarda* with MICs of 4 and 2 µg/mL, respectively [140].

![Figure 18. Structures of metabolites 324–342 isolated from Anamorphic Ascomycetes.](image-url)
A new harziane diterpenoid with a 4/7/5/6 tetracyclic scaffold, harzianol I (325, Figure 18) was isolated from *Trichoderma atroviride* B7, an endophyte associated with the plant *Colquhounia coccinea* var. *mollis*. Compound 325 exhibited potent inhibitory activity against *S. aureus*, *B. subtilis*, and *M. luteus*, with EC50 values of 7.7, 7.7, and 9.9 µg/mL, respectively [141].

The compound dendrobine (326, Figure 18) was purified from *Trichoderma longibrachiatum* MD33, an endophyte of *Dendrobium nobile*. Compound 326 inhibited *Bacillus mycoides*, *B. subtilis*, and *Staphylococcus* spp., with zones of inhibition of 9, 12 and 8 mm, respectively [142].

Trichocadinins B-D and G (327–330, Figure 18), new cadinane-type sesquiterpene derivatives, were isolated from *Trichoderma virens* QA-8 residing inside the plant *Artemisia argyi*. Compounds 327–330 displayed antibacterial activity against *E. coli*, *Aeromonas hydrophilia* QDIO-1, *Edwardsiella tarda*, *E. ictarda*, *Micrococcus luteus*, *P. aeruginosa*, *Vibrio alginolyticus*, *V. anguillarum*, *V. harveyi*, *V. parahemolyticus*, and *V. vulnificus* (MICs in the range of 8–64 µg/mL). Compound 330 inhibited *Ed. tarda* and *V. anguillarum* with MIC values of 1 and 2 µg/mL, respectively [143].

New diterpenes koninginols A (331) and B (332, Figure 18) were isolated from *Trichoderma koningiopsis* A729, an endophyte of *Morinda officinalis*. Compounds 331–332 exhibited potent inhibition against *B. subtilis*, with MIC values of 10 and 2 µg/mL, respectively [144].

*Trichoderma koningiopsis* QA-3, isolated from the plant *Artemisia argyi*, produced five new polyketides: ent-koninginin A (333), 1,6-di-epi-koninginin A (334), 15-hydroxykoninginin A (335), 10-deacetylkoningiopisin D (336) and koninginin T (337) and two known analogs, koninginin L (338), trichoketide A (339, Figure 18). Compounds 333 and 339 inhibited the aquatic bacteria *E. tarda*, *V. anguillarum*, and *V. parahemolyticus*, and the human pathogen *E. coli* (MICs ranging from 8 to 64 µg/mL). Compound 333 also showed activity against the aquatic bacteria *M. luteus* and *P. aeruginosa* and agropathogens. Compounds 333–339 were found to be active against *E. coli* (each with MIC values of 64 µg/mL) and *E. tarda*, *V. alginolyticus*, and *V. anguillarum* (MICs ranging from 8 to 64 µg/mL) while compounds 333 and 339 also showed antimicrobial activity against *M. luteus*, *V. parahemolyticus*, and *V. vulnificus* (MIC values ranging from 4 to 64 µg/mL). Compound 333 was also found active against *V. vulnificus* with a MIC of 4 µg/mL [145].

2.2.5. *Alternaria*

A novel polyketide derivative, isotalaroflavone (340), along with the known compounds 4-hydroxyalternariol-9-methyl ether (341) and verrulactone A (342, Figure 18) were obtained from *Alternaria alternata* ZHJG5 that was isolated from the leaves of *Cercis chinensis* collected from Nanjing Botanical Garden (Nanjing, China). Compounds 340–342 were found to be active against *Xanthomonas oryzae* pv. *oryzae* (Xoo), *Xanthomonas oryzae* pv. *oryzicola* (Xoc) and *Ralstonia solanacearum* (Rs) with MICs ranging from 0.5 to 64 µg/mL. In addition, compound 340 showed a potent protective effect against rice bacterial leaf blight caused by Xoo with a protective efficacy of 75.1% at a concentration of 200 µg/mL [146].

A new biphenyl compound altertoxin VII (343), and the related compounds altenuisol (344, Figure 19), alternariol (44), were purified from *Alternaria* sp. PfuH1 is associated with *Pogostemon cablin*. Compounds 44, 343, 344 showed activity against *S. agalactiae* with MIC values of 9.3, 17.3, and 85.3 µg/mL, respectively, and compound 343 also showed poor activity against *E. coli* with MIC value of 128 µg/mL [147].
Figure 19. Structures of metabolites 343–356 isolated from Anamorphic Ascomycetes.

Known metabolites altenuisol (344), alterlactone (345), and dehydroaltenusin (346, Figure 19) and alternariol (44), were isolated from Alternaria alternata ZHJG5 residing inside the leaves of Cercis chinensis. The compounds 44, 344, 345, 346, showed inhibitory activities on FabH of X. oryzae pv. oryzae (Xoo) with IC\(_{50}\) values ranging from 29.5 to 74.1 \(\mu\)M and also displayed a varying degree of antibacterial activities against X. oryzae pv. oryzae (Xoo) with MIC values ranging from 4 to 64 \(\mu\)g/mL. Molecular modeling was then used to picture how these compounds interact with XooFabH. Compounds 44, and 343, displayed significant bactericidal activity against rice bacterial leaf blight with a protective efficiency of 66.2 and 82.5% at concentration of 200 \(\mu\)g/mL, respectively [148].

The compound alternariol 9-Me ether (347, Figure 19) was purified from Alternaria alternata MGTMMP031 associated with Vitex negundo. Compound 347 exhibited potential activity against B. cereus, Klebsiella pneumoniae with a MIC at 30 \(\mu\)M/L. The compound inhibited the growth of E. coli, Salmonella typhi, Proteus mirabilis, S. aureus and S. epidermidis at a MIC of 35 \(\mu\)M/L [149].

An endophytic fungus, Alternaria alternata, associated with Grewia asiatica yielded a new structural isomer of alternariol, i.e., 3,7-dihydroxy-9-methoxy-2-methyl-6H-benzo[c]-chromen-6-one (348, Figure 19), along with alternariol (44). Compound 44 inhibited S. aureus, VRE, and MRSA with MIC values of 32, 32 and 8 \(\mu\)g/mL, respectively. Compound
also inhibited *S. aureus*, VRE, and MRSA with MIC values of 128, 128, and 64 µg/mL, respectively [150].

The compounds 4-hydroxyalternariol-9-methyl ether (349, Figure 19) altenuisol (344), and alternariol (44) were purified from *Alternaria* sp. Samif01, an endophytic fungus of *Salvia miltiorrhiza*. Compounds 44, 344, and 349 showed inhibition against *A. tumefaciens*, *B. subtilis*, *P. lachrymans*, *R. solanacearum*, *Staphylococcus hemolyticus* and *Xanthomonas vesicatoria* with MIC values in the range of 86.7–364.7 µM [151]. Previously alternariol 9-Me ether (347, Figure 19) was isolated the same fungus and was found active against *B. subtilis*, *S. haemolyticus*, *A. tumefaciens*, *P. lachrymans*, *R. solanacearum*, and *X. vesicatoria* with IC50 values ranging from 16.00 to 38.27 g/mL [152].

An endophytic fungus *Alternaria* sp. and *Pyrenochaeta* sp., purified from *Hydrastis canadensis* yielded altersetin (350) and macrophelide A (351, Figure 19). Compounds 350 and 351 displayed antibacterial activity against *S. aureus* with MIC values of 0.23 and 75 µg/mL, respectively [153].

2.2.6. *Simplicillium*

The fungal strain *Simplicillium lanoseoniteum* associated with *Hevea brasiliensis*, yielded a new depsidone, simplicidone K (352), together with the known compounds botryorhodine C (353), and simplicidole A (354, Figure 19). Compounds 353 and 354 displayed activity against *S. aureus*, MRSA with equal MIC values of 32 µg/mL, whereas 352 exhibited 4-fold less activity against both strains (MIC values of 128 µg/mL) [154].

The compounds botryorhodine C (353), and simplicidole A (354, Figure 19), were purified from *Simplicillium* (350)-H41 which is associated with the leaves of *Hevea brasiliensis*. Compounds 353 and 354 exhibited poor activity against *S. aureus* (MIC of 32 µg/mL each). Compound 353 was found to be active against MRSA with the same MIC value [155].

2.2.7. *Cladosporium*

An endophytic fungus, *Cladosporium cladosporioides*, residing inside the leaves of *Zygophyllum mandavillei* yielded isocladosporin (355), 5′-hydroxyasperentin (356, Figure 19), 1-acetyl-17-methoxyaspidospermidin-20-ol (357), and 3-phenylpropionic acid (358, Figure 20). Compounds 355–358 displayed antibacterial activity against *X. oryzae* and *Pseudomonas syringae* with MIC values in the range of 7.81 to 125 µg/mL [156].

A new hybrid polyketide, named cladosin L (359, Figure 20) was discovered in the endophytic fungus *Cladosporium sphaerospermum* WBS017 associated with the bulbs of *Fritillaria unibracteata var. wabuensis*. Compound 359 inhibited *S. aureus* ATCC 29213 and *S. aureus* ATCC 700699 with MICs of 50 and 25 mM, respectively [157].

A naphthoquinone Me ether of fusarubin (360, Figure 20), was purified from a *Cladosporium* sp. associated with the *Rauwolfia serpentina*. Compound 360 (40 µg/disk) displayed potent activity against *S. aureus*, *E. coli*, *P. aeruginosa* and *B. megaterium* with 27, 25, 24 and 22 mm zones of inhibition, respectively and the activities were compared with kanamycin (30 µg/disk) [158].

2.2.8. *Pestalotiopsis*

The genus *Pestalotiopsis* is reported as an endophyte from rain forests in almost all parts of the world and is a prolific producer of chemically diverse bioactive compounds. One such compound is the new drimane sesquiterpenoid 11-dehydro-3a-hydroxyisodrimeninol (361, Figure 20), produced by *Pestalotiopsis* sp. M-23, an endophytic fungus of *Leucoceptrum canum*. Compound 361 displayed poor inhibitory effect against *B. subtilis* with IC50 value of 280.27 µM [159].

The compounds (1S,3R)-asturocortirubin (362), (1S,3S)-asturocortirubin (363), and 1-deoxyaustrocortirubin (364, Figure 20), were obtained from *Pestalotiopsis* sp., an endophyte of *Melaleuca quinquenervia*. Compounds 362–364 displayed with poor antibacterial activity (100 µM) against Gram-positive isolates [160].
Figure 20. Structures of metabolites 357–374 isolated from Anamorphic Ascomycetes.
A new tetracyclic acid analog, neopestalotin B (365, Figure 20), was extracted from Neopestalotiopsis sp. and inhibited B. subtilis, S. aureus, S. pneumoniae, with MIC values of 10, 20, and 20 µg/mL, respectively [161].

2.2.9. Phoma

Two known thiodiketopiperazine derivatives 366 and 367 (Figure 20) were purified from Phoma cucurbitacearum (now known as Stagonosporopsis cucurbitacearum), an endophyte of Glycrrhiza glabra. Compounds 366 and 367 were found to inhibit the battery of bacterial pathogens, including S. aureus and Streptococcus pyogenes with IC50 values of <10 µM. Both compounds potentially inhibited biofilm formation in S. aureus and S. pyogenes and acted synergistically with streptomycin and inhibited transcription/translation. It was also observed that the agrA gene was overexpressed by several fold on treatment with compound 366 while its expression was not affected significantly with compound 367. The expression of agrA gene was also not affected significantly in S. aureus with the treatment of either of the compounds [162].

Barceloneic acid C (368, Figure 20), purified from a Phoma sp. JS752 residing inside Phragmites communis. Compound (368) exhibited average antibacterial activities against Listeria monocytogenes and Staphylococcus pseudintermedius, (MIC of 1.02 µg/mL each) [163].

The polyketides thiellavins T (369), U (370), and V (371, Figure 20) were purified from Setophoma sp., an endophytic fungus of Psidium guajava. Compounds 369–371 displayed antibacterial activity against pathogenic S. aureus with MIC values of 6.25, 50, and 25 µg/mL, respectively [164].

2.2.10. Colletotrichum

Two new γ-butyrolactone derives., colletolides A and B (372, 373), together with the already reported compounds sclerone (374, Figure 20), and 3-methylenesoindolinolin (375, Figure 21) were purified from Colletotrichum gloeosporioides B12, an endophyte of plant Illigera rhodantha. Compounds 372, 373, 375 were found to be active against Xanthomonas oryzae pv. oryzae, with the same MIC values of 128 µg/mL, while compound 374 was found active against X. oryzae pv. oryzae with MIC values of 64 µg/mL [165].

The new compounds colletotrichones A (376), B (377), and C (378, Figure 21) were purified from Colletotrichum sp. BS4 residing inside the leaves of Buxus sinica. Compound 376 inhibits E. coli and B. subtilis with MIC values 1.0 and 0.1 µg/mL, respectively. Compound 377 inhibited S. aureus with a MIC value of 5.0 µg/mL. Compound 378 has shown antibacterial activity against E. coli with a MIC value of 5.0 µg/mL [166].

2.2.11. Minor Taxa of Anamorphic Ascomycetes

New dibenzo-α-pyrones, rhizopynolide A (379), rhizopcin C (380) and rhizopycnin D (381), together with known congeners TMC-264 (382), palmariol B (383) penicilliumolide D (384, Figure 21) alternariol 9-methyl ether (347) and alternariol (44) and were purified from Rhizopycnis vagum (now known as Acrocalymma vagum) isolated from Nicotiana tabacum. Compounds 380, 384, 44 inhibited A. tumefaciens, B. subtilis, Pseudomonas lachrymans, R. solanacearum, Staphylococcus hemolyticus, and Xanthomonas vesicatoria, with MICs in the 25–100 µg/mL range. Rhizopycnolide A (379) was active against A. tumefaciens, B. subtilis, and P. lachrymans, with MIC values of 100, 75, and 100 µg/mL, respectively. Rhizopycin D (381) was found to be active against A. tumefaciens, B. subtilis, and R. solanacearum, with an equal MIC value of 50 µg/mL, and against X. vesicatoria, with a MIC value of 75 µg/mL. TMC-264 (382) was selectively active against B. subtilis (MIC value of 50 µg/mL). Compounds 383 and 347 inhibited A. tumefaciens, B. subtilis, P. lachrymans, R. solanacearum, and X. vesicatoria, with IC50 values in the range 16.7–34.3 µg/mL [167].
Rhizoperemophilane K (385), 1α-hydroxyhydroisofukinon (386) and 2-oxo-3-hydroxyeremophilane-1(10),3,7(11),8-tetraen-8,12-olide (387, Figure 21) were purified from *Rhizopycnis vagum* (now known as *Acrocalymma vagum*), an endophyte of *Nicotiana tabacum*. Compounds 385, 386 and 387 displayed inhibition against *A. tumefaciens*, *B. subtilis*, *P. lachrymans*, *Ralstonia solanacearum*, *S. haemolyticus* and *X. vesicatoria*, with MIC values in the range of 32–128 µg/mL [168].

Rhizopycnis acids A (388) and B (389, Figure 21), were purified from *Rhizopycnis vagum* (now known as *Acrocalymma vagum*) an endophyte of *Nicotiana tabacum* from China Agricultural University (Beijing, China). Compound 388 inhibited *A. tumefaciens*, *B. subtilis*, *P. lachrymans*, *R. solanacearum*, *S. haemolyticus* and *X. vesicatoria* with MIC values of 20.82,
16.11, 23.48, 29.46, 21.11, and 24.31 µg/mL, respectively. Compound 389 also inhibited A. tumefaciens, B. subtilis, P. lachrymans, R. solanacearum, S. haemolyticus, and X. vesicatoria with MIC values of 70.89, 81.28, 21.23, 43.40, 67.61, and 34.86 µg/mL, respectively [169].

Leptosphaeria sp. XL026 associated with Panax notoginseng yielded a new sesquiterpenoids, leptosphin B (390), along with three known diterpenes, conidiogone C (391), conidiogone D (392) and conidiogone G (393, Figure 21). The site of the collection was Shijiazhuang (Hebei Province, China). Compounds 390–393 showed average antibacterial activity against B. cereus, with MIC values of 12.5–6.25 µg/mL and compound 392 also showed antibacterial activity against P. aeruginosa with a MIC value of 12.5 µg/mL [170].

Two 2-azaanthaquinones, scorpine (394, Figure 21) and 5-deoxybostrycoindin (395, Figure 22), were purified from Lophiostoma sp. Eef-7 is associated with Eucalyptus exserta. Compounds 394 and 395 displayed poor antibacterial activity against Ralstonia solanacearum with 9.86 and 9.58 mm zones of inhibition when 64 µg was added (positive control was streptomycin sulfate with a 13.03 mm zone of inhibition at an added amount of 6.25 µg) [171].

Two new cytochalasan alkaloids, cytochrysins A and C (396 and 397, Figure 22), were isolated from Cytospora chrysosperma, an endophytic fungus isolated from Hippophae rhamnoides. Compound 396 showed significant antibacterial activity against multi-drug resistant Enterococcus faecium with MIC value of 25 µg/mL, and compound 397 was active against MRSA with a MIC value of 25 µg/mL [172].

Two known α-pyridones, (8R,9S)-dihydroisoflavipucine (398) and (8S,9S)-dihydrosoflavipucine (399, Figure 22) were isolated from Lophiostoma sp. SigrfI10 is associated with Siratia grosvenori. Compounds 398 and 399 were active against B. subtilis, A. tumefaciens, R. solanacearum, and X. vesicatoria, with IC50 values in the range of 35.68–44.85 µM [173].

Microsphaerol (400), a novel polychlorinated triphenyl diether was extracted from Microsphaeropsis sp and seimatorone (401, Figure 22), a new naphthalene derivative, was purified from the endophyte Seimatosporium sp. Compound 400 displayed potent antibacterial activity against B. megaterium and E. coli, with 8 and 9 mm zones of inhibition at 0.05 mg concentration (50 mL of 1 mg/mL). Compound 401 exhibited moderate antibacterial activity against B. megaterium and E. coli, with 3 and 7 (partial inhibition) mm zones of inhibition at a 0.05 mg concentration (50 mL of 1 mg/mL) [174].

Known compounds epicocconigrone A (402), epipyrene A (403), and epicoccolide B (404, Figure 22) were purified from Epicocicum nigrum MK214079 associated with Salix sp. Compounds 402–404 exhibited moderate activity against S. aureus, with MICs ranging from 25 to 50 µM [175].

The known compounds p-hydroxybenzaldehyde (223), indole-3-carboxylic acid (405) and quinizarin (406, Figure 22) and beauvericin (267), were isolated from Epicocicum nigrum associated with the Entada abyssinica. Compound 267 displayed activity against S. aureus, B. cereus, and Salmonella typhimurium, with MIC values of 3.12, 12.5, and 12.5 µg/mL. Compound (223) displayed activity against S. aureus, B. cereus, P. aeruginosa, and E. coli with MIC values of 50, 25, 50, and 25 µg/mL. Compound 405 was found to be active against S. aureus and E. faecalis (MICs of 6.25 and 50 µg/mL) while compound 406 displayed activity against S. aureus, B. cereus St (MICs of 50 µg/mL each) [176].

The endophytic fungus Stemphylium lycopersici from S. tonkinensis yielded xylapeptide B (407), cytochalasin E (408), 6-heptanoyl-1-methoxy-2H-pyran-2-one (409) and (−)-5-carboxymellein (410, Figure 22). Compound 407 showed average inhibition against B. subtilis with a MIC value of 12.5 µg/mL, and against S. aureus and E. coli with MIC values of 25 µg/mL. Compound 408 inhibited B. subtilis, S. aureus, B. anthracis, S. dysenteriae, and E. coli with MIC values ranging from 12.5 to 25 µg/mL. Compound 409 inhibited S. paratyphi B with MIC value of 12.5 µg/mL. Compound 410 inhibited B. subtilis, S. aureus, B. anthracis, S. dysenteriae, S. paratyphi, E. coli and S. paratyphi B with MIC values ranging from 12.5 to 25 µg/mL [177].

A new tetrahydroantraquinone derivative, dihydroaltersolanol C (411, Figure 22) was purified from Stemphylium globuliferum residing inside the plant Juncus acutus. Compound 411 exhibited moderate growth inhibition effects against S. aureus with a MIC of 49.7 µM [178].
Figure 22. Structures of metabolites 395–415 isolated from Minor Anamorphic Ascomycetes.

An endophytic fungus *Lecanicillium* sp. (BSNB-SG3.7 Strain) associated with *Sandwithia guyanensis* yielded stephensiolides I (412), D (413), G (414), and stephensiolide F (415, Figure 22). Compounds 412–415 displayed anti-MRSA activity with MIC values of 4, 32, 16 and 32 µg/mL, respectively [179].
The compound phomalactone (416, Figure 23) was isolated from the endophyte Ni-
grospora sphaerica associated with Adiantum philippense. Compound 416 displayed good
antibacterial activity against E. coli and X. campestris with MIC values of 3.12 µg/mL and
moderate activity against S. typhi, B. subtilis, B. cereus, and K. pneumonia with a MIC value
of 6.25 µg/mL. A MIC of 12.5 µg/mL was found against S. aureus, and S. epidermidis [180].

Figure 23. Structures of metabolites 416–435 isolated from Minor Anamorphic Ascomycetes.
A new naturally occurring compound, nigrosporone B (417, Figure 23), was purified from Nigrospora sp. BCC 47789 associated with the leaves of Choerospondias axillaris. Compound 417 exhibited antibacterial activity against \textit{M. tuberculosis}, \textit{B. cereus} and \textit{E. faecium} with MIC values of 172.25, 21.53 and 10.78 µM, respectively [181].

Two bioactive compounds, 2''-deoxyribolactone (418) and hexylitaconic acid (419, Figure 23) were purified from Curvularia sorghina BRIP 15900 associated with the stem bark of Rauwolfia macrophylla. Compounds 418 and 419 inhibited \textit{Staphylococcus warneri} \textit{E. coli}, \textit{Pseudomonas agarici} and \textit{Micrococcus luteus}, with MICs ranging between 0.17 µg/mL and 0.58 µg/mL [182].

Known compounds, namely the triticones E (420) and F (421, Figure 23), were purified from Curvularia lunata, isolated from healthy capitula of Paepalanthus chiquitensis. Compounds 420 and 421 showed good antibacterial activity for \textit{E. coli}, with MIC values of 62.5 µg/mL [183].

The known compounds cochlioquinones B (422), C (423), and isocochlioquinone C (424, Figure 23) were purified from Bipolaris sp. L1-2 which is associated with the leaves of \textit{Lycium barbarum}. Compounds 422–424 showed antimicrobial activity against \textit{B. subtilis}, \textit{C. perfringens}, and \textit{P. viridiflava}, with MICs of 26 µM [184].

A new previously undescribed chromone, \textit{(S)}-5-hydroxyl-2-(1-hydroxyethyl)-7-methylchromone (425) and the known sativene-type sesquiterpenoid 5,7-dihydroxy-2,6,8-trimethylchromone (426, Figure 23), were purified from Bipolaris eleusines associated with potatoes from Yunnan Agricultural University (Kunming, Yunnan, China). Compounds 425 and 426 displayed poor inhibitory activities against \textit{S. aureus} sub sp. \textit{aureus} with the inhibition rates of 56.3 and 32 %, respectively, at the concentration of 128 µg/mL (penicillin G: 99.9% at 5 µg/mL) [185].

Two new diketopiperazines, bionectin D (427) and bionectin E (428) and the known compounds verticillin A (429) sch 52901 (430) and gliocladicillin C (431, Figure 23) were purified from Bionectria sp. Y1085, isolated from Huperzia serrata. Bionectin D (427) is a rare diketopiperazine with a single methylthio substitution at the α-carbon of a cyclized amino acid residue. Compounds 427–331 exhibited antibacterial activity against \textit{E. coli}, \textit{S. aureus}, and \textit{S. typhimurium}, with MIC values ranging from 6.25–25 µg/mL [186].

Known compounds pyrrocidine A (432) and 19-O-methylpyrrocidine B (433, Figure 23) were extracted from the endophytic fungus, Cylindrocarpon sp., isolated from Sapium ellipticum. Compound 433 exhibited moderate antibacterial activity against \textit{S. aureus} ATCC 25923 and ATCC 700699 with MIC values of 50 and 25 µM, respectively. Compound 432 showed strong to moderate inhibitory effects against \textit{S. aureus} strain ATCC 25923 and ATCC 700699, \textit{E. faecalis} strain ATCC 29212 and ATCC 51299, \textit{E. faecium} strain ATCC 35667 and ATCC 700221 with MIC values ranging from 0.78 to 25 µM [187].

Two new decalin-containing compounds, eupenicincols C (434), and D (435, Figure 23), along with two biosynthetically-related known metabolites, eujavanicol A (436), and eupenicinicol A (437, Figure 24) were obtained from Eupenicillium sp. LG41.9 (now considered as \textit{Penicillium}) residing inside the roots of Xanthium sibiricum when treated with the HDAC inhibitor nicotinamide (15 mg/100 mL). Compound 435 exhibited pronounced efficacy against \textit{S. aureus} with a MIC of 0.1 µg/mL, and compound 436, was active against \textit{E. coli} with a MIC of 5.0 µg/mL [188].
Figure 24. Structures of metabolites 436–443 isolated from Minor Anamorphic Ascomycetes, 444–450 from Basidiomycetes and 451 from Zygomycetes.

A new anthranilic acid derivative, 2-phenylethyl 3-hydroxyanthranilate (438) and 2-phenylethyl anthranilate (439, Figure 24) were extracted from Dendrothyrium variisporum extracted from the roots of Globularia alypum. Metabolite 438 was found to be active against B. subtilis and M. luteus (MICs of 8.33 and 16.66 µg/mL). Compound 439 showed potent activity against B. subtilis and S. aureus with MIC values of 66.67 µg/mL each [189].

Ravenelin (440, Figure 24) was extracted from Exserohilum rostratum, an endophyte of Phanera splendens, an endemic medicinal plant of the Amazon region. Ravenelin (440) displayed antibacterial activity against B. subtilis and S. aureus with MIC values of 7.5 and 484 µM, respectively (amoxicillin MIC against B. subtilis and S. aureus 1.3 and 21.4 µM; another positive control terramycin MIC against B. subtilis and S. aureus 16.3 and 16.3 µM, respectively) [190].

The compounds monocerin (441), annularin I (442), and annularin J (443, Figure 24) were purified from Exserohilum rostratum isolated from Bauhinia guianensis. Compound 441 displayed antibacterial activity with MIC values of 62.5 µg/mL against P. aeruginosa. Compound 442 exhibited antibacterial activity with MIC values of 62.50 and 31.25 µg/mL.
against *E. coli* and *B. subtilis*, respectively. Compound 443 displayed weak activity against *E. coli* and *B. subtilis* with MIC values of 62.50 µg/mL each [191].

2.3. Basidiomycetes

The compounds quercetin (444), carboxybenzene (445), and nicotinamide (446, Figure 24) were purified from *Psathyrella candolleana* residing inside the seeds of *Ginkgo biloba*. Compounds 444–446 have antibacterial activity against *S. aureus* (MIC 0.3906, 0.7812 and 6.25 µg/mL) [192].

A new tremulane sesquiterpene, irpexlacte A (447), and three new furan derivatives, irpexlates B-D (448–450, Figure 24), were isolated from the endophytic fungus *Irpex lacteus* DR10-1 of the waterlogging-tolerant plant *Distylium chinense*. Compounds 447–450 showed moderate antibacterial activity against *P. aeruginosa* with MIC values ranging from 23.8 to 35.4 µM [193].

2.4. Zygomycetes

A flavonoid compound, chlorflavonin (451, Figure 24) was purified from the endophytic fungus *Mucor irregularis*, isolated from *Moringa stenopetala*. It has shown antibacterial activity (MIC<sub>90</sub>) against *M. tuberculosis* at a 1.56 µM concentration. Chlorflavonin also had shown synergistic effects with isoniazid and delamanid in combination treatment experiments. Various molecular and docking techniques have shown that chlorflavonin interacts with the acetohydroxyacid synthase catalytic subunit IlvB1 and inhibits their activity. Recently, Rehberg et al. [194] found the antimicrobial activity of chlorflavonin (451) to be higher in comparison to streptomycin treatment against macrophages infected with *M. tuberculosis*.

3. Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are chemical entities which have low molecular weights and typically evaporate or get into the vapor phase at normal temperature and pressure. They generally possess a characteristic odor [195]. Several reviews have emphasized the production of biogenic VOCs as possible signal molecules in the course of interaction with a host or that play a role in the process of host integration. At times they are also identified as indicators of fungal growth [196–198]. Fungal VOCs largely comprise aliphatic as well as aromatic hydrocarbons, aldehydes, mono-, di- and sesquiterpenes, esters and ketones. Some of the interesting aspects of fungal volatiles is their possible role during interactions among the microbes i.e., with bacteria as well as fungi. However, the application of fungal VOCs as an arsenal to kill bacteria and fungi has not been extensively explored.

The discovery of the endophytic fungus *Muscodor albus* Cz 620 which exhibited potent antibiotic type activity, wiping out all the microbes in its vicinity was serendipitous. This was attributed due to the volatile cocktail produced by *Muscodor albus* Cz 620. This marked the beginning of the exploration of fungal endophytes with the potential to produce volatile antibiotics. The genus *Muscodor* has expanded in the last two decades owing to the addition of novel members that were largely based on the chemical signatures and genetic profiles. Presently there are ~22 known type species that have been documented [199].

Uniquely, all the species of *Muscodor* reported to date are sterile in nature and exhibit a characteristic spectrum of antibacterial as well as anti-fungal activities largely driven by the chemical composition of their volatile gas mixtures. It has also been shown that a single component of the volatile gas is unable to mimic the anti-microbial action suggesting it to be a synergistic action of the finely tuned composition of different VOCs [200].

The pharmaceutical importance of the VOCs produced by *Muscodor* species was exemplified by the anti-bacterial and anti-fungal potential of the VOCs emitted by the fungus. VOCs of *Muscodor albus* Cz620 inhibited *E. coli* and *Bacillus subtilis* while only *E. coli* was inhibited in the presence of volatiles of other isolates of *Muscodor albus* viz. KN-26, KN-27, GP-100, GP-115, TP-21, which inhibited only *E. coli* [201]. The volatiles of *M. albus* I-41.3s on the other hand inhibited *Bacillus subtilis*, *E. coli*, and *Salmonella typhi*. All the VOC emissions were predominantly bacteriostatic and not bactericidal [202].
Muscodor crispans (B-23) has a characteristic VOC spectrum which exhibited anti-mycobacterial activity i.e., against Mycobacterium marianum apart from S. aureus ATCC6538, Salmonella choleraesuis, and Yersinia pestis [203]. Muscodor fengyangensis exclusively inhibited E. coli [204]. The volatiles produced by Muscodor kashayum has a potent bactericidal activity towards E. coli, Pseudomonas aeruginosa, Salmonella typhi and S. aureus [205]. Four isolates of Muscodor reported from Southeast Asia, viz. M. oryzae, M. musae, M. suthepensis and M. equisetii, exerted bactericidal activity against Enterococcus faecalis, E. coli, Proteus mirabilis, S. aureus and Pseudomonas pneumoniae [206]. The VOCs of Muscodor have also inspired development of a veterinary medicine formulation which is used as an anti-diarrhoeal product. The formulation is called Sx calf, that is currently being produced and marketed by Ecoplanet Environment LLC (Belgrade, MT, USA) [207]. Similarly, the volatiles of Muscodor cinnamomi was found to be effective against Staphylococcal spp., Salmonella sp., E. coli, Klebsiella spp., Streptococcus spp. and Enterococcus species which contaminate eggs thereby not only affecting their shelf life but also making them unfit for human consumption [208]. The volatile cocktail of Muscodor crispans (B-23) was found to kill the bacterial pathogen of citrus Xanthomonas axonopodis pv. citri [203].

The introspection of the spectrum of the volatile organic mixture from different Muscodor species has revealed the antibacterial spectrum of some commonly occurring entities such as isobutyric acid [209–211], β-bisabolol and azulene and its derivatives [212]. Thus, creating artificial mixtures and evaluating them for their anti-bacterial activities may prove to be very useful for preventing drug-resistant film-forming bacteria from causing infections in clinical as well as non-clinical settings. Hence the present study, opens avenues to explore higher numbers of fungal endophytes for their unique volatile signatures and assess them for anti-bacterial activities for developing interventions that could check the spread and infections caused by the drug-resistant bacteria by using them in volatile form or as gaseous sprays.
Table 1. Anti-bacterial metabolites reported from endophytic fungi.

| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|---------------------------------|-----------|
| Ascomycetes | Diaporthe | | | | | | |
| 1 | Diaporthe sp. | Uncaria gambier | | (+)-1,1′-Bislunatin (1) and (+)-2,2′-epicytoskyrin A (2) | Mycobacterium tuberculosis strains H37Rv | MICs 0.422 and 0.844 μM | [18] |
| 2 | Diaporthe sp. GDG-118 | Sophora tonkinensis | Hechi City, China | 21-Acetoxycytochalasin J (3) | Bacillus anthraci and E. coli | inhibited at 12.5 μg/mL concentration | [19] |
| 3 | Phomopsis fukushii. | | | 1-(3-Hydroxy-1-(hydroxymethyl)-2-methoxy-6-methylnaphthalen-7-yl)propan-2-one (4) and 1-(3-hydroxy-1-(hydroxymethyl)-6-methylnaphthalen-7-yl)propan-2-one (5) | MRSA | Zone of inhibition of 10.2 and 11.3 mm (6 mm sterile filterpaper disc were impregnated with 20 μL (50 μg) of each compound) | [20] |
| 4 | Phomopsis fukushii | Paris polyphylla var. yunnanensis | Kunming, Yunnan, China | 3-Hydroxy-1-(1,8-dihydroxy-3,6-dimethoxynaphthalen-2-yl)propan-1-one (6), 3-hydroxy-1-(1,3,8-trihydroxy-6-methoxynaphthalen-2-yl)propan-1-one (7) and 3-hydroxy-1-(1,8-dihydroxy3,5-dimethoxynaphthalen-2-yl)propan-1-one (8) | MRSA-ZR11 | MIC, 8, 4, and 4 μg/mL, | [21] |
| 5 | Phomopsis fukushii | Paris polyphylla var. yunnanensis | Kunming, Yunnan, China | 1-[2-Methoxy-4-(3-methoxy-5-methylphenoxo)-6-methylphenyl]ethanone (9) and 1-[4-(3-hydroxymethyl)-5-methoxyphenoxo)-2-methoxy-6-methylphenyl]ethanone (10) | MRSA | Zone of inhibition 13.8 and 14.6 mm | [22] |
| Sr. No. | Fungus                  | Source                        | Locality                  | Compounds Isolated                                                | Biological Target | Biological Activity (MIC/IC₅₀/ID₅₀) | Reference |
|--------|-------------------------|-------------------------------|---------------------------|-------------------------------------------------------------------|-------------------|--------------------------------------|-----------|
| 6      | *Phomopsis fukushii*    | *Paris polyphylla var. yunnanensis* | Kunming, Yunnan, P. R. China | 4-(3-Methoxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-methylphenol (11), 4-(3-Hydroxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-methylphenol (12) and 4-(3-methoxy-5-methylphenoxy)-2-(3-hydroxypropyl)-6-methylphenol (13) | MRSA              | Zone of inhibition of 20.2, 17.9 and 15.2 mm (tested at 50µg/6 mm disc) | [23]      |
| 7      | *Phomopsis fukushii*    | *Paris polyphylla var. yunnanensis* | Kunming, Yunnan, China. | 1-(4-(3-Methoxy-5-methylphenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (14), 1-(4-(3-hydroxymethyl)-5-methoxyphenoxymethyl-6-methylphenyl)-3-methylbut-3-en-2-one (15), 1-(4-(3-hydroxy-5-(hydroxymethyl)phenoxy)-2-methoxy-6-methylphenyl)-3-methylbut-3-en-2-one (16) | MRSA              | Zone of inhibition of 21.8, 16.8 and 15.6 mm, (50 µg/6 mm disc) | [24]      |
| 8      | *Phomopsis sp.*         | -                             | -                         | 3-Hydroxy-6-hydroxymethyl-2,5-dimethylantraquinone (17), 6-hydroxymethyl-3-methoxy-2,5-dimethylantraquinone (18) | MRSA              | IZD 14.2 and 14.8 mm                | [25]      |
| 9      | Diaporthe sp.           | *Pteroceltis tatarinowii*     | Mufu Mountain of Nanjing, China. | Diaporone A (19)                                               | B. subtilis       | MIC, 66.7 µM                        | [26]      |
| 10     | *Phomopsis prunorum*    | (F4-3).                       | -                         | (−)-1 and (+)- Phomoterpenes A and B (20) phomoisocoumarins C (21), D (22) | *X. citri pv. phaseoli var. fuscans* | MIC, 31.2, 62.4, 31.2, and 31.2 µg/mL | [27]      |
|        |                         |                               |                           |                                                                 | *Pseudomonas syringae pv. Lachrymans* | MIC, 31.2, 15.6, 31.2 and 15.6 µg/mL |          |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC\textsubscript{50}/ID\textsubscript{50}) | Reference |
|---------|---------|--------|----------|--------------------|-------------------|-------------------------------------------------|----------|
| 11      | *Diporthe vochysiae* LGMF1583 | *Vochysia divergens* | Vochysia divergens | Vochysiamides A (23) | KPC (*Klebsiella pneumoniae* carbapenemase producing). | MIC, 1.0 \(\mu\)g/mL | [28] |
|         |         |        |          | Vochysiamides B (24) | KPC, MSSA, MRSA | MIC, 0.08, 1.0, and 1.0 \(\mu\)g/mL |          |
| 12      | *Phomopsis asparagi* | *Paris polyphylla var. yunnanensis* | Kunming, Yunnan, China | 4-(3-Methoxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-(hydroxymethyl)phenol (25), 4-(3-Hydroxy-5-methylphenoxy)-2-(2-hydroxyethyl)-6-(hydroxymethyl)phenol(26) | MRSA | Zone of inhibition of 10.8 and 11.4 mm | [29] |
| 13      | *Phomopsis* sp. | *Paris polyphylla var. yunnanensis* | ShiZhong, Yunnan, China | 5-Methoxy-2-methyl-7-(3-methyl-2-oxobut-3-enyl)-1-naphthaldehyde (27), 2-(hydroxymethyl)-5-methoxy-7-(3-methyl-2-oxobut-3-enyl)-1-naphthaldehyde (28) | MRSA | Zone of inhibition of 14.5 and 15.2 mm | [30] |
| 14      | *Diaporthe terebinthifolii* LGMF907 | *Schinus terebinthifolius* | Curitiba, Paraná, Brazil | Diaporthin (29) | *E. coli*, *Micrococcus luteus*, MRSA, and *S. aureus* | Zone of inhibition 1.73, 2.47, 9.50, and 9.0 mm tested at 100 \(\mu\)g disk. | [31] |
|         |         |        |          | Orthosporin (30) | | Zone of inhibition of 1.03, 1.53, 9.0, and 9.33 mm |          |
| 15      | *Phomopsis / Diaporthe* sp. GJJM 16 | *Vitex negundo* | Azhiyar, Pollachi, Tamilnadu, India | (2Z)-2-(1,4-dihydro-2-hydroxy-1-((E)-2-mercapto-1-(methylimino)ethyl)pyrimidine-4-ylimino)-1-(4,5-dihydro-5-methylfuran-3-yl)-3-methylbutane-1-one (31) | *S. aureus*, and *P. aeruginosa* | MIC of 1.25 \(\mu\)g/mL against each organism | [32] |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|--------|--------|--------|----------|--------------------|-------------------|-------------------------------------------|-----------|
| 16     | *Phomopsis* sp. PSU-H188 | *Hevea brasiliensis* | Trang Province, Thailand. | Diaporthalasin (32), Cytosporone B (33), Cytosporone D (34) | *S. aureus* ATCC 25923, MRSA | MIC, 4 µg/mL each, MIC, 32 and 16 µg/mL, MIC, 64 and 32 µg/mL | [33] |
| 17     | *Diaporthe terebinthifolii* GG3F6 | *Glycyrrhiza glabra* | Jammu, J & K, India | Diapolic acid A (35), B (36), xylarolide (37), phomolide G (38) | *Yersinia enterocolitica* | IC_{50}, 78.4, 73.4, 72.1 and 69.2 µM | [34] |
| 18     | *Diaporthe* sp. F2934 | leaves of *Siparuna gesnerioides* | Chagres National Park, a protected area of Panama | Phomosine A (39) | *S. aureus* (ATCC 25923), *Streptococcus oralis* (ATCC 35037), *Enterococcus faecalis* (ATCC 19433), *Enterococcus cloacae* (ATCC 13047), *Bordetella bronchiseptica* (CECT 440), | Zone of Inhibition 12, 9, 10, 11, 10 and 10 mm at 4 µg/mL concentration | [35] |
| 19     | *Phomopsis* sp., *Garcinia kola* nuts | bought at Mokolo local market in Yaounde (Cameroon) | | 18-Methoxycytochalasin J (41), cytochalasins H (42) and J (43), alternariol (44) | *Shigella flexneri* | MIC, 128 µg/mL each | [36] |
| 20     | *Diaporthe* sp. LG23 | *Mahonia fortunei* | Shanghai, China | 19-nor-Lanosta-5(10),6,8,24-tetraene-1α,3β,12β,22S-tetraol (45) | *S. aureus* (ATCC 25923), *E. coli*, *Bacillus subtilis*, *P. aeruginosa*, *Streptococcus pyogenes* | MIC, 5.0, 5.0, 2.0, 2.0 and 0.1 µg/mL | [37] |
| 21     | *Diaporthales* sp. E6927E | *Ficus sphenophyllum* | Ecuadorean dry forest near the Napo River, USA | 3β,5α,9α-Trihydroxy-(22E,24R)-ergosta-7,22-dien-6-one (46), and chaxine C (47) | *B. subtilis* | MIC, 5.0 µg/mL each | [38] |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|------------------------------------------|-----------|
| 22      | *Xylaria ellisi* | Blueberry (*Vaccinium angustifolium*) | Ellisiiamide (49) | *Escherichia coli* | MIC, 100 µg/mL | [39] | |
| 23      | *Xylaria* sp. GDG-102 | *S. tonkinensis* Hechi, Guangxi province, China | Xylareremophil (50), Mairetolides B (51), and G (52) | *Micrococcus luteus* and *Proteus vulgaris*<br> Mairetolide G (52) | *M. luteus*<br> *P. vulgaris M. luteus*<br> Micrococcus lysodeikticus and *Bacillus subtilis*<br> *B. subtilis*<br> *S. aureus*<br> *B. megaterium*<br> *S. aureus*<br> *E. coli*<br> *S. dysenteriae*<br> *S. paratyphi B* | MIC 25 µg/mL each<br> MIC 25 and 50 µg/mL<br> MIC 100 µg/mL<br> MIC, 12.5 µg/mL each<br> MIC 25 µg/mL each<br> MIC, 12.5 µg/mL<br> MIC, 25 µg/mL | [40] | |
| 24      | *Xylaria* sp. (GDG-102) | Leaves of *S. tonkinensis* | 6-Heptanoyl-4-methoxy-2H-pyran-2-one (53) | *E. coli* as well as *S. aureus* | | MIC, 50 µg/mL | [41] | |
| 25      | *Xylaria* sp. GDG-102 | *S. tonkinensis* Hechi, Guangxi province, China | Xylarphthalide A (54) | *B. subtilis* and *E. coli*,<br> *B. megaterium*, *S. aureus*, *S. dysenteriae* and *S. paratyphi*<br> B. Subtilis | | | | [42] | |
|         |        |        | (−)-5-Carboxymellein (55) | *B. anthracis*, *B. megaterium*, *S. aureus*, *E. coli*, *S. dysenteriae* and *S. paratyphi* B | | | | |
|         |        |        | (−)-5-Methylmellein (56) | *B. subtilis* and *S. aureus*<br> *B. megaterium*, *E. coli* and *S. dysenteriae* | | 25 µg/mL | |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|---------|--------|--------|----------|---------------------|-------------------|-----------------------------------------------|-----------|
| 26      | Xylaria sp., Taxus mairei. |        |          | 3,7-Dimethyl-9-(-2,2,5,5-tetramethyl-1,3-dioxolan-4-yl) nona-1,6-dien-3-ol (57) | B. subtilis ATCC 9372, B. pumilus ATCC 7061 and S. aureus ATCC 25923 | 48.1, 31.6 and 47.1% inhibition. | [43] |
|         |        |        |          | Nalgiouvinsin (58) | S. aureus ATCC 25923, B. subtilis ATCC 9372, B. pumilus ATCC 7061 and E. coli ATCC 25922 | 42.1, 36.8, 47.1 and 41.2% inhibition. |          |
| Chaetomium |        |        |          | Xanthoquinodin B9 (59), xanthoquinodin A1 (60), xanthoquinodin A3 (61) | B. cereus | MICs of 0.87, 0.44 and 0.22 µM, |          |
|         |        |        |          | Xanthoquinodin B9 (59), xanthoquinodin A1 (60), xanthoquinodin A3 (61) | S. aureus and MRSA | MIC values ranging from 0.87 to 1.75 µM |          |
|         |        |        |          | 3-Epipylothyldioxopiperazines, chetomin (62), chaetocochin C (63) and dethio-tetra(methylthio) chetomin (64) | B. cereus ATCC 11778, S. aureus ATCC 6538, and MRSA | MIC values ranging from 0.02 pM to 10.81 µM. | [45] |
| 27      | C. globosum 7s-1, Rhapis cochinchinensis |        |          | Chetomin (62) | B. cereus, S. aureus and MRSA | MICs, 0.35 µM, 10.74 and 0.02 pM |          |
|         |        |        |          | Compounds 59–64 | E. coli ATCC 25922, P aeruginosa ATCC 27853, and Salmonella typhimurium ATCC 13311 | MICs of 45.06 to >223.72 µM |          |
|         |        |        |          | Epipolythiodioxopiperazines (62–64) | Mycobacterium tuberculosis | MICs, 0.55, 4.06 and 8.11 µM, |          |
| 28      | Chaetomium sp. SYP-F7950, Panax notoginseng | Wenshan, Yunnan, China |          | Chaetocochin C (63), chetomin A (65), and chetomin (62) | S. aureus, B. subtilis, Enterococcus faecium | MIC values ranging from 0.12 to 19.3 µg/mL | [46] |
| Sr. No. | Fungus                  | Source                      | Locality                              | Compounds Isolated                             | Biological Target                      | Biological Activity (MIC/IC\textsubscript{50}/ID\textsubscript{50}) | Reference |
|--------|------------------------|-----------------------------|---------------------------------------|-----------------------------------------------|----------------------------------------|---------------------------------------------------------------|-----------|
| 29     | Chaetomium sp. HQ-1,   | Astragalus chinensis        | Tai’an, Shandong Province, China      | Differanisole A (66)                          | L. monocytogenes S. aureus and MRSA,   | MIC, 16, 128, 128 \(\mu\)g/mL                                 | [47]      |
|        |                        |                             |                                       | 2,6-Dichloro-4-propylphenol (67),           | L. monocytogenes                        | MICs of 64 and 32 \(\mu\)g/mL,                               |           |
|        |                        |                             |                                       | 4,5-dimethylresorcinol (68)                 |                                        |                                                               |           |
| 30     | Chaetomium nigricolor F5, | Mahonia fortune            | Qingdao, People’s Republic of China  | Chamiside A (69)                              | S. aureus                              | MIC of 25 \(\mu\)g/mL                                        | [48]      |
| 31     | C. globosum            | Salvia miltiorrhiza         | Shenyang, Liaoning province, China    | Equisetin (70)                                | Multidrug-resistant E. faecalis, E. faecium, S. aureus, and S. epidermis | MIC values of 3.13, 6.25, 3.13, and 6.25 \(\mu\)g/mL | [49]      |
| 32     | Chaetomium sp. Eef-10, | Eucalyptus exserra         | Guangdong Province, China             | Mollicellins H (71)                           | S. aureus ATCC29213, S. aureus N50, MRSA, | IC\textsubscript{50}, 5.14, and 6.21 \(\mu\)g/mL |           |
|        |                        |                             |                                       | Mollicellin O (72)                            | S. aureus ATCC29213 and S. aureus N50   | IC\textsubscript{50}, 79.44 and 76.35 \(\mu\)g/mL |           |
|        |                        |                             |                                       | Mollicellin I (73)                            |                                        | IC\textsubscript{50}, 70.14 and 63.15 \(\mu\)g/mL |           |
| 33     | Chaetomium sp. M336    | Huperzia serrata           | Xichou County, Yunnan Province, China | 6-Formamidochetomin (74)                      | E. coli, S. aureus, S. typhimurium ATCC 6539 and E. faecalis | MIC, 0.78 \(\mu\)g/mL                                      | [51]      |
| 34     | Chaetomium globosum    | Nymphaea nouchali          | Udugampola in the Gampaha District, Sri Lanka | Chaetoglobosin A (75)                        | B. subtilis, S. aureus, and MRSA        | MIC, 16, 32 and 32 \(\mu\)g/mL                               | [52]      |
|        |                        |                             |                                       | Chaetoglobosin B (76)                         |                                        | >64 \(\mu\)g/mL                                               |           |
|        | **Talaromyces**        |                             |                                       |                                               |                                        |                                                               |           |
| 35     | Talaromyces pinophilus XL-1193 | Salvia miltiorrhiza      | Shenyang, Liaoning province, China    | Pinophol A (77)                               | Bacterium paratyphosum B                 | MIC, 50\(\mu\)g/mL                                            | [53]      |
| 36     | Talaromyces purpureogenus XL-25 | Panax notoginseng        | Shijiazhuang, Hebei Province, China   | Talaroconvolutin A (78)                       | B. subtilis Micrococcus lysodeikticus, Vibrio para-haemolyticus | MIC value of 1.56 \(\mu\)M                                   | [54]      |
|        |                        |                             |                                       | Talaroconvolutin B (79)                       |                                        | MIC = 0.73 and 0.18 \(\mu\)M                                  |           |
Table 1. Cont.

| Sr. No. | Fungus                          | Source              | Locality                  | Compounds Isolated                                                                 | Biological Target                                      | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|---------------------------------|---------------------|---------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------------------------|-----------|
| 37      | *Talaromyces purpureogenus*     | *Panax notoginseng* |                           | (1S,5S,7S,10S)-dihydroxyconfertifolin (80)                                          | *E. coli*                                              | MIC, 25 µM                               | [55]      |
|         |                                  |                     |                           | Talafun (81)                                                                         | *E. coli, S. aureus*                                   | MIC, 18 and 93 µM                         |           |
|         |                                  |                     |                           | N-(2′-hydroxy-3′-octadecenoyl)-9-methyl-4,8-sphingadienin (82)                      | *Mycobacterium smegmatis, S. aureus, Micrococcus tetragenus, and *E. coli* | MIC, 85, 90, 24, and 68, 93 µM               | [56]      |
| 38      | *Talaromyces funiculosus -Salicorn 58.* |                   |                           | Chrodrimanin A (83)                                                                | *S. aureus, M. tetragenus, Mycobacterium phlei, and *E. coli* | MIC, 67, 28, 47, and 26 µM               |           |
|         |                                  |                     |                           | Chrodrimanin B (84)                                                                | *E. coli*                                              | MIC, 43 µM                               |           |
| 39      | *Talaromyces* sp. LGT-2         | *Tripterygium willofordii.* |                           | Alkaloids 85–90                                                                    | *E. coli, P. aeruginosa, S. aureus, Bnfillus licheniformis, and Streptococcus pneumoniae* | MICs in the range of 0.125 to 1.0 50 µg/mL | [57]      |
| 40      | *Rhytidhysteron* sp. BZM-9      | *Leptospermum brachyandrum* |                           | Euphorbol (91)                                                                      | MRSA                                                  | MIC, 62.5 µg/mL                           | [58]      |
| 41      | *Stagonosporopsis oculihominis* | *Dendrobium huoshanense.* |                           | Stagonosporopsin C (92)                                                            | *Staphylococcus aureus subsp. aureus ATCC29213         | MIC_{50}, 41.3 µM                         | [59]      |
| 42      | *Eutypella scoparia* SCBG-8     | *Leptospermum brachyandrum* | SCBG, Chinese Academy of Sciences, China | Eutyscoparols H (93), I (94), tetrahydroauroglucin (95), flavoglaucin (96)         | *Staphylococcus aureus and MRSA*                      | MICs in the range of 1.25 to 6.25 µg/mL  | [60]      |
| 43      | *Eutypella scoparia* SCBG-8     | *Leptospermum brachyandrum* | SCBG, Chinese Academy of Sciences, Guangzhou 510650, China | Eutyscoparin G (97)                                                                | *S. aureus and MRSA*                                  | MIC values of 6.3 µg/mL                  | [61]      |
Table 1. Cont.

| Sr. No. | Fungus                          | Source                  | Locality                                      | Compounds Isolated                                                                 | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|---------------------------------|-------------------------|-----------------------------------------------|-------------------------------------------------------------------------------------|------------------|------------------------------------------|-----------|
| 44      | *Sarocladium oryzae* DX-THL3,   | *Oryza rufipogon* Griff.|                                               | Saro cladilactone A (98), saro cladilactone B (99), helvolic acid (100), helvolinic acid (101), 6-desacetoxy-helvolic acid (102), 1,2-dihydrohelvolic acid (103) | *S. aureus*      | MIC values of 64, 4, 8, 1, 4 and 16 µg/mL | [62]      |
|         |                                 |                         |                                               | Compound 101                                                                       | *B. subtilis*     | MIC, 64 µg/mL                            |           |
|         |                                 |                         |                                               | Compounds 99, 101, 103                                                             | *E. coli*         | MIC 64 µg/mL each                        |           |
| 45      | *Paraphaeosphaeria sporulosa*    | *Fragaria x ananassa*   | Caserta province, Southern Italy              | Cyclo(L-Pro-L-Phe) (104)                                                            | *Salmonella* strains, S1 and S2 | MIC 71.3 and 78.6 µg/mL                  | [63]      |
| 46      | *Aplosporella javeedii*          | *Orychophragmus violaceus* | Beijing, China                                | Terpestacin (105), fusaproliferin (106), mutolide (108)                            | *M. tuberculosis* H37Rv | MICs of 100 µM                           | [64]      |
|         |                                 |                         |                                               | 6,7,9,10-Tetrahydromutolide (107)                                                   | *S. aureus*,      | MICs of 100 µM                           |           |
| 47      | *Pleosporales* sp. Sigrf05       | roots of *Siratia*      | Guangxi Province of China                     | Pleospyrone E (109)                                                                | *B. subtilis*, *Agrobacterium tumefaciens*, *Ralstonia solanacearum*, and *Xanthomonas vesicatoria* | MIC 100.0 µM each | [65]      |
| 48      | *Aplosporella javeedii*          | *Orychophragmus violaceus* | Beijing, China                                | Aplojaveediin A (110)                                                              | *Staphylococcus aureus* strain ATCC 29213, *S. aureus* strain ATCC 700699 and *Bacillus subtilis* (ATCC 169) | MICs 50, 50 and 25 µM, | [66]      |
|         |                                 |                         |                                               | Aplojaveediin F (111)                                                              | *S. aureus* ATCC 29213 and ATCC 700699 | MICs of 25 and 50 µM |           |
| 49      | *Paecilomyces variotii*          | *Lawsonia Alba*         | University of Karachi, Pakistan               | Lawsozaheer (112)                                                                 | *S. aureus* (NCTC 6571) | 84.26% inhibition at 150 µg/mL          | [67]      |
| Sr. No. | Fungus                  | Source                  | Locality                             | Compounds Isolated                                                                 | Biological Target                                      | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|--------|-------------------------|-------------------------|--------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------------------------|-----------|
| 50     | Preussia isomera        | OSiMAC strategy         | Wenshan, Yunnan Province, China      | Setosol ([113])                                                                   | Multidrug-resistant E. faecium, methicillin-resistant S. aureus and multidrug-resistant E. faecalis | MIC 25 µg/mL                              | [68]      |
|        | Preussia isomera.       | XL-1326,                | Panax notoginseng                    | (+)- and (−)-Preuisolactone A ([114, 115])                                        | U. isomera. XL-1326, Panax notoginseng (+)- and (−)-Preuisolactone A ([114, 115]) | MIC, 10.2 and 163.4 µM                   | [69]      |
| 51     | Neurospora udagawae     | Quercus macranthera     | Kaleybar region in northwestern Iran | Udagawanones A ([116])                                                            | S. aureus                                              | MIC, 66 µg/mL                             | [70]      |
| 52     | Xylomelasma sp.         | Salvia miltiorrhiza Bunge | 2,6-Dimethyl-5-methoxy-7-hydroxychromone ([117]), 6-hydroxymethylglucogenin ([118]), 6-methoxymethylglucogenin ([119]), isoeugenol ([120]), diaporthin ([29]), 8-hydroxy-6-methoxy-3-methylisocoumarin ([121]) | 2,6-Dimethyl-5-methoxy-7-hydroxychromone ([117]), 6-hydroxymethylglucogenin ([118]), 6-methoxymethylglucogenin ([119]), isoeugenol ([120]), diaporthin ([29]), 8-hydroxy-6-methoxy-3-methylisocoumarin ([121]) | Bacillus subtilis, Staphylococcus haemolyticus, A. tumefaciens, Erwinia carotovora, and Xanthomonas vesicatoria | MIC values at the range of 25 ~ 100 µg/mL | [71]      |
|        | Xylomelasma sp.         | Salvia miltiorrhiza Bunge | 2,6-Dimethyl-5-methoxy-7-hydroxychromone ([117]), diaporthin ([29])               | 2,6-Dimethyl-5-methoxy-7-hydroxychromone ([117]), diaporthin ([29])               | B. subtilis, E. carotovora                            | MIC, 50 and 100 µg/mL                    |           |
|        | Xylomelasma sp.         | Salvia miltiorrhiza Bunge | 6-Hydroxymethylglucogenin ([118]), 6-methoxymethylglucogenin ([119]), isoeugenol ([120]), diaporthin ([29]) | 6-Hydroxymethylglucogenin ([118]), 6-methoxymethylglucogenin ([119]), isoeugenol ([120]), diaporthin ([29]) | S. haemolyticus and E. carotovora             | MIC, 75 µg/mL each                      |           |
|        | Xylomelasma sp.         | Salvia miltiorrhiza Bunge | 8-Hydroxy-6-methoxy-3-methylisocoumarin ([121])                                   | 8-Hydroxy-6-methoxy-3-methylisocoumarin ([121])                                   | B. subtilis, A. tumefaciens, and X. vesicatoria       | MICs 25, 75, and 25 µg/mL               |           |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|---------------------|-------------------|-------------------------------------------------|----------|
| 53      | *Amphirosellinia nigrospora* JS-1675 | *Pteris cretica* |          | (45,55,6S)-5,6-epoxy-4-hydroxy-3-methoxy-5-methylcyclohex-2-en-1-one (122) | *Acidovorax avenae* subsp. *catliae*, *A. tumefaciens*, *Burkholderia glumae*, *Clavibacter michiganensis* subsp. *michiganensis*, *Pectobacterium carotovorum* subsp. *carotovorum*, *Pectobacterium chrysanthemi*, *Ralstonia solanacearum*, *Xanthomonas arboricola* pv. *pruni*, *Xanthomonas axonopodis* pv. *Citri*, *Xanthomonas euvesicatoria*, *Xanthomonas oryzae* pv. *oryzae* | MICs ranging between 31.2 and 500 µg/ml [72] |
| 54      | Emericella sp. XL029 | *Panax notoginseng* | Shijiazhuang, Hebei Province, China | 5-(Undeca-3′,5′,7′-trien-1′-yl)furan-2-ol (123) and 5-(undeca-3′,5′,7′-trien-1′-yl)furan-2-carbonate (124) | *B. subtilis*, *B. cereus*, *S. aureus*, *B. paratyphosum* B, *S. typhi*, *P. aeruginosa*, *E. coli*, and *E. aerogenes* | MIC values ranging from 6.3 to 50 µg/mL [73] |
| 56      | Emericella sp. XL029 | *Panax notoginseng* | Shijiazhuang, Hebei Province, China | 14-Hydroxytajixanthone (125), 14-hydroxytajixanthonehydrate (126), 14-hydroxy-15-chlorotajixanthone hydrate (127), 14-methoxytajixanthone-25-acetate (130), questin (132), and carnemycin B (133) | *M. luteus*, *S. aureus*, *B. megaterium*, *B. anthracis*, and *B. paratyphosum* B | MIC, in the range of of 12.5 and 25µg/mL |
|         |        |        |          | Epitajixanthone hydrate (128) | *M. luteus*, *S. aureus*, *B. megaterium*, and *B. paratyphosum* B | MIC 25 µg/mL [74] |
|         |        |        |          | Tajixanthone hydrate (129), 15-chlorotajixanthone hydrate (131) | *S. aureus*, *B. megaterium*, and *B. paratyphosum* B | MICs 25 and 12.5 µg/mL, |
|         |        |        |          | 14-Hydroxytajixanthone (125) Epitajixanthone hydrate (128), carnemycin B (133) | drug resistant *S. aureus* | MIC 50 µg/mL |
|         |        |        |          | Compounds 125–133 | *P. aeruginosa*, *E. coli*, and *E. aerogenes* | MIC 50 µg/mL |
| Sr. No. | Fungus                     | Source                        | Locality                                                        | Compounds Isolated                          | Biological Target                  | Biological Activity (MIC/IC50/ID50) | Reference |
|---------|----------------------------|-------------------------------|----------------------------------------------------------------|---------------------------------------------|--------------------------------------|-----------------------------------|-----------|
| 57      | *Byssochlamys spectabilis* | *Edgeworthia chrysantha*      | Hangzhou Bay, Hangzhou, Zhejiang Province, China                | Bysspectin C (134)                           | *E. coli* ATCC 25922 and *S. aureus* ATCC 25923 | MIC, 32 and 64 µg/mL             | [75]      |
| 58      | *Poculum pseudosydowianum* | *(TNS-F-57853), Quercus crispula var. crispula* | Yoshiwa, Hatsukaichi, Hiroshima prefecture, Japan               | Sydowianumols A (135), and B (136)          | MRSA                                | MIC90 values of 12.5 µg/mL        | [76]      |
| 59      | *Lachnum palmae* exposure to a HDAC inhibitor SAHA | *Przewalskia tangutica*     | Linzhou Country of the Tibet Autonomous Region, China          | Palmaerones A-B, E-G (137, 138, 140, 141, 142) | *B. subtilis*                        | MICs 35, 30, 10, 50, and 55 µg/mL | [77]      |
|         |                            |                               |                                                                | Palmaerones A-C, E (137, 138, 139, 140)     | *S. aureus*                           | MICs 65, 55, 60, and 55, µg/mL    |           |
| 60      | *Nemania serpens*         | *Vitis vinifera*              | Canada’s Niagara region                                         | Nemanifuranone A (143)                     | *E. coli*                            | MIC 200 µg/mL                     |           |
|         |                            |                               |                                                                | S. *aureus*, *B. subtilis* and *M. luteus* |                                    | >75% inhibition at a concentration of 100–200 µg/mL | [78]      |
|         |                            |                               |                                                                | Triterpenoid 144                           | *S. cerevisiae*                      | (>25% inhibition) against at 200 µg/mL |           |
|         |                            |                               |                                                                |                                             | *M. luteus*                          | (>75% inhibition) of at a concentration of 100 µg/mL |           |
| 61      | *Paraconiothyrium variabile* | *Cephalotaxus harringtonia*  |                                                                  | Variabilone (145)                          | *B. subtilis*                        | IC50 of 2.13 µg/mL after 24 h (0.36 µg/mL for kanamycin) | [79]      |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|---------------------------------|---------|
| 62      | Pyronema sp. (A2-1 & D1-2) | Taxus mairei | Shennongjia National Nature Reserve, Hubei province, China. | Methyl 2-[(E)-2-[4-(formyloxy)phenyl]ethenyl]-4-methyl-3-oxopentanoate (146), (3R,6R)-4-methyl-6-(1-methylethyl)-3-phenylmethylperhydro-1,4-oxazine-2,5-dione (147), (3R,6R)-N-methyl-N-(1-hydroxy-2-methylpropyl)-phenylalanine (148), siccanol (149), fusaproliferin (106), and sambutoxin (150) | Mycobacterium marinum ATCCBA-535, E. coli | IC<sub>50</sub> of 64, 59, 57, 84, 43 and 32 µM, (positive control rifampin IC<sub>50</sub> of 2.1 µM) | [80] |
| 63      | Pulvinula sp. 11120 | Cupressus arizonica | Tucson, AZ, USA | Pulvinulin A (151), graminin C (152), cis-gregatin B (153), and graminin B (154) | E. coli | 12, 18, 16 and 14 mm zone of inhibition at 100 µg/mL | [81] |
| 64      | Stelliosphaera formicum | Duroia hirsuta | Yasuni’ National Park off the Napo River in Ecuador | Stelliosphaerols A (155) and B (156) | S. aureus | MIC values of 250 µg/mL | [82] |
| 65      | Unidentified Ascomycete | Melilotus dentatus | | cis-4-Acetoxoxyxymellein (157) | E. coli and B. megaterium | Zone of inhibition of 10 and 10 mm (Partial inhibition) at a concentration of 0.05 mg | [83] |
|         |        |        |          | 8-Deoxy-6-hydroxy-cis-4-acetoxoxyxymellein (158) | E. coli and B. megaterium | Zone of inhibition of 9 and 9 mm (Partial inhibition) at a concentration of 0.05 mg | |
|         | Anamorphic Ascomycetes | | | | | |
|         | Aspergillus | | | | | |
| 66      | Aspergillus sp. FT1307 | Heliotropium sp. | | Aspochalasin P (159), alatinone (160), β-11-methoxy curvularine (161), 12-keto-10,11-dehydrocurvularine (162) | S. aureus ATCC12600, B. subtilis ATCC6633 and MRSA ATCC43300 | MIC in the range of 40 to 80 µg/mL | [84] |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|-----------------------------------------------|-----------|
| 67      | Aspergillus cristatus | Pinellia ternata | Aspergillone A (163) | B. subtilis and S. aureus | MIC<sub>50</sub>, 8.5 and 32.2 µg/mL | [85] |
| 68      | Aspergillus versicolor strain Eich.5.2.2 | Eichhornia crassipes | 22S-Aniduquinolone A (164), 22R-aniduquinolone A (165) | S. aureus (ATCC700699) | MIC, 0.4 µg/mL | [86] |
| 69      | Aspergillus versicolor | roots of Pulicaria crispa | Aspergilletteher B (166) | S. aureus, B. cereus, and E. coli | MICs, 4.3, 3.7, and 3.9 µg/mL | [87] |
| 70      | Aspergillus ochraceus SX-C7 | Setaginella stauntoniana | 3-O-β-D-Glucopyranosyl stigmasta-5(6),24(28)-diene (167) | Bacillus subtilis | MIC, 2 µg/mL | [88] |
| 71      | Aspergillus amstelodami (MK215708) | Ammi majus | Egypt | Dihydroauroglaucain (168) | E. coli, Streptococcus mutans, S. aureus | MIC, 1.95, 1.95 and 3.9 µg/mL | [89] |
| 72      | Aspergillus micronesiensis | Phyllanthus glaucus | LuShan Mountain, Jiangxi Province, China | Cyschalasins A (169) and B (170) | MRSA | MIC<sub>50</sub>, 17.5 and 10.6 µg/mL; MIC<sub>90</sub>, 28.4 and 14.7 µg/mL | [90] |
| 73      | A. niger | Acanthus montanus | Kala Mountain neighborhood of Yaounde, Africa | Methylsulochrin (171) | S. aureus, Enterobacter cloacae and Enterobacter aerogenes | MIC, 15.6, 7.8 and 7.8 µg/mL | [91] |
| 74      | Aspergillus tubingensis | stem of Decaisnea insignis | Qinling Mountain, Shaanxi Province, China | 3-(5-Oxo-2,5-dihydrofuran-3-yl)propanoic acid (172) | Streptococcus lactis | MIC value of 32 µg/mL | [92] |
| 75      | Aspergillus flavipes Y-62 | Suaeda glauca | Zhoushan coast, Zhejiang province, East China | Methyl 2-(4-hydroxybenzyl)-1,7-dihydroxy-6-(3-methylbut-2-enyl)-1H-indene-1-carboxylate (173) | MRSA | MIC, 128 µg/mL | [93] |
Table 1. Cont.

| Sr. No. | Fungus          | Source                          | Locality                        | Compounds Isolated                                                                 | Biological Target                  | Biological Activity (MIC/IC\text{50}/ID\text{50}) | Reference |
|---------|----------------|---------------------------------|---------------------------------|------------------------------------------------------------------------------------|------------------------------------|---------------------------------------------------|-----------|
| 76      | Aspergillus sp. | Rhizome of Zingiber cassumunar  |                                 | 4-Amino-1,1-(3,6-dihydroxy-1-(4-nitrophenyl)propan-2-yl)-1H-1,2,3-triazole-5(4H)one (174) | *Xanthomonas oryzae*, *Bacillus subtilis* and *E. coli* | Zone of inhibition 37, 30 and 27 mm | [5]       |
|         |                |                                 |                                 | 3,6-Dibenzyl-3,6-dimethylpiperazine-2,5-dione (175)                                 | *E. coli* and *X. oryzae*         | Zone of inhibition 21 and 16 mm.                  |           |
| 77      | Aspergillus fumigatus | Edgeworthia chrysantha | Hangzhou Bay (Hangzhou, China) | Pseurotin A (176), spirotroyprostatin A (177)                                         | *S. aureus*                        | MIC of 0.39 µg/mL each | [94]      |
|         |                |                                 |                                 | Spirotroyprostatin A (177)                                                           | *E. coli*                          | MIC, 0.39 µg/mL                                   |           |
| 78      | Aspergillus sp. | Astragalus membranaceus         |                                 | Fumiquinazoline J (178), fumiquinazoline C (180), fumiquinazoline H (181), fumiquinazoline D (182) | *B. subtilis*, *S. aureus*, *E. coli* and *P. aeruginosa* | MICs in the range of 0.5–8 µg/mL | [95]      |
|         |                |                                 |                                 | Fumiquinazoline I (179), fumiquinazoline B (183)                                      |                                    |                                                    |           |
| 79      | Aspergillus fumigatiaffinis | Tribulus terrestris              |                                 | (−)-Palitantin (184)                                                                | *E. faecalis UW 2689* and *Streptococcus pneumoniae* | MIC, 64µg/mL                                     | [96]      |
| 80      | Aspergillus sp. TJ23 | Hypericum perforatum (St John' Wort) | Shennongjia areas of Hubei Province, China | Aspermerodione (185)                                                              | MRSA                              | MIC, 32 µg/mL/potential inhibitor of PBP2a        | [97]      |
|         |                |                                 |                                 | Andiconin C (186)                                                                  |                                    | marginal antimicrobial activity (>100µg/mL)       |           |
| 81      | Aspergillus sp. YXF3 | Ginkgo biloba                   |                                 | Prenylterphenyllin D (187), prenylterphenyllin E (188), 2′-O-Methylprenylterphenyllin (189), prenylterphenyllin (190) | *X. oryzae pv. oryzicola* Swings and *E. amylovora* | MIC, 20 µg/mL each | [98]      |
|         |                |                                 |                                 | Prenylterphenyllin B (191)                                                          | *E. amylovora*                     | MIC, 10 µg/mL                                    |           |
Table 1. Cont.

| Sr. No. | Fungus                | Source              | Locality                                    | Compounds Isolated                  | Biological Target              | Biological Activity (MIC/IC₅₀/ID₅₀) | Reference |
|---------|-----------------------|---------------------|---------------------------------------------|-------------------------------------|----------------------------------|-------------------------------------|-----------|
| 82      | Aspergillus sp.       | Pinellia ternata    | Nanjing, Jiangsu Province, China            | Aspergillussanone D (192)           | P. aeruginosa, and S. aureus     | MIC₅₀, 38.47 and 29.91 µg/mL       | [99]      |
|         |                       |                     |                                             | Aspergillussanone E (193)           | E. coli                         | MIC₅₀, 7.83 µg/mL                  |           |
|         |                       |                     |                                             | Aspergillussanone F (194)           | P. aeruginosa, and S. aureus     | MIC₅₀, 26.56, 3.93 and 16.48 µg/mL  |           |
|         |                       |                     |                                             | Aspergillussanone G (195)           | P. aeruginosa, and S. aureus     | MIC₅₀, 24.46 and 34.66 µg/mL       |           |
|         |                       |                     |                                             | Aspergillussanone H (196)           | P. aeruginosa, and E. coli       | MIC₅₀, 8.59 and 5.87 µg/mL         | [99]      |
|         |                       |                     |                                             | Aspergillussanone I (197)           | P. aeruginosa                   | MIC₅₀, 12.0 µg/mL                  |           |
|         |                       |                     |                                             | Aspergillussanone J (198)           | P. aeruginosa, E. coli and S. aureus | MIC₅₀, 28.50, 5.34 and 29.87 µg/mL |           |
|         |                       |                     |                                             | Aspergillussanone K (199)           | P. aeruginosa, and S. aureus     | MIC₅₀, 6.55 and 21.02 µg/mL        |           |
|         |                       |                     |                                             | Aspergillussanone L (200)           | P. aeruginosa, S. aureus, and B. subtilis | MIC₅₀, 1.87, 2.77, and 4.80 µg/mL |           |
|         |                       |                     |                                             | Compound 201                        | P. aeruginosa, and E. coli       | MIC₅₀, 19.07 and 1.88 µg/mL        |           |
| 83      | Aspergillus terreus JAS-2 | Achyranthus aspera | Varanasi, India                             | Terrein (202)                       | E. faecalis                      | IC₅₀, 20 µg/mL                     | [100]     |
|         |                       |                     |                                             |                                     | S. aureus and Aeromonas hydrophila | 20 µg/mL                          |           |
| 84      | Aspergillus terreus   | roots of Carthamus lanatus | Al-Azhar University campus in Cairo, Egypt | (22E,24R)-Stigmasta-5,7,22-trien-3-β-ol (203) | MRSA                            | IC₅₀, 2.29 µM                      | [101]     |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|---------------------|-------------------|-------------------------------------------------|-----------|
| 85      | *Aspergillus flavus* | *Cephalotaxus fortunei* | Taibai Mountains, Shaanxi Province, China | 5-Hydroxymethylfuran-3-carboxylic acid (204), 5-acetoxyfuran-3-carboxylic acid (205) | *S. aureus* | MIC, 31.3 and 15.6 µg/mL [102] |          |
| 86      | *Aspergillus allahabadii* | BCC45335 root of *Cinnamomum subvenium* | Khao Yai National Park, Nakhon Ratchasima Province, Thailand | Allahabadolactone B (206), (22E,5α,8α-epidioxyergosta-6,22-dien-3β-ol (207) | *B. cereus* | IC<sub>50</sub>, 12.50 and 3.13 µg/mL [103] |          |
| 87      | *Aspergillus tubingensis* | *Lycium ruthenicum* | Qinling Mountain in China’s Shaanxi province | 6-Isovaleryl-4-methoxypyran-2-one (208), asperpyrone A (210), campyrone A (211) | *E. coli, Pseudomonas aeruginosa, Streptococcus lactis* and *S. aureus* | MIC values ranging from 62.5 to 500 µg/mL [104] |          |
| 88      | *Aspergillus tamarii* | FR02 roots of *Ficus carica* | | Malformin E (212) | *B. subtilis, S. aureus, P. aeruginosa*, and *E. coli* | MIC, 0.91, 0.45, 1.82, and 0.91 µM [105] |          |
| 89      | *Aspergillus terreus* | Roots of *Carthamus lanatus* | Al-Azhar University campus, Egypt | (22E,24R)-Stigmasta-5,7,22-trien-3β-ol (203) | *MRSA* | IC<sub>50</sub>, 0.96 µg/mL [106] |          |
| 90      | *Aspergillus* sp. (SbDS) | Leaves of *Andrographis paniculata* | Indralaya, Ogan Ilir, South Sumatra. | 1-(3,8-Dihydroxy-4,6,6-trimethyl-6H-benzochromen-2-yloxy)propane-2-one (214), 5-hydroxy-4-(hydroxymethyl)-2H-pyran-2-one (215), (5-hydroxy-2-oxo-2H-pyran-4-yl)methyl acetate (216) | *S. aureus, E. coli, S. dysenteriae* and *Salmonella typhi* | Zone of inhibition diameters ranging from 8.1 to 12.1 mm at a concentration 500 µg/mL [107] |          |
Table 1. Cont.

| Sr. No. | Fungus                  | Source                  | Locality                        | Compounds Isolated                                                                 | Biological Target                                                                 | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|-------------------------|-------------------------|----------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------|-----------|
| 91      | Aspergillus sp. IFB-YXS | Ginkgo biloba           |                                  | Xanthoascin (217)                                                                  | X. oryzae pv. oryzicola, Swings, E. amylovora, P. syringae pv. Lachrymans and C. michiganense subsp. sepedonicus | MICs, 20, 10, 5.0 and 0.31 µg/mL                                | [108]     |
|         |                         |                         |                                  | Prenylterphenyllin B (218)                                                        | X. oryzae pv. oryzicola Swings, E. amylovora, P. syringae pv. Lachrymans,         | MICs of 20 µg/mL each                                       |           |
|         |                         |                         |                                  | Prenykcandidusin (219)                                                             | X. oryzae pv. oryzicola Swings X. oryzae pv. oryzicola Swings                    | MIC values of 10 and 20 µg/mL                                   |           |
|         | **Penicillium**         |                         |                                  |                                                                                   |                                                                                   |                                                             |           |
| 92      | Penicillium ochrochloron SWUKD4.1850 | Kadsura angustifolia |                                  | 4-O-Desmethylaigialomycin B (220), penochroclactones C (221) and D (222)           | Staphylococcus aureus, Bacillus subtilis, Escherichia coli, and Pseudomonas aeruginosa | MIC values between 9.7 and 32.0 µg/mL                         | [109]     |
| 93      | Penicillium brefeldianum | Syzygium zeylanicum    |                                  | p-Hydroxybenzaldehyde (223)                                                        | S. typhi, E. coli, and B. subtilis                                               | MIC values of 64 µg/mL                                      | [110]     |
| 94      | Penicillium vulpinum GDGJ-91 | Sophorae tonkinensis | Baise, Guangxi Province, China  | 10-Demethylated andrastone A (224), andrastin A (227)                              | Bacillus megaterium                                                              | MIC value of 6.25 µg/mL                                      | [111]     |
|         |                         |                         |                                  | Citreohybridone E (225), citreohybridonol (226), citreohybridone B (228)            | B. megaterium                                                                     | MIC values of 25, 12.5 and 25 µg/mL                           |           |
|         |                         |                         |                                  |                                                                                   | B. paratyphosus B, E. coli and S. aureus                                          | MIC, 6.25, 25 and 25 µg/mL                                   |           |
|         |                         |                         |                                  | 10-Demethylated andrastone A (224), citreohybridone E (225), andrastin A (227), andrastin B (228) | B. paratyphosus B                                                              | MIC, 12.5 or 25 µg/mL                                      |           |
| Sr. No. | Fungus                          | Source               | Locality                               | Compounds Isolated                                                                                      | Biological Target                      | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|---------------------------------|----------------------|----------------------------------------|---------------------------------------------------------------------------------------------------------|----------------------------------------|------------------------------------------|-----------|
| 95      | *Penicillium nothofagi* P-6     | *Abies beshanzuensis* | Baishanzu Mountain in Lishui, Zhejiang Province of China | Chromenopyridin A (229), viridicatol (230)                                                            | *S. aureus* ATCC29213                 | MIC, 62.5 and 15.6 µg/mL                 | [112]     |
| 96      | *Penicillium restrictum* (strain G85) | *Silybum marianum*    | Horizon Herbs, LLC (Williams, OR, USA). | ω-Hydroxyemodin (231)                                                                                  | Clinical isolates of MRSA              | Quorum-sensing inhibition in both in vitro and in vivo models | [113]     |
| 97      | *Penicillium vulgarum* | *S. tonkinensis*      | Baise, Guangxi Province, China         | (−)-3-Carboxypropyl-7-hydroxyphthalimide (232)                                                        | *S. dysenteriae* and *Enterobacter aerogenes* | MIC, 12.5 µg/mL each                      | [114]     |
|         |                                 |                      |                                        | (−)-3-Carboxypropyl-7-hydroxyphthalide methyl ester (233)                                              | *B. subtilis*                          | MIC, 25 µg/mL                            |           |
|         |                                 |                      |                                        |                                                                                                         | *B. megaterium* and *Micrococcus lysodeikticus* | MIC, 50 µg/mL                           |           |
| 98      | *Penicillium sumatrense* GZWMJZ-313 | *Leaf of Garcinia multiflora* | Libo, Guizhou Province of China        | Citridone E (234), (−)-dehydrocurvularin (235)                                                          | *S. aureus, P. aeruginosa, Clostridium perfringens, and E. coli* | MIC values ranging from 32 to 64 µg/mL | [115]     |
| 99      | *Penicillium ochrochloronthe*   | Roots of *Taxus* media | Qingfeng Mountain, Chongqing, China    | 3,4,6-Trisubstituted α-pyrene derivatives, namely 6-(2′R-hydroxy-3′E,5′E-diene-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (236), 6-(2′S-hydroxy-3′E-ene-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (237), 6-(2′S-hydroxy-1′-heptyl)-4-hydroxy-3-methyl-2H-pyran-2-one (238), trichodermic acid (239) | *B. subtilis, Micrococcus luteus, S. aureus, B. megaterium, Salmonella enterica, Proteusbacilllm vulgaris, Salmonella typhi, P. aeruginosa, E. coli and Enterobacter aerogenes* | MIC values ranging from 25 to 50 µg/mL | [116]     |
Table 1. Cont.

| Sr. No. | Fungus                  | Source                | Locality                               | Compounds Isolated                                | Biological Target             | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|-------------------------|-----------------------|----------------------------------------|---------------------------------------------------|-------------------------------|-------------------------------------------|-----------|
| 100     | *Penicillium janthinellum* SYPF 7899 | *Panax notoginseng* | Wenshan region, Yunnan province, China | Brasilamide J-a (240), brasiliamide J-b (241)       | *B. subtilis* and *S. aureus* | MIC, 15 and 18 µg/mL,                   | [117]     |
|         |                         |                       |                                        | Peniciolidone (242), austin (243)                 | *B. subtilis*                | MIC, 35 and 50 µg/mL                    |           |
|         |                         |                       |                                        |                                                   | *S. aureus*                  | MIC, 39, and 60 µg/mL                   |           |
| 101     | *Penicillium cataractum* SYPF 7131 | *Ginkgo biloba*       |                                        | Penicimenolidyu A (244), penicimenolidyu B (245) and rasfonin (246) | *S. aureus*                  | MIC 65, 59 and 10 µg/mL                 | [118]     |
|         |                         |                       |                                        | 3′-Methoxycitreovirone (247), citreovirone (249)  | *E. coli* and *S. aureus*   | MIC = 62.6 and 76.6 µg/mL               |           |
|         |                         |                       |                                        | Helvolic acid (100)                                |                               |                                            |           |
|         |                         |                       |                                        | *S. aureus*, *P. aeruginosa*, *B. subtilis* and *E. coli* |                               |                                            |           |
|         |                         |                       |                                        | *cis*-bis-(Methylthio)-silvatin (248), trypacidin A (250) | *S. aureus*                  | MIC values of 43.4 and 76.0 µg/mL       | [119]     |
| 102     | *Penicillium sp.*         | Tubers of *Pinellia ternata* | suburb of Nanjing, Jiangsu, China. |                                                   |                               |                                            |           |
|         |                         |                       |                                        |                                                   |                               |                                            |           |
| 103     | *Penicillium sp.*         | *Nerium indicum*      | Qinling Mountain, Shaanxi Province, China | Viridicatol (251)                               | *S. aureus*                  | MIC value of 15.6 µg/mL                 | [120]     |
| 104     | *Penicillium sp.* (NO. 24) | *Tapiscia sinensis*   | Shennongjia National Forest Park China | Penicitroamide (252)                              | Erwinia carotovora subsp. Carotovora | MIC_{50} at 45 µg/mL                    | [121]     |
|         |                         |                       |                                        |                                                   |                               |                                            |           |
| 105     | *Penicillium sp.*         | Leaves of *Garcinia nobilis* | Mount Etinde, Southwest region Cameroon | Penialidin A (253), Penialidin B (254), Penialidin C (255) | Vibrio cholerae SG24 (1), V. cholerae CO6, V. cholerae NB2, V. cholerae PC2, S. flexneri SDINT, | MIC, 8–32 µg/mL, MIC, 4–32 µg/mL, MIC, 0.50, 16, 8, 0.50 and 8 µg/mL, MIC, 64–128 µg/mL | [122]     |
|         |                         |                       |                                        | Citromycetin (256), brefelfin A (258)             |                               |                                            |           |
|         |                         |                       |                                        |                                                   |                               |                                            |           |
|         |                         |                       |                                        | *p*-Hydroxyphe nylglyoxalaldoxime (257)           |                               |                                            |           |
Table 1. Cont.

| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|-------------------------------------------|-----------|
| 106     | *Purpureocillium lilacinum* | roots of *Rauvolfia macrophylla* | Mount Kalla in the Center Region of Cameroon | Purpureone (259) | *B. cereus*, *L. monocytogenes*, *E. coli* ATCC 8739, *K. pneumoniae* ATCC 1296, *P. stuartii* ATCC 29916, *P. aeruginosa* ATCC PA01 | Zone of inhibition of 10.6, 12.3, 13.0, 8.7, 12.3, and 10.0 mm against (10 µL/6 mm Filter paper disks). | [123] |
| 107     | *Fusarium* sp. | *Mentha longifolia* | Al Madinah Al Munawwarah, Saudi Arabia | Fusaribenzamide A (264) | *S. aureus* and *E. coli* | MICs, 62.8 and 56.4 µg/disc | [125] |
Table 1. Cont.

| Sr. No. | Fungus               | Source                  | Locality         | Compounds Isolated                                                   | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|----------------------|-------------------------|------------------|-----------------------------------------------------------------------|-------------------|------------------------------------------------------------|-----------|
| 108     | *F. proliferatum* AF-04 | Green Chinese onion     |                  | 5-O-Methylsolaniol (270), 5-O-methyljavanicin (271), methyl ether fusarubin (272), anhydrojavanicin (273) | *B. megaterium*   | MICs 25 µg/mL each.                                        | [126]     |
|         |                      |                         |                  | 5-O-Methylsolaniol (270), 5-O-methyljavanicin (271), methyl ether fusarubin (272) | *B. subtilis*     | MICs, 50 µg/mL each.                                       |           |
|         |                      |                         |                  | Indol-3-acetic acid (265), beauvericin (267), epicyclonerodiol oxide (269) | *B. megaterium*   | MICs 50 µg/mL each.                                       |           |
|         |                      |                         |                  | Cyclonerodiol (268)                                                   | *B. megaterium*   | MIC 12.50 µg/mL.                                           |           |
|         |                      |                         |                  | *epi*-Cyclonerodiol oxide (269), methyl ether fusarubin (272)          | *E. coli*         | MIC 50 µg/mL.                                              |           |
|         |                      |                         |                  | 5-O-Methylsolaniol (270), 5-O-methyljavanicin (271), anhydrojavanicin (273) | *E. coli*         | MIC 25 µg/mL.                                              |           |
|         |                      |                         |                  | *epi*-Cyclonerodiol oxide (269), 1,4-naphthoquinones, 5-O-methylsolaniol (270), 5-O-methyljavanicin (271), methyl ether fusarubin (272) | *Clostridium perfringens* | MICs 50, 50, 12.5 and 50 µg/mL |           |
|         |                      |                         |                  | Beauvericin (267), fusaproliferin (106), 5-O-methylsolaniol (270), 5-O-methyljavanicin (271), methyl ether fusarubin (272), anhydrojavanicin (273) | MRSA | MIC value of 50, 50, 12.5, 12.5, and 25 µg/mL respectively. |           |
|         |                      |                         |                  | 5-O-Methyljavanicin (271), methyl ether fusarubin (272), anhydrojavanicin (273) | RN4220            | MIC value of 50 µg/mL each.                               |           |
|         |                      |                         |                  | Methyl ether fusarubin (272), anhydrojavanicin (273)                   | NewmanWT          | MIC value of 50 µg/mL each.                               |           |
|         |                      |                         |                  | Bassiatin (266)                                                        | NewmanWT          | MIC, 50 µg/mL.                                              |           |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|---------|--------|--------|----------|-------------------|-------------------|---------------------------------------------|-----------|
| 109     | *Fusarium* sp. TP-G1 | *Dendrobium officinale* | Chongqing Academy of Chinese Materia Medica in China | Trichosetin (274), beauvericin (267), beauvericin A (275), enniatin H (277), enniatin I (278), enniatin MK1688 (279) | *S. aureus* and MRSA | IC$_{50}$ values in the range of 2–32 µg/mL | [127] |
|         |        |        |          | Enniatin B (276)  | *S. aureus* and MRSA | IC$_{50}$, 128 µg/mL each |          |
|         |        |        |          | Fusaric acid (280), dehydrofusaric acid (281) | *Acinetobacter baumannii* | MIC, 64 and 128 µg/mL |          |
| 110     | *Fusarium* sp. YD-2 | *Santalum album* | Dongguan, Guangdong Province, China | Fusariumin A (282) | *S. aureus* and *P. aeruginosa* | MIC, 6.3 µg/mL | |
|         |        |        |          | Asperterpenoid A (283) | *Salmonella enteritidis* and *Microoccus luteus* | MIC, 25.2 and 6.3 µg/mL | [128] |
|         |        |        |          | Agathic acid (284) | *B. cereus* and *M. luteus* | MIC, 12.5 and 25.4 µg/mL |          |
| 111     | *Fusarium* chlamydosporium | Leaves of *Anvillea garcinii* | Al-Azhar University campus, Egypt | Fusaritheioamide B (285) | *E. coli*, *B. cereus*, and *S. aureus* | MIC value of 3.7, 2.5 and 3.1 µg/mL | [129] |
|         |        |        |          | 3,6,9-Trihydroxy-7-methoxy-4,4-dimethyl-3,4-dihydro-1H-benzo[g]-isochromene-5,10-dione (286), fusarubin (287), 3-O-methylfusarubin (288), javanicin (289) | *S. aureus* (MTCC 96), *K. pneumonia* (MTCC 109), *S. pyogenes* (MTCC 442), *B. subtilis* (MTCC 121), *B. cereus* (IIIM 25), *Micrococcus luteus* (MTCC 2470) and *E. coli* (MTCC 730) | MIC values in the range of <1 to 256 µg/mL. | [130] |
|         | *Fusarium* solani A2 | *Glycyrrhiza glabra* | Kashmir Himalayas of Jammu and Kashmir State, India | Fusarubin (287) | Mycobacterium tuberculosis strain H37Rv | MIC, 8 µg/mL, | |
|         |        |        |          | 3,6,9-Trihydroxy-7-methoxy-4,4-dimethyl-3,4-dihydro-1H-benzo[g]-isochromene-5,10-dione (286), 3-O-methylfusarubin (288), javanicin (289) | | MIC values of 256, 64, 32 µg/mL | |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|--------|--------|----------|--------------------|------------------|-------------------------------------------|-----------|
| 112     | Fusarium chlamydosporium | Anvillea garcinii | Al-Azhar University, Saudi Arabia | Fusarithmetic A (290) | B. cereus, S. aureus, and E. coli | MICs values of 3.1, 4.4, and 6.9 μg/mL | [131] |
| 113     | Fusarium sp. | Rhoeo spathacea | Pondok Cabe, Banten, Indonesia | Javanicin (289) | M. tuberculosis and M. phlei | MIC 25 and 50 μg/mL | [132] |
| 114     | Fusarium sp. | Ficus carica | Qinling Mountain, Shaanxi Province, China | Helvolic acid Me ester (291), Helvolic acid (100), hydrohelvolic acid (292) | B. subtilis, S. aureus, E. coli and P. aeruginosa | MICs 6.25, 12.5, 6.25, and 3.13 μg/mL | [133] |
| 115     | Fusarium sp. | - | - | Colletorin B (293), 4,5-dihydroaschochlorin (294) | B. megaterium | 5 and 10 mm zone of inhibition at 10 μg/mL concentration of | [134] |
| 116     | Fusarium sp. | Opuntia dillenii | South-Eastern arid zone of Sri Lanka | Equisetin (295) | B. subtilis | MIC, 8 μg/mL | [135] |
| 117     | Trichoderma harzianum | Zingiber officinale | Banyumas, Central Java, Indonesia | Pretrichoderamamide A (296) | M. tuberculosis | MIC, 25 μg/mL (50 μM) | [136] |
| 118     | Trichoderma koningiiopsis YIM PH30002 | Panax notoginseng | | Koningin W (297), koninginin D (298), 7-O- and koninginin A (301), Koningin W (297), 7-O-methylkoninginin D (299), Koningin W (297), koninginin (300) | B. subtilis | MIC of 128 μg/mL | [137] |
| 119     | Trichoderma virens QA-8 | Artemisia argyi | | Trichocarotins I–M (302–306), CAF-603 (307), 7β-hydroxy CAF-603 (308), trichocarotins E–H (309–312), and trichocarane A (313) | E. coli EMBLC-1, Micrococcus luteus | MIC values ranging from 0.5 to 32 μg/mL; MIC = 0.5 μg/mL | [138] |
| Sr. No. | Fungus | Source | Local-ity | Compounds Isolated | Biological Target | Biological Activity (MIC/IC/ID) | Reference |
|---------|--------|--------|-----------|--------------------|-------------------|---------------------------------|-----------|
| 120     | *Trichoderma koningiopsis* QA-3 | *Artemisia argyi.* |          | Trichodermaketone E (314), trichopyranone A (316), 3-hydroxyharziandione (317) and 10,11-dihydro-11-hydroxyclononediol (318), harziandione (321) | *E. coli* | MIC values ranging from 0.5 to 64 µg/mL | |
|         |        |        |           | Trichopyranone A (316), 3-hydroxyharziandione (317), 10,11-dihydro-11-hydroxyclononediol (318), cyclononediol (319), 6-(3-hydroxypent-1-en-1-yl)-2H-pyran-2-one (320), harziandione (321) | *M. luteus* | MIC values ranging from 1 to 16 µg/mL | |
|         |        |        |           | Trichodermaketone E (314), 4-epi-7-O-methylkoninginin D (315), 3-hydroxyharziandione (317), 10,11-dihydro-11-hydroxyclononediol (318), cyclononediol (319), 6-(3-hydroxypent-1-en-1-yl)-2H-pyran-2-one (320), harziandione (321) | *P. aeruginosa* | with MIC values ranging from 4 to 16 µg/mL | [139] |
|         |        |        |           | Trichodermaketone E (314), 10,11-dihydro-11-hydroxyclononediol (318), cyclononediol (319), 6-(3-hydroxypent-1-en-1-yl)-2H-pyran-2-one (320), harziandione (321) | *V. parahaemolyticus* | MIC values ranging from 4 to 16 µg/mL | |
|         |        |        |           | 3-Hydroxyharziandione (317) | *E. coli* | MIC value of 0.5 µg/mL | |
|         |        |        |           | 6-(3-Hydroxypent-1-en-1-yl)-2H-pyran-2-one (320) | *M. luteus* | MIC value of 1 µg/mL | |
| Sr. No. | Fungus          | Source                  | Locality                                         | Compounds Isolated                                      | Biological Target                      | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|--------|-----------------|-------------------------|--------------------------------------------------|--------------------------------------------------------|----------------------------------------|---------------------------------------------|-----------|
| 121    | *Trichoderma*    | *Artemisia argyi*       | Qichun of the Hubei Province, China              | 15-Hydroxy-1,4,5,6-tetra-epi-koninginin G (322)         | *Vibrio alginolyticus*                 | MIC, 1 µg/mL                                | [140]    |
|        | *koningiopsis*   |                         |                                                  | Koninginin U (323), 14-ketokoninginin B (324)          | *Vibrio harveyi* and *Edwardsiella tarda* | MICs 4 and 2 µg/mL                         |          |
| 122    | *Trichoderma*    | *Colquhounia coccinea*  | Kunming Botanical Garden, Yunnan, China         | Harzianol I (325)                                      | *S. aureus, B. subtilis, and M. luteus* | EC$_{50}$ 7.7, 7.7, and 9.9 µg/mL          | [141]    |
|        | *atroviride*     | var. mollis             |                                                  |                                                        |                                        |                                             |          |
| 123    | *Trichoderma*    | *Dendrobium nobile*     | Jinshishi, Chishui, China                       | Dendrobine (326)                                      | *Bacillus mycoides, B. subtilis, and Staphylococcus* | Zone of inhibition of 9, 12 and 8 mm          | [142]    |
|        | *longibrachiatum*|                         |                                                  |                                                        |                                        |                                             |          |
|        | *MD33*           |                         |                                                  |                                                        |                                        |                                             |          |
| 124    | *Trichoderma*    | *Artemisia argyi*       | Qichun of Hubei Province in central China       | Trichocadinins B-D and G (327–330)                     | *E. coli* EMBLC-1, *Aeromonas* hydrophila QDIO-1, *Edwardsiella tarda* QDIO-2, *E. ictaria* QDIO-10, *Micrococcus luteus* QDIO-3, *P. aeruginosa* QDIO-4, *Vibrio alginolyticus* QDIO-5, *V. anguillarum* QDIO-6, *V. harveyi* QDIO-7, *V. parahaemolyticus* QDIO-8, and *V. vulnificus* QDIO-9 | MIC in the range of 8–64 µg/mL               | [143]    |
|        | *virens*         | QA-8                    |                                                  |                                                        |                                        |                                             |          |
| 125    | *Trichoderma*    | *Morinda officinalis*   |                                                  | Trichocadinin G (330)                                  | *Ed. tarda* and *V. anguillarum*        | MIC values of 1 and 2 µg/mL                  | [144]    |
|        | *koningiopsis*   | A729                    |                                                  |                                                        |                                        |                                             |          |
| Sr. No. | Fungus                          | Source           | Locality | Compounds Isolated                                                                                      | Biological Target                          | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|--------|---------------------------------|------------------|----------|-------------------------------------------------------------------------------------------------------|--------------------------------------------|----------------------------------------------------------|-----------|
| 126    | *Trichoderma koningiopsis* QA-3  | *Artemisia argyi* | Qichun   | Ent-koninginin A (333), trichoketide A (339)                                                         | *V. vulnificus*                           | MIC, 4 µg/mL                                              | [145]     |
|        |                                 |                  |          | Ent-koninginin A (333), trichoketide A (339)                                                         | *E. coli, E. tarda, V. anguillarum, and V. parahemolyticus* | MICs ranging from 8 to 64 µg/mL                         |           |
|        |                                 |                  |          | Ent-koninginin A (333), 1,6-di-epi-koninginin A (334), 15-hydroxykoninginin A (335), 10-deacetylkoninigin A (336), koninginin T (337), koninginin L (338), trichoketide A (339) | *E. coli*                                  | MIC, 64 µg/mL each                                       |           |
|        |                                 |                  |          |                                                                                                        | *E. tarda, V. alginolyticus, and V. anguillarum* | MIC values ranging from 4 to 64 µg/mL                    |           |
| 127    | *Alternaria alternata* ZHJG5     | *Cercis chinensis* |          | Isotalaroflavone (340), 4-hydroxyalternariol-9-methyl ether (341), verrulactone A (342)             | *Xanthomonas oryzae pv. Oryzae, Xanthomonas oryzae pv. oryzae col* and *Ralstonia solanacearum* (Rs) | MIC ranging from 0.5 to 64 µg/mL                         | [146]     |
| 128    | *Alternaria* sp. PfuH1          | *Pogostemon cablin* (Pacholi). |          | Alternariol (44), altertoxin VII (343), alternuisol (344)                                           | *S. agalactiae*                           | MIC, 9.3, 17.3 and 85.3 µg/mL                           | [147]     |
|        |                                 |                  |          | Alternuisol (344)                                                                                     | *E. coli*                                  | MIC, 128 µg/mL                                           |           |
| 129    | *Alternaria alternata* ZHJG5     | *Cercis chinensis* |          | Alternariol (44), alternuisol (344), alterlactone (345), Dehydroalterusin (346) | *FabH* of *Xanthomonas oryzae* pv. *oryzae* (Xoo) | IC<sub>50</sub> values from 29.5 to 74.1 µM              | [148]     |
|        |                                 |                  |          |                                                                                                        | *Xanthomonas oryzae* pv. *Oryzae*          | MIC values from 4 to 64 µg/mL                            |           |
|        |                                 |                  |          |                                                                                                        |                                             | a protective efficiency of 66.2 and 82.5% at the concentration of 200 µg/mL |           |
Table 1. Cont.

| Sr. No. | Fungus            | Source             | Locality          | Compounds Isolated                          | Biological Target                              | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|---------|-------------------|--------------------|-------------------|---------------------------------------------|------------------------------------------------|-----------------------------------------------|----------|
| 130     | Alternaria alternata | MGTMMP031         | Vitex negundo     | Alternariol Me ether (347)                  | B. cereus, Klebsiella pneumoniae              | MIC, 30 µM/L                                   | [149]    |
|         |                    |                    | Madurai, Tamil Nadu, India |                | E. coli, Salmonella typhi, Proteus mirabilis, S. aureus and S. epidermidis | MIC, 35 µM/L                                   |          |
| 131     | Alternaria alternata | Grewia asiatica   |                   | 3,7-Dihydroxy-9-methoxy-2-methyl-6H-benzo[c] chromen-6-one (348) | S. aureus (ATCC 29213), VRE, and MRSA       | MIC, 32, 32 and 8 µg/mL                         | [150]    |
|         |                    |                    |                   | Alternariol (44)                              | S. aureus (ATCC 29213), VRE, and MRSA       | MIC, 128, 128, and 64 µg/mL                     |          |
| 132     | Alternaria sp. Samif01 | Salvia miltiorrhiza | Beijing Medicinal Plant Garden, Beijing, China | Altenuisol (344), 4-hydroxyalternariol-9-methyl ether (349) and alternariol (44) | A. tumefaciens, B. subtilis, Pseudomonas lachrymans, Ralstonia solanacearum, Staphylococcus hemolyticus and Xanthomonas vesicatoria | MIC values in the range of 86.7–364.7 µM | [151]    |
| 133     | Alternaria sp. Samif01 | Salvia miltiorrhiza | Beijing, China    | Alternariol 9-Me ether (347)                | Bacillus subtilis ATCC 11562 and Staphylococcus haemolyticus ATCC 29970, A. tumefaciens ATCC 11158, Pseudomonas lachrymans ATCC 11921, Ralstonia solanacearum ATCC 11696, and Xanthomonas vesicatoria ATCC 11633 | IC$_{50}$ values varying from 16.00 to 38.27 g/mL | [152]    |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|--------------------------------------|-----------|
| 134     | Alternaria sp. and Pyrenochaeta sp., | Hydrastis canadensis | William Burch in Hendersonville, North Carolina | Altersetin (350), macrosphelide A (351) | S. aureus | MIC, 0.23, and 75 µg/mL | [153] |
| 135     | Simplicillium lanozoneum | Hevea brasiliensis | Songkhla Province, Thailand | Simplicildones K (352) | S. aureus ATCC25923, MRSA | MIC, 128µg/mL | [154] |
|         |        |        |          | Botryorhodine C (353), simplicildones A (354) | S. aureus ATCC25923, MRSA | MIC, 32 µg/mL each |          |
| 136     | Simplicillium sp. PSU-H41 | Hevea brasiliensis | Songkhla Province, Thailand | Botryorhodine C (353), simplicilone A (354) | S. aureus | MIC, 32 µg/mL each | [155] |
|         |        |        |          | Botryorhodine C (353) | MRSA | MIC, 32 µg/mL |          |
|         | **Cladosporium** |        |          |                     |                  |                                      |          |
| 137     | Cladosporium cladosporioides | Zygoaphyllum mandavillei | Al-Ahsa, Saudi Arabia | Isocladosporin (355), 5′-hydroxyasperentin (356), 1-acetyl-17-methoxyaspidospermidin-20-ol (357), and 3-phenylpropionic acid (358) | Xanthomonas oryzae and Pseudomonas syringue | MIC values in the range of 7.81 to 125 µg/mL | [156] |
| 138     | Cladosporium sphaerspermum WBS017 | Fritillaria unibracteata var. wabuensis | Western Sichuan Plateau of China | Cladosin L (359) | S. aureus ATCC 29213 and S. aureus ATCC 700699 | MICs, 50 and 25 mM, | [157] |
| 139     | Cladosporium sp. | Rauwolfia serpentina | | Me ether of fusarubin (360) | S. aureus, E. coli, P. aeruginosa and B. megaterium | Zone of inhibition of 27, 25, 24 and 22 mm (40µg/disk) | [158] |
| 140     | Pestalotiopsis sp. M-23 | Leucosceptrum canum | Kunming Botanical Garden, China | 11-Dehydro-3a-hydroxyisodrimeninol (361) | B. subtilis | IC$_{50}$, 280.27 µM | [159] |
| Sr. No. | Fungus              | Source               | Locality                      | Compounds Isolated                                         | Biological Target | Biological Activity (MIC/IC₅₀/ID₅₀) | Reference |
|---------|---------------------|----------------------|-------------------------------|-------------------------------------------------------------|-------------------|-------------------------------------|-----------|
| 141     | Pestalotiopsis sp.  | Melaleuca quinquenervia | Toohey Forest, Queensland, Australia | (1S,3R)-austrocortirubin (362), (1S,3S)-austrocortirubin (363), 1-deoxyaustrocortirubin (364) | Gram-pos.         | 100 µM                              | [160]     |
| 142     | Neopestalotiopsis sp. | Neopestalotins B (365) |                                |                                                              | B. subtilis, S. aureus, S. pneumoniae | MIC, 10, 20, and 20 µg/mL | [161]     |
| 143     | Phoma cucurbitacearum | Glycyrrhiza glabra   | Jammu (J&K).                   | Thiodiketopiperazine derivatives (366) and (367)            | S. aureus and Streptococcus pyogenes | IC₅₀, 10 µM                         | [162]     |
| 144     | Phoma sp. JS752     | Phragmites communis  | Seochun, South Korea           | Barceloneic acid C (368)                                     | Listeria monocytogenes and Staphylococcus pseudintermedius | MIC, 1.02 µg/mL each | [163]     |
| 145     | Setophoma sp., Psidium guajava fruits |                        |                                | Thielavins T (369), U (370) and V (371)                      | S. aureus ATCC 25923 | MIC, 6.25, 50, and 25 µg/mL | [164]     |
|         | **Colletotrichum**  |                      |                               |                                                             |                   |                                     |           |
| 146     | Colletotrichum gloeosporioides B12 | Illigera rhodantha | Qionghai City, Hainan Province, China | Colletolides A (372) and B (373), 3-methyleneis oindolinon (374) | Xanthomonas oryzae pv. oryzae, | MIC, 128 µg/mL each | [165]     |
|         |                     |                      |                               | Sclerone (375)                                               | X. oryzae pv. oryzae | MIC, 64 µg/mL                       |           |
| 147     | Colletotrichum sp. BS4 | Buxus sinica        | Guangzhou, Guangdong Province, China | Colletotrichones A (376)                                    | E. coli and B. subtilis | MIC, 1.0 and 0.1 µg/mL             | [166]     |
|         |                     |                      |                               | Colletotrichone B (377)                                     | E. coli            | MIC, 5.0 µg/mL                      |           |
|         |                     |                      |                               | Colletotrichone C (378)                                     |                   |                                  |           |
| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|------------------------------------------------|-----------|
| 148     | *Rhizopycnis vagum* Nitaf22 (synonym *Acrocalymma vagum*) | Nicotiana tabacum | Agricultural University Beijing, China | Rhizopycnolide A (379) | *A. tumefaciens, B. subtilis, and P. lachrymans* | MICs 100, 75, and 100 µg/mL | [167] |
|         |        |        |          | Rhizopycnolide C (380), penicilliumolide D (384), alternariol (44) | *A. tumefaciens, B. subtilis, Pseudomonas lachrymans, Ralstonia solanacearum, Staphylococcus hemolyticus, and Xanthomonas vesicatoria* | MICs in the range 25–100 µg/mL |          |
|         |        |        |          | Rhizopycnin D (381) | *A. tumefaciens, B. subtilis, and R. solanacearum, X. vesicatoria* | MIC 50 µg/mL each, X. vesicatoria MIC 75 µg/mL |          |
|         |        |        |          | Palmariol B (383), Alternariol 9-methyl ether (347) | *A. tumefaciens, B. subtilis, P. lachrymans, R. solanacearum, and X. vesicatoria* | IC<sub>50</sub> values in the range 16.7–34.3 µg/mL |          |
|         |        |        |          | TMC-264 (382) | *B. subtilis* | MIC 50 µg/mL |          |
| 149     | *Rhizopycnis vagum* Nitaf22 (synonym *Acrocalymma vagum*) | Nicotiana tabacum | China Agricultural University, Beijing | Rhizoperemophilane K (385), 1α-hydroxyhydroxyisofukinon (386), 2-oxo-3-hydroxyeremophil-1(10),3,7(11),8-tetraen-8,12-olide (387) | *A. tumefaciens, B. subtilis, P. lachrymans, R. solanacearum, S. haemolyticus, and X. vesicatoria* | MIC, 32–128 µg/mL | [168] |
### Table 1. Cont.

| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC₅₀/ID₅₀) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|--------------------------------------|-----------|
| 150     | *Rhizopycnis vagum*<br>Nitaf22 (synonym *Acrocalymma vagum*) | Nicotiana tabacum | China Agricultural University (CAU), Beijing 100101, China | Rhizopycnis acid A (388)<br>Rhizopycnis acid B (389) | *A. tumefaciens, B. subtilis, P. lachrymans, R. solanacearum, S. hemolyticus and X. vesicatoria* | MICs, 20.82, 16.11, 23.48, 29.46, 21.11, and 24.31 µg/mL<br>MICs, 70.89, 81.28, 21.23, 43.40, 67.61, and 34.86 µg/mL | [169] |
| 151     | *Leptosphaeria* sp.<br>XL026 | Panax notoginseng | Shijiazhuang, Hebei province, China | Leptosphin B (390), conidiogenone C (391), conidiogenone D (392), conidiogenone G (393) | *B. cereus* | MICs 12.5–6.25 µg/mL | [170] |
|         |        |        |          | Conidiogenone D (392) | *P. aeruginosa* | MIC, 12.5 µg/mL |         |
| 152     | *Lophiostoma* sp. Eef-7 | Eucalyptus exserta. |              | Scorpine (394), 5-deoxybostrycochinid (395) | *Ralstonia solanacearum* | Zone of inhibition of 9.86 and 9.58 mm at 64 µg concentration | [171] |
|         |        |        |          | |        | |         |
|         | *Lophiostoma* sp. Sigrf10 | Siraitia grosvenorii | Guangxi Province of China | (8R,9S)-dihydroisoflavipucine (396), (8S,9S)-dihydroisoflavipucine (397) | *B. subtilis, A. tumefaciens, Ralstonia solanacearum, and Xanthomonas vesicatoria* | IC₅₀ in the range of 35.68–44.85 µM | [172] |
| 153     | *Cytospora chrysosperma* | Hippophae rhamnoides |              | Cytochrysin A (398) | *Enterococcus faecium* | MIC, 25 µg/mL | [173] |
|         |        |        |          | Cytochrysin C (399) | MRSA | MIC, 25 µg/mL |         |
| 154     | *Microsphaeropsis* sp.<br>*Seimatosporium* sp. | Salsola oppositifolia | Gomera, Spain | Microsphaerol (400)<br>Seimatorone (401) | *B. megaterium and E. coli,*<br>*B. megaterium and E. coli,* | Zone of inhibition 8 and 9 mm at 0.05 mg concentration<br>Zone of inhibition 3 and 7 (partial) mm at a 0.05 mg concentration | [174] |
Table 1. Cont.

| Sr. No. | Fungus                  | Source                        | Locality                     | Compounds Isolated                                      | Biological Target             | Biological Activity (MIC/IC<sub>50</sub>/ID<sub>50</sub>)                  | Reference |
|---------|-------------------------|--------------------------------|-------------------------------|----------------------------------------------------------|------------------------------|--------------------------------------------------------------------------------|-----------|
| 155     | Epicoccum nigrum        | Salix sp.                      | Caucasus mountains, Lago-Naki, Russia | Epicocconigrone A (402), epipyrone A (403), and epicoccolide B (404) | S. aureus ATCC 29213         | MIC values ranging from 25 to 50 µM                                         | [175]     |
|         |                         |                                |                               | p-Hydroxybenzaldehyde (223)                              | S. aureus, B. cereus, P. aeruginosa, and E. coli | MICs 50, 25, 50, and 25 µg/mL                                               |           |
| 156     | Epicoccum nigrum        | Entada abyssinica              | Balatchi (Mbouda), in the West region of Cameroon | Beauvericin (267)                                        | S. aureus, B. cereus, and Salmonella typhimurium | MICs 3.12, 12.5, and 12.5 µg/mL                                               | [176]     |
|         |                         |                                |                               | Indole-3-carboxylic acid (405)                           | S. aureus, and E. faecalis  | MIC values of 6.25 and 50 µg/mL each                                         |           |
|         |                         |                                |                               | Quinizarin (406)                                         | S. aureus, B. cereus St      | MIC values of 50 µg/mL each                                                   |           |
|         |                         |                                |                               | Xylapeptide B (407)                                      | B. subtilis, S. aureus and E. coli | MIC, 12.5, 25 and 25 µg/mL                                                    |           |
|         |                         |                                |                               | Cytochalasin E (408)                                     | B. subtilis, S. aureus, B. anthracis, S. dysenteriae, and E. coli | MIC 12.5 to 25 µg/mL                                                     |           |
| 157     | Stemphylium lycopersici | S. tonkinensis                 |                                | 6-Heptanoyl-4-methoxy-2H-pyran2-one (409)                | S. paratyphi B               | MIC, 12.5 µg/mL                                                               | [177]     |
|         |                         |                                |                               | (-)-5-Carboxymellein (410)                               | B. subtilis, S. aureus, B. anthracis, S. dysenteriae, S. paratyphi, E. coli and S. paratyphi B | MIC values from 12.5 to 25 µg/mL                                             |           |
| 158     | Stemphylium globuliferum, | Juncus acutus                  | Egypt                         | Dihydroaltersolanol C (411)                              | S. aureus                    | MICs of 49.7 µM                                                               | [178]     |
Table 1. Cont.

| Sr. No. | Fungus | Source | Locality | Compounds Isolated | Biological Target | Biological Activity (MIC/IC_{50}/ID_{50}) | Reference |
|---------|--------|--------|----------|--------------------|-------------------|---------------------------------------------|-----------|
| 159     | Lecanicillium sp. (BSNB-SG3.7 Strain) | Sandwithia guyanensis | St Elie, France. | Stephensiolides I (412), D (413), G (414), stephensiolide F (415) | MRSA | MICs 4, 32, 16 and 32 µg/mL | [179] |
| 160     | Nigrospora sphaerica | Adiantum philippense | Western Ghats region near Virajpete, India | Phomalactone (416) | E. coli and X. campestris | MIC 3.12 µg/mL | [180] |
|         |        |        |          |                    | S. typhi, B. subtilis, B. cereus, and K. pneumonia | MIC value of 6.25 µg/mL |
|         |        |        |          |                    | S. aureus, S. epidermidis, and C. albicans | MIC of 12.5 µg/mL |
| 161     | Nigrospora sp. BCC 47789 | Choerospondias axillaris | Khao Yai National Park, Nakhon Ratchasima Province, Thailand | Nigrosporone B (417) | M. tuberculosis, B. cereus and E. faecium | MICs 172.25, 21.53 and 10.78 µM | [181] |
| 162     | Curvularia sorghina BRIP 15900) | Rauwolfia macrophylla | Mount Kalla in Cameroon | 2′-Deoxyribolactone (419), hexylitaconic acid (419) | E. coli, Micrococcus luteus, Pseudomonas agarici and Staphylococcus warneri | MIC ranging between 0.17 µg/mL and 0.58 µg/mL | [182] |
| 163     | Curvularia lunata | Paepalanthus chiquitensis | Serra do Cipó, in Minas Gerais State, Brazil | Triticons E (420), F (421) | E. coli, | MIC 62.5 µg/mL | [183] |
| 164     | Bipolaris sp. L1-2 | Lycium barbarum | Ningxia Province, China | Cochlioquinones B (422), C (423), isocochlioquinones (424) | B. subtilis, C. perfringens, and P. viridiflava | MICs 26 µM | [184] |
| Sr. No. | Fungus                     | Source                          | Locality                                                                 | Compounds Isolated                                                                                     | Biological Target                          | Biological Activity (MIC/IC₅₀/ID₅₀) | Reference |
|---------|---------------------------|---------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------------------------------|-----------|
| 165     | Bipolaris eleusines       | Potatoes                        | nursery of Yunnan Agricultural University, Kunming, Yunnan China         | (S)-5-Hydroxy-2-(1-hydroxyethyl)-7-methylchromone (425), 5,7-dihydroxy-2,6,8-trimethylchromone (426) | Staphylococcus aureus subsp. Aureus       | inhibition rates of 56.3 and 32 %, at the concentration of 128 µg/mL | [185]     |
| 166     | Bionectria sp. Y1085, Huperzia serrata | Xichou County, Yunnan Province, China | Bionectin D (427), bionectin E (428), verticillin A (430), sch 52901 (429), gliocladicillin C (431) | E. coli, S. aureus, and S. typhimurium ATCC 6539,                                               | MIC values ranging from 6.25–25 µg/mL | [186]     |
| 167     | Cylindrocarpon sp., Sapium ellipticum | Haut Plateaux region, Cameroon | Pyrrocidine A (432)                                                                                              | S. aureus, ATCC 25923, S. aureus ATCC 700699, S. aureus ATCC 700699, E. faecalis ATCC 29212, E. faecalis ATCC 51299, E. faecium ATCC 35667, E. faecium ATCC 700221 | MIC values ranging from 0.78 to 25 µM | [187]     |
|         |                           |                                 | 19-O-Methylpyrrocidine B (433)                                                                        | S. aureus ATCC25923 and ATCC700699                                                                | MIC, 50 and 25 µM,                                  |         |
| 168     | Eupenicillium sp. LG41.9 treated with HDAC inhibitor, nicotinamide (15 mg/100 mL) | Xanthium sibiricum             | Eupenicinicol C (434)                                                                                             | S. aureus, ATCC 25923, S. aureus ATCC 700699, E. faecalis ATCC 29212, E. faecalis ATCC 51299, E. faecium ATCC 35667, E. faecium ATCC 700221 | MIC 0.1 µg/mL,                                  | [188]     |
|         |                           |                                 | Eupenicinicol D (435), Eujavanicol A (436), Eupenicinicol A (437)                                                            | E. coli                                                                                              | MIC 5.0 µg/mL,                                  |         |
| 169     | Dendrothyrium variisporum | Xanthium alypum                 | 2-Phenylethyl 3-hydroxyanthranilate (438)                                                                 | B. subtilis and M. luteus                                                                            | MICs 8.33 and 16.66 µg/mL                     | [189]     |
|         |                           |                                 | 2-Phenylethyl anthranilate (439)                                                                  | B. subtilis and M. luteus                                                                            | 66.67 µg/mL each                              |         |
| Sr. No. | Fungus                  | Source                        | Locality                              | Compounds Isolated           | Biological Target                  | Biological Activity (MIC/IC$_{50}$/ID$_{50}$) | Reference |
|--------|-------------------------|-------------------------------|-----------------------------------------|-------------------------------|-------------------------------------|---------------------------------------------|-----------|
| 170    | *Exserohilum rostratum* | *Phanera splendens* (Kunth) Vaz |                                         | Ravenelin (440)               | *Bacillus subtilis* and *Staphylococcus aureus* | MICs, 7.5 and 484 µM                       | [190]     |
| 171    | *Exserohilum rostratum* | *Bauhinia guianensis*         |                                         | Monocerin (441)               | *P. aeruginosa*                     | MIC, 62.5 µg/mL                            | [191]     |
|        |                         |                               |                                         | Annularin I (442)             | *E. coli* and *B. subtilis*         | MIC, 62.50 and 31.25 µg/mL                 |           |
|        |                         |                               |                                         | Annularin J (443)             | *E. coli* and *B. subtilis*         | MIC, 62.50 µg/mL each                      |           |
|        | **Basidiomycete**       |                               |                                         |                               |                                     |                                             |           |
| 172    | *Psathyrella candolleana* | *Ginkgo biloba*               |                                         | Quercetin (444), carboxybenzene (445), and nicotinamide (446) | *S. aureus*                          | MIC 0.3906, 0.7812 and 6.25 µg/mL         | [192]     |
| 173    | *Irpex lacteus DR10-1*  | *Distylium chinense*          | Banan district of Chongqing in the TGR area, China | Irpexlacte A (447), irpexlacte B-D (448–450) | *P. aeruginosa*                     | MIC values ranging from 23.8 to 35.4 µM    | [193]     |
|        | **Zygomycetes**         |                               |                                         |                               |                                     |                                             |           |
| 174    | *Mucor irregularis*     |                               |                                         | Chlorflavonin (451)           |                                     |                                             | [194]     |
4. Methods Used for Activation of Silent Biosynthetic Genes

It has been reported that fungi have various unexpressed gene clusters related to bioactive secondary metabolites, which do not express in mass multiplications of the axenic form [213,214]. The expression of such gene clusters directly or indirectly depends on the surrounding environment of the microorganism. In axenic form, various induction or activation signals are or may be absent for some bioactive molecule production in the culture, which are usually present in natural habitats [215]. Such biosynthetic gene clusters (BGC) are part of the heterochromatin of fungal chromosomes, which do not express at laboratory conditions [216].

To induce such silent biosynthetic gene clusters two major approaches have been reported, including pleiotropic- and pathway-specific approaches, which include various techniques like knocking down, mutation induction [217], co-culture methods [218], heterologous expression [219,220], interspecies crosstalk [221], one strain many compounds (OSMAC) [222] and epigenetic manipulation [223]. Changes in media composition and physical factors like pH, temperature, light, salt concentration, metal and elicitor also support the induction of silent BGC and improve production of secondary metabolites in microbes. The generation of various types of stresses significantly affects the metabolic activities of growing culture and microbes to release compounds for their survival under stress conditions. Changes in physical conditions or stresses impacted gene regulation by upregulating or downregulating the gene expression [126,224]. Nowadays, high throughput elicitor screening technique (HiTES) is also employed to save time in exposing culture against various types of elicitors. In this technique selected culture is grown in 96 well plates with various elicitors in each well and after the incubation period metabolites are identified by mass spectrometry or assay system.

The mutation is one of the other approaches to induce silent biosynthetic gene clusters (BGC). Mutation in RNA polymerase genes and ribosomal proteins changes the transcription and translational process and upregulates the expression of biosynthetic gene clusters. Some of the genes related to biosynthetic gene clusters are silent from decades and overexpression of \textit{adpA}, a global regulatory gene, induced the expression of silent lucensomycin in \textit{Streptomyces cyanogenus} S136 [225]. Cloning is another type of molecular technique used to express the silent BGC incompatible strains. In the cloning method, isolation of high-quality DNA, fragmentation, library construction and development of suitable expression vectors for large sequences of BGC is a challenging task and many groups are working on this aspect [226]. In addition to this, use of bioinformatics also helps in direct cloning of silent BGCs and their expression for secondary metabolites production. Development of various bioinformatics tools such as PRISM3, BiG-SCAPE and anti-SMASH etc facilitated the scientist to identify bioactive gene clusters in unknown strains without time consumption used in identification of active BGC sites [227]. The CRISPR-Cas system is also a excellent tool for cloning system or genome editing that provides better expression of silent BGC in comparison to conventional molecular techniques [228]. Similarly, promoter engineering, transcriptional regulation engineering and ribosome engineering also support the activation of silent BGC through molecular approaches [229]. Recent use of Cpf1 nuclease in genome editing was also found to be a suitable tool for induction of silent BGC [230].

4.1. Epigenetic Modification

On the other hand, epigenetic modification played a great role to induce the silent genes related to bioactive molecules, which are actively produced under symbiotic interactions. Epigenetics refers to the study of DNA sequences that do not changes in mutation but change in gene function [231]. The epigenetic regulations such as methylation, demethylation, acetylation, deacetylation and phosphorylation of histones also regulate the transcription of biosynthetic genes of fungi and are helpful in silencing or expression of such genes related to the production of secondary metabolites [232]. The importance of epigenetic regulation in secondary metabolite production by fungi has been shown in a few reports published [231,233–236]. Modification or alteration in DNA or chromatin changes
the expression level of the selected genes, which directly impacted the biosynthesis of the metabolites in the strain.

4.2. The Co-Culture Strategy

The co-culture is another method to induce the silent biosynthetic gene clusters by interspecies cross-talking of microorganisms. In this method, various combinations of inducers with producer microbial strains are screened for the production of novel molecules. In co-culture technique real-time bioactivity screening can also be measured by the growth of pathogen as co-culture [218]. Recently, Kim et al. [237] reviewed the co-culture interactions of fungi with various actinomycetes for induction of silent biosynthetic gene clusters and reported upregulation and production of novel antibiotics and bioactive compounds. Co-culturing of microbes provides the habitat type environment to producers and helps to promote silent BGCs by producing signal molecules. Exchange of chemical signals of growing organisms is helpful in the induction of defense molecules and other silent BGC, and usually results in the production of new natural products or secondary metabolites in the culture [238].

Another concept has also been introduced to elicit the production of silent secondary metabolites by scaffold technique. In this technique, two types of scaffold named cotton and talc powder are introduced in the medium which physically interacts with the grown culture and elicit chemical signaling of the culture and activate the production of silent BGC. The addition of scaffold in the medium supports the grown culture in formation of biofilm and provides a mimic architecture of natural habitat [239,240]. The addition of scaffold in medium affects the morphology of growing culture and sporulation pattern like an agglomeration of spores, oxygen diffusion in comparison to non-scaffold containing medium and then facilitates more metabolites production [241].

4.3. OSMAC

In the OSMAC technique different cultivation approaches are applied to induce silent bioactive gene clusters to promote more production of secondary metabolites including media variations, variation in media composition, co-cultivation with other strains and variations in cultivations strategy [222,242]. Variation in growth conditions also supports the induction of silent biosynthetic gene clusters and the production of novel compounds. Scherlach and Hertweck [243] and Scherlach et al. [244] reported the production of novel aspoquinolone and aspernidine alkaloid compounds from Aspergillus nidulans by variation in growth conditions.

5. Conclusions

Increasing resistance among microbial pathogens against existing antibiotics has been a major concern during the past several decades. Scientists are exploring new sources of novel antibiotics and other bioactive compounds that can curb pathogenic infections and overcome antimicrobial resistance. Endophytic fungi have been reported to secrete a wide spectrum of bioactive compounds to counter pathogens. In the current review, we have reported 453 new bioactive compounds, including volatile compounds, isolated during the period of 2015-21 from various endophytic fungi belonging to the Ascomycetes, Basidiomycetes, and Zygomycetes classes. Newly reported bioactive compounds have shown activity against various pathogenic bacteria and shown scaffold similarity with alkaloids, benzopyranones, chinones, cytochalasins, mullein, peptides, phenols, quinones, flavonoids, steroids, terpenoids, sesquiterpene, tetralones, xanthones, and others. The lowest in vitro activity in terms of minimum inhibitory concentrations (MICs) in the 0.1–1 μg/mL range against various pathogens was reported for the compounds vochysiamides A (23) and B (24), colletotrichone A (376), 15-hydroxy-1,4,5,6-tetra-epi-koninginin G (322), trichocadin G (330) and eupenicinicol D (435). Compounds like fusarubin (287), chetomin (62), chaetocochin C (63), and dethiotretramethylthiochetomin (64), pretrichodermamide A (296), terpestacin (105), fusaproliferin (106), mutolide (108), isoeugenitol (120) and nigrosporone B (417) were
reported to have significant in vitro anti-mycobacterial activity and could be developed as potential drugs against resistant mycobacterial infections. The production of such bioactive compounds and their activity is also affected by the surrounding environment and conditions. Various techniques related to induction of silent gene clusters such as epigenetic modifications, co-culture, OSMAC and mutation have been reported.

In most of cases only in vitro data against a limited number of bacteria is reported and there is a great need for extensive in vitro studies including their mode of action, kill curve studies, mutation induction frequency, resistance occurrence frequency studies, in vitro cytotoxicity and initial in vivo evaluation followed by formulation studies. Moreover, there is also a need to perform extensive in vitro efficacy testing studies using panels of references strains and clinical strains to establish MIC\textsubscript{90} and MIC\textsubscript{50} values. Generation of comparative efficacy data with benchmark clinical compounds is very important from a further development perspective. These extensive studies also help to generate data for understanding the scope of work when we consider such potent molecules for semisynthetic work. The exact studies to be performed during screening and further shortlisting of semisynthetic molecules can be extracted from this initial extensive work.

Still, more research is required to investigate a new generation of antibiotics which can control the increasing resistance of infectious microorganisms in a sustainable manner. The success of this exploration depends upon screening more and more endophytic fungi and ways of their isolation, fermentation and scale-up.

**Author Contributions:** Conceptualization: (S.K.D., L.D.), Literature search and compilation: (S.K.D., H.C., S.S.); Writing abstract, introduction, conclusion, proof reading: (S.K.D., G.B.M., S.S., H.C., M.K.G.). Preparation of data tables: (M.K.G., S.K.D.). Generating structures: M.K.G., S.K.D. Overall compilation and coordination: (S.K.D., L.D.). All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not Applicable.

**Informed Consent Statement:** Not Applicable.

**Data Availability Statement:** Not Applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**

1. Deshmukh, S.K.; Verekar, S.A.; Bhave, S. Endophytic fungi: An untapped source for antibacterials. *Front. Microbiol.* 2015, 5, 715. [CrossRef] [PubMed]

2. Jakubczyk, D.; Dussart, F. Selected Fungal Natural Products with Antimicrobial Properties. *Molecules* 2020, 25, 911. [CrossRef] [PubMed]

3. Xu, T.C.; Lu, Y.H.; Wang, J.F.; Song, Z.Q.; Hou, Y.G.; Liu, S.S.; Liu, C.S.; Wu, S.H. Bioactive secondary metabolites of the genus *Diaporthe* and anamorph *Phomopsis* from terrestrial and marine habitats and endophytes: 2010–2019. *Microorganisms* 2021, 9, 217. [CrossRef] [PubMed]

4. Kim, J.W.; Choi, H.G.; Song, J.H.; Kang, K.S.; Shim, S.H. Bioactive secondary metabolites from an endophytic fungus *Phoma* sp. PF2 derived from *Artemisia princeps* Pamp. *J. Antibiot.* 2019, 72, 174–177. [CrossRef]

5. El-hawary, S.S.; Moawad, A.S.; Bahr, H.S.; Abdelmohsen, U.R.; Mohammed, R. Natural product diversity from the endophytic fungi of the genus *Aspergillus*. *RSC Adv.* 2020, 10, 22058–22079. [CrossRef]

6. Deshmukh, S.K.; Mishra, P.D.; Kulkarni-Almeida, A.; Verekar, S.A.; Sahoo, M.R.; Periyasamy, G.; Goswami, H.; Khanna, A.; Balakrishnan, A.; Vishwakarma, R. Anti-inflammatory and anti-cancer activity of ergoflavin isolated from an endophytic fungus. *Chem. Biodivers.* 2009, 6, 784–789. [CrossRef]

7. Martinez-Luis, S.; Cherigo, L.; Arnold, E.; Spadafora, C.; Gerwick, W.H.; Cubilla-Rios, L. Antiparasitic and anticancer constituents of the endophytic fungus *Aspergillus* sp. strain F1544. *Nat. Prod. Commun.* 2012, 7, 165–168. [CrossRef]

8. Deshmukh, S.K.; Verekar, S.A.; Ganguli, B.N. Fungi: An Amazing and Hidden Source of Antimycobacterial compounds. In *Fungi: Applications and Management Strategies*; Deshmukh, S.K., Misra, J.K., Tiwari, J.P., Papp, T., Eds.; CRC Press: Boca Raton, FL, USA, 2016; pp. 32–60.

9. Deshmukh, S.K.; Gupta, M.K.; Prakash, V.; Saxena, S. Endophytic Fungi: A Source of Potential Antifungal Compounds. *J. Fungi* 2018, 4, 77. [CrossRef]
10. Deshmukh, S.K.; Gupta, M.K.; Prakash, V.; Reddy, M.S. Mangrove-associated fungi a novel source of potential anticancer Compounds. J. Fungi 2018, 4, 101. [CrossRef]

11. Deshmukh, S.K.; Agrawala, S.; Gupta, M.K.; Patidar, R.K.; Ranjan, N. Recent advances in the discovery of antiviral metabolites from fungi. Curr. Pharm. Biotechnol. 2022, 23, 495–537. [CrossRef]

12. Wang, W.X.; Cheng, G.G.; Li, Z.H.; Ai, H.L.; He, J.; Li, J.; Feng, T.; Liu, J.K. Curtachalasins, immunosuppressive agents from the endophytic fungus Xylaria cf. curta. Org. Biomol. Chem. 2019, 17, 7985–7994. [CrossRef]

13. Bedi, A.; Gupta, M.K.; Conlan, X.A.; Cabill, D.M.; Deshmukh, S.K. Endophytic and marine fungi are potential source of antioxidants. In Fungi Bio-Prospects in Sustainable Agriculture, Environment and Nano-Technology; Sharma, V.K., Shah, M.P., Parmar, S., Kumar, A., Eds.; Elsevier: San Diego, CA, USA, 2021; pp. 23–89.

14. Toghueo, R.M.K.; Boyom, F.F. Endophytic Penicillium species and their agricultural, biotechnological, and pharmaceutical applications. J Biotech 2020, 10, 1–35. [CrossRef]

15. Toghueo, R.M.K. Bioprospecting endophytic fungi from Fusarium genus as sources of bioactive metabolites. Mycology 2020, 11, 1–21. [CrossRef]

16. Selvakumar, V.; Panneerselvam, A. Bioactive compounds from endophytic fungi. In Fungi and Their Role in Sustainable Development: Current Perspectives; Gehlot, P., Singh, J., Eds.; Springer: Singapore, 2018; pp. 699–717.

17. Preethi, K.; Manon Mani, V.; Lavanya, N. Endophytic fungi: A potential source of bioactive compounds for commercial and therapeutic applications. In Endophytes; Patil, R.H., Maheshwari, V.L., Eds.; Springer: Singapore, 2021; pp. 247–272.

18. Oktavia, L.; Krishna, V.S.; Rekha, E.M.; Fathoni, A.; Sriram, D.; Agusta, A. Anti-mycobacterial activity of two natural Bisanthraquinones (+)-1, 1′-Bisluatin and (+)-2, 2′-Epicytoskyrin A. In IOP Conference Series: Earth and Environmental Science. IOP Pub. 2020, 591, 12025.

19. Huang, X.; Zhou, D.; Liang, Y.; Liu, X.; Cao, F.; Qin, Y.; Mo, T.; Xu, Z.; Li, J.; Yang, R. Cytochalasins from endophytic Diaporthe sp. GDG-118. Nat. Prod. Res. 2021, 35, 3396–3403. [CrossRef]

20. Guo, L.; Niu, S.; Chen, S.; Liu, L. Diaporone A, a new antibacterial secondary metabolite from the plant endophytic fungus Phomopsis fukushii. J. Antibiot. 2019, 73, 293–296. [CrossRef]

21. Yang, H.Y.; Duan, Y.Q.; Yang, Y.K.; Li, J.; Liu, X.; Ye, L.; Mi, Q.L.; Kong, W.S.; Zhou, M.; Yang, G.Y.; et al. Three new naphthalene derivatives from the fermentation products of the endophytic fungus Phomopsis fukushii. Chem. Nat. Compd. 2021, 59, 428–431. [CrossRef]

22. Yang, H.Y.; Duan, Y.Q.; Yang, Y.K.; Li, J.; Liu, X.; Ye, L.; Mi, Q.L.; Kong, W.S.; Zhou, M.; Yang, G.Y.; Hu, Q.F.; et al. Two new diphenyl ether derivatives from the fermentation products of an endophytic fungus Phomopsis fukushii. Chem. Nat. Compd. 2019, 55, 428–431. [CrossRef]

23. Gao, Y.H.; Zheng, R.; Li, J.; Kong, W.S.; Liu, X.; Ye, L.; Mi, Q.L.; Kong, W.S.; Zhou, M.; Yang, G.Y.; et al. Three new diphenyl ether derivatives from the fermentation products of an endophytic fungus Phomopsis fukushii. J. Asian Nat. Prod. Res. 2019, 21, 316–322. [CrossRef]

24. Li, Z.J.; Yang, H.Y.; Li, J.; Liu, X.; Ye, L.; Kong, W.S.; Tang, S.Y.; Du, G.; Liu, Z.H.; Zhou, M.; et al. Isopentylated diphenyl ether derivatives from the fermentation products of an endophytic fungus Phomopsis fukushii. J. Antibiot. 2018, 71, 359–362. [CrossRef]

25. Wu, F.; Zhu, Y.N.; Hou, Y.T.; Mi, Q.L.; Chen, J.H.; Zhang, C.M.; Miao, D.; Zhou, M.; Wang, W.G.; Hu, Q.F.; et al. Two new antibiotic anthraquinones from cultures of an endophytic fungus Phomopsis sp. Chem. Nat. Compd. 2021, 57, 823–827. [CrossRef]

26. Guo, L.; Niu, S.; Chen, S.; Liu, L. Diaporone A, a new antibacterial secondary metabolite from the plant endophytic fungus Diaporthe sp. J. Antibiot. 2017, 70, 116–119. [CrossRef] [PubMed]

27. Qu, H.R.; Yang, W.W.; Zhang, X.Q.; Lu, Z.H.; Deng, Z.S.; Guo, Z.Y.; Cao, F.; Zou, K.; Proksch, P. Antibacterial bisabolane sesquiterpenoids and isocoumarin derivatives from the endophytic fungus Phomopsis prunorum. Phytochem. Lett. 2020, 37, 1–4. [CrossRef]

28. Noriler, S.A.; Savi, D.C.; Ponomareva, L.V.; Rodrigues, R.; Rohr, J.; Thorson, J.S.; Glienke, C.; Shaaban, K.A. Vochysia metabolites. In Bioprospecting of Diaporthe terebinthifolii LGMF907 for antimicrobial compounds. Folia Microbiol. 2018, 63, 499–505. [CrossRef]

29. Jayanthi, G.; Arun Babu, R.; Ramachandran, R.; Karthikeyan, K.; Muthumary, J. Production, isolation and structural elucidation of a novel antimicrobial metabolite from the endophytic fungus, Phomopsis/Diaporthe theae. Int. J. Pharm. Biol. Sci. 2018, 8, 8–26.

30. Kongprapan, T.; Xu, X.; Rukachaisirikul, V.; Phongpaichit, S.; Sakayaroj, J.; Chen, J.; Shen, X. Cytosporone derivatives from the endophytic fungus Phomopsis sp. PSU-H188. Phytochem. Lett. 2017, 22, 219–223. [CrossRef]
34. Yedukondalu, N.; Arora, P.; Wadhwa, B.; Malik, F.A.; Vishwakarma, R.A.; Gupta, V.K.; Riyaz-Ul-Hassan, S.; Ali, A. Diapolic acid A-B from an endophytic fungus, *Diaportha terebinthifolii* depicting antimicrobial and cytotoxic activity. *J. Antimicrob. Chemother.* 2017, 70, 212–215. [CrossRef]

35. Sousa, J.P.B.; Aguilar-Pérez, M.M.; Arnold, A.E.; Rios, N.; Coley, P.D.; Kursar, T.A.; Cubilla-Rios, L. Chemical constituents and their antibacterial activity from the tropical endophytic fungus *Diaporthe* sp. F2934. *J. Appl. Microbiol.* 2016, 120, 1501–1508. [CrossRef]

36. Jouda, J.B.; Mbazoza, C.D.; Douala-Meli, C.; Sarkar, P.; Bag, P.K.; Wandji, J. Antibacterial and cytotoxic cytochalasins from the endophytic fungus *Phomopsis* sp. harbored in *Garcinia kola* (Heckel) nut. BMC Complement Altern. Med. 2016, 16, 1–9. [CrossRef]

37. Li, G.; Kusari, S.; Kusari, P.; Kayser, O.; Spiteller, M. Endophytic *Diaporthe* sp. LG23 produces a potent antibacterial tetracyclic triterpenoid. *J. Nat. Prod.* 2015, 78, 2128–2132. [CrossRef]

38. Patridge, E.V.; Darnell, A.; Kucera, K.; Phillips, G.M.; Bokesch, H.R.; Gustafson, K.R.; Spakowicz, D.J.; Zhou, L.; Hungerford, W.M.; Plummer, M.; et al. Pyrrolacin a, a 3-decalinol tetrameric acid with selective biological activity, isolated from Amazonian cultures of the novel endophyte *Diaphorales* sp. E6927E. *Nat. Prod. Commun.* 2015, 10, 1649–1654. [CrossRef]

39. Ibrahim, A.; Tanney, J.B.; Fei, F.; Seifert, K.A.; Cutler, G.C.; Capretta, A.; Miller, J.D.; Sumarah, M.W. Metabolomic-guided discovery of cyclic nonribosomal peptides from *Xylaria ellisi* sp. nov., a leaf and stem endophyte of *Vaccinium angustifolium*. *Sci. Rep.* 2020, 10, 1–17. [CrossRef]

40. Liang, Y.; Xu, W.; Liu, C.; Zhou, D.; Liu, X.; Qin, Y.; Cao, F.; Li, J.; Yang, R.; Qin, J. Eremophilane sesquiterpenes from the endophytic fungus *Xylaria* sp. GDG-102. *Nat. Prod. Res.* 2019, 33, 1304–1309. [CrossRef]

41. Zheng, N.; Yao, F.; Liang, X.; Liu, Q.; Xu, W.; Liang, Y.; Liu, Y.; Li, J.; Yang, R. A new phthalide from the endophytic fungus *Xylaria* sp. GDG-102. *Nat. Prod. Res.* 2018, 32, 755–760. [CrossRef]

42. Zheng, N.; Liu, Q.; He, D.L.; Liang, Y.; Li, J.; Yang, R.Y. A new compound from the endophytic fungus *Xylaria* sp. from *Sophora tonkinensis*. *Chem. Nat. Compd.* 2018, 54, 447–449. [CrossRef]

43. Lin, X.; Yu, M.; Lin, T.; Zhang, L. Secondary metabolites of *Xylaria* sp., an endophytic fungus from *Taxus mairei*. *Nat. Prod. Res.* 2016, 30, 2442–2447. [CrossRef]

44. Zhang, Q.; Li, H.Q.; Zong, S.C.; Gao, J.M.; Zhang, A.L. Chemical and bioactive diversities of the genus *Chaetomium* secondary metabolites. *Mini Rev. Med. Chem.* 2012, 12, 127–148. [CrossRef]

45. Tantapakul, C.; Promgool, T.; Kanokmedhakul, K.; Soytong, K.; Song, J.; Hadsadee, S.; Jungsuttiwong, S.; Kanokmedhakul, S. Bioactive xanthoquinodins and epipolythiodioxopiperazines from *Chaetomium globosum* 7s-1, an endophytic fungus isolated from *Rhipus cochinchinensis* (Lour.) Mart. *Nat. Prod. Res.* 2020, 34, 494–502. [CrossRef][PubMed]

46. Peng, F.; Hou, S.Y.; Zhang, T.Y.; Wu, Y.Y.; Zhang, M.Y.; Yan, X.M.; Xia, M.Y.; Zhang, Y.X. Cytotoxic and antimicrobial indole alkaloids from an endophytic fungus *Chaetomium globosum* sp. GDG-102. *Nat. Prod. Res.* 2018, 14, 1680–1688. [CrossRef][PubMed]

47. Liu, P.; Zhang, D.; Shi, R.; Yang, Z.; Zhao, F.; Tian, Y. Antimicrobial potential of endophytic fungi from *Astragalus chinensis*. *3 Biotech* 2019, 9, 1–9. [CrossRef][PubMed]

48. Wang, H.H.; Li, G.; Qiao, Y.N.; Sun, Y.; Peng, X.P.; Lou, H.X. Chemiside A, a cytochalasan with a tricyclic core skeleton from the endophytic fungus *Xylaria* sp. GDG-102. *Molecules* 2020, 25, 3218. [CrossRef]

49. Yang, S.X.; Zhao, W.T.; Chen, H.Y.; Zhang, L.; Liu, T.K.; Yang, J.; Yang, X.L. Aureonitols A and B, two new phthalide derivatives from the endophytic fungus *Xylaria ellisi* sp. BZM-9. *Molecules* 2021, 26, 6092. [CrossRef]
60. Zhang, W.; Lu, X.; Wang, H.; Chen, Y.; Zhang, J.; Zou, Z.; Tan, H. Antibacterial secondary metabolites from the endophytic fungus Eutypella scaporia SCBG-8. *Tetrahedron Lett.* 2021, 83, 1714–1724. [CrossRef]

61. Zhang, W.; Lu, X.; Huo, L.; Zhang, S.; Chen, Y.; Zou, Z.; Tan, H. Sesquiterpenes and steroids from an endophytic *Eutypella scaporia*. *J. Nat. Prod.* 2021, 84, 1714–1724. [CrossRef]

62. Zhang, Z.B.; Du, S.Y.; Ji, B.; Ji, C.J.; Xiao, Y.W.; Yan, R.M.; Zhu, D. New Hervolic Acid derivatives with antibacterial activities from *Sarocradium oryzae* DX-THL3, an endophytic fungus from Dongxiang wild rice (*Oryza rufipogon* Griff.). *Molecules* 2021, 26, 1828. [CrossRef]

63. Carrieri, R.; Borriello, G.; Piccirillo, G.; Lahoz, E.; Sorrentino, R.; Cermola, M.; Bolletti Censi, S.; Grauso, L.; Mangoni, A.; Vinale, F. Antibiotic Activity of a Paraphaeosphaeria sporulosa -Produced diketopiperazine against *Salmonella enterica*. *J. Fungi* 2020, 6, 83. [CrossRef]

64. Gao, Y.; Stuhldreier, F.; Schmitt, L.; Wesselborg, S.; Wang, L.; Müller, W.E.; Kalscheuer, R.; Guo, Z.; Zou, K.; Liu, Z.; et al. Sesterterpenes and macrolide derivatives from the endophytic fungus *Apolsporella jaudredi*. *Fitoterpia* 2020, 146, 104652. [CrossRef]

65. Lai, D.; Mao, Z.; Zhou, Z.; Zhao, S.; Xue, M.; Dai, J.; Zhou, L.; Li, D. New chlamydosporol derivatives from the endophytic fungus *Pleosporales* sp. Signr05 and their cytotoxic and antimicrobial activities. *Sci. Rep.* 2020, 10, 1–9. [CrossRef]

66. Gao, Y.; Wang, L.; Kalscheuer, R.; Liu, Z.; Proksch, P. Antifungal polyketide derivatives from the endophytic fungus *Apolsporella jaudredi*. *Bioorg. Med. Chem.* 2020, 28, 115456. [CrossRef]

67. Abbas, Z.; Siddiqui, B.S.; Shahzad, S.; Sattar, S.; Begum, S.; Bato, A.; Choudhary, M.I. Lawsozaheer, a new chromone produced naturally occurring tetrahydro-2H-1, 2-oxazin skeleton from an endophytic fungus *Preussia isomera* by using OSMAC strategy. *Fitoterapia* 2020, 141, 104475. [CrossRef]

68. Chen, H.L.; Zhao, W.T.; Liu, Q.P.; Chen, H.Y.; Zhao, W.; Yang, D.F.; Yang, X.L. (+)-Preisomide: A new alkaloid featuring a rare naturally occurring tetrahydro-2H-1, 2-oxacin skeleton from an endophytic fungus *Preussia isomera* isolated from Lawsonia Alba Lam. inhibits the growth of *Staphylococcus aureus*. *Nat. Prod. Res.* 2021, 35, 4451–4453. [CrossRef]

69. Xu, L.L.; Chen, H.L.; Hai, P.; Gao, Y.; Xie, C.D.; Yang, X.L.; Abe, I. (+)- and (−)-Preisolactone A: A pair of caged norsesquiterpenoid enantiomers with a tricyclo.4.4.4.01, 6.02, 8. decane carbon skeleton from the endophytic fungus *Preussia isomera*. *Org. Lett.* 2019, 21, 1078–1081. [CrossRef]

70. Macabeo, A.P.G.; Cruz, A.J.C.; Narmani, A.; Arzanlou, M.; Babai-Ahari, A.; Pilapil, L.A.E.; Garcia, K.Y.M.; Huch, V.; Stadler, M. Tetrasubstituted α-pyrene derivates from the endophytic fungus *Neurospora adagawae*. *Phytochem. Lett.* 2020, 35, 147–151. [CrossRef]

71. Lai, D.; Li, J.; Zhao, S.; Gu, G.; Gong, X.; Proksch, P.; Zhou, L. Chromone and isocoumarin derivatives from the endophytic fungus *XYlomelasma sp.* Sami07, and their antibacterial and antioxidant activities. *Nat. Prod. Res.* 2021, 35, 4616–4620. [CrossRef]

72. Nguyen, H.T.; Kim, S.; Yu, N.H.; Park, A.R.; Yoon, H.; Bae, C.H.; Yeo, J.H.; Kim, I.S.; Kim, J.C. Antimicrobial activities of an oxygenated cyclohexanone derivative isolated from *Amphisellonia nigrospera* JS-1675 against various plant pathogenic bacteria and fungi. *J. Appl. Microbiol.* 2019, 126, 894–904. [CrossRef]

73. Wu, X.; Fang, X.J.; Xu, L.L.; Zhao, T.; Long, X.Y.; Zhang, Q.Y.; Qin, H.L.; Yang, D.F.; Yang, X.L. Two new alkylated furan derivatives with antibacterial and antifungal activities from the endophytic fungus *Emericeri sp.* XL029. *Nat. Prod. Res.* 2018, 32, 2625–2631. [CrossRef]

74. Wu, X.; Fang, L.Z.; Liu, F.L.; Pang, X.J.; Qin, H.L.; Zhao, T.; Xu, L.L.; Yang, D.F.; Yang, X.L. New prenylhexanones, polyketide hemiterpenoid pigments from the endophytic fungus *Emericeri sp.* XL029 and their anti-agricultural pathogenic fungal and antibacterial activities. *RSC Adv.* 2017, 7, 31115–31122. [CrossRef]

75. Wu, Y.Z.; Zhang, H.W.; Sun, Z.H.; Dai, J.G.; Hu, Y.C.; Li, R.; Lin, P.C.; Xia, G.Y.; Wang, L.Y.; Qiu, B.L.; et al. Bysspectin A, an unusual octaketide dimer and the precursor derivatives from the endophytic fungus *Byssoschlamys spectabilis* IMI00002 and their biological activities. *Eur. J. Med. Chem.* 2018, 145, 717–725. [CrossRef] [PubMed]

76. Kashawima, D.; Hosoya, T.; Tomoda, H.; Kita, M.; Shigemori, H. Sydowianumols A, B, and C. Three new compounds from discomycete *Pocusum pseudosydneyanum*. *Chem. Pharm. Bull.* 2018, 66, 826–829. [CrossRef] [PubMed]

77. Zhao, M.; Yuan, L.Y.; Guo, D.L.; Ye, Y.; Da-Wa, Z.M.; Wang, X.L.; Ma, F.W.; Chen, L.; Gu, Y.C.; Ding, L.S.; et al. Bioactive halogenated dihydroisocoumarins produced by the endophytic fungus *Lachnum palmae* isolated from *Przewalskia tangutica*. *Tetrahedron Lett.* 2017, 58, 45–49. [CrossRef]

78. Ibrahim, A.; Serensen, D.; Jenkins, H.A.; Ejim, L.; Capretta, A.; Sumarah, M.W. Ephxynemianone A, nemafuranone A–F, and nemanilactones A–C, from *Nemania serpens*, an endophytic fungus isolated from Riesling grapevines. *Phytochemistry* 2017, 140, 16–26. [CrossRef] [PubMed]

79. Amand, S.; Vallet, M.; Guedon, L.; Genta-Jouve, G.; Wien, F.; Mann, S.; Dupont, J.; Prado, S.; Nay, B. A reactive eremophiane and its antibacterial 2 (1 H)-naphthalenone rearrangement product, witnesses of a microbial chemical warfare. *Org. Lett.* 2017, 19, 4038–4041. [CrossRef] [PubMed]

80. Deng, Z.; Li, C.; Luo, D.; Teng, P.; Guo, Z.; Tu, X.; Zou, K.; Gong, D. A new cinnamic acid derivative from plant-derived endophytic fungus *Pyronema* sp. *Nat. Prod. Res.* 2017, 31, 2413–2419. [CrossRef] [PubMed]
81. Wijeratne, E.K.; Xu, Y.; Arnold, A.E.; Gunati, A., L-Pulvinulins A, graminin C, and cis-gregatin B—new natural furanones from Pulvinula sp. 11120, a fungal endophyte of Cupressus arizonica. Nat. Prod. Commun. 2015, 10, 107-111. [CrossRef]

82. Forcina, G.C.; Castro, A.; Bokesch, H.R.; Spakowicz, D.J.; Legaspi, M.E.; Kucera, K.; Villoita, S.; Narvaez-Trujillo, A.; McMahon, J.B.; Gustafson, K.R.; et al. Stelliosphaerols A and B, sesquiterpene—polysaccharide conjugates from an ecuadorian fungal endophyte. J. Nat. Prod. 2015, 78, 3005-3010. [CrossRef]

83. Hussain, H.; Jabeen, F.; Khoob, K.; Al-Harrasi, A.; Ahmad, M.; Maboood, F.; Shah, A.; Al-Badhshah, A.; Hein, N.U.; Green, I.R.; et al. Antimicrobial activity of two mellein derivatives isolated from an endophytic fungus. Med. Chem. Res. 2015, 24, 2111-2114. [CrossRef]

84. Qader, M.; Zaman, K.H.; Hu, Z.; Wang, C.; Wu, X.; Cao, S. Aspochalasin H1: A new cyclic Aspochalasin from Hawaiian Plant-Associated Endophytic Fungus Sp. T1307. Molecules 2021, 26, 4239. [CrossRef]

85. Wang, M.L.; Chen, R.; Sun, F.J.; Cao, P.R.; Chen, X.R.; Yang, M.H. Three alkaloids and one poly ketide from Aspergillus cristatus harbored in Pinellia ternata tubers. Tetrahedron Lett. 2021, 62, 152914. [CrossRef]

86. Elkhayat, E.S.; Ibrahim, S.R.; Mohamed, G.A.; Ross, S.A. Terrenolide S, a new antileishmanial butenolide from the endophytic fungus of Cupressus arizonica. J. Agric. Food Chem. 2016, 64, 3789-3793. [CrossRef] [PubMed]
106. Ibrahim, S.R.M.; Elkhayat, E.S.; Mohamed, G.A.; Khedr, A.M.; Foud, M.A.; Koth, M.H.R.; Ross, S.A. Aspernomides F and G, new butyroloactones from the endophytic fungus Aspergillus terreus. Phytochem. Lett. 2015, 14, 84–90. [CrossRef]

107. Elfite, E.; Munawar, M.; Muharni, M.; Ivanti, I. Chemical constituents from an endophytic fungus Aspergillus sp. (SbD5) isolated from Sambaloto (Andrographis paniculata Nees). Microbiol. Indones. 2015, 9, 6.

108. Zhang, W.; Wei, W.; Shi, J.; Chen, C.; Zhao, G.; Jiao, R.; Tan, R. Natural phenolic metabolites from endophytic Aspergillus sp. IFB-YXS with antimicrobial activity. Bioorg. Med. Chem. Lett. 2015, 25, 2698–2701. [CrossRef]

109. Song, H.C.; Qin, D.; Liu, H.Y.; Dong, J.Y.; You, C.; Wang, Y.M. Resorcylic acid lactones produced by an endophytic Penicillium ochrochloron strain from Kadsura angustifolia. Planta Med. 2021, 87, 225–235. [CrossRef]

110. Syarifah, S.; Elfita, E.; Widijanjati, H.; Setiawan, A.; Kurniawati, A.R. Diversity of endophytic fungi from the root bark of Syzygium zeylanicum, and the antibacterial activity of fungal extracts, and secondary metabolite. Biodivers. J. 2021, 22, 4572–4582. [CrossRef]

111. Qin, Y.Y.; Huang, X.S.; Liu, X.B.; Mo, T.X.; Xu, Z.L.; Li, B.C.; Qin, X.Y.; Li, J.; Schieberle, T.F.; Yang, R.Y. Three new arstandin derivatives from the endophytic fungus Penicillium vilpinum. Nat. Prod. Res. 2020, 1–9. [CrossRef]

112. Zhu, Y.X.; Peng, C.; Ding, W.; Hu, J.E.; Li, J. Chromenopyridin A, a new N-methoxy-1-pyridone alkaloid from the endophytic fungus Penicillium nothofagi f-6 isolated from the critically endangered conifer Abies beshanzuensis. Nat. Prod. Res. 2020, 1–7. [CrossRef]

113. Graf, T.N.; Kao, D.; Rivera-Chavez, J.; Gallagher, J.M.; Raja, H.A.; Oberlies, N.H. Drug leads from endophytic fungi: Lessons learned via scaled production. Planta Med. 2020, 86, 988–996. [CrossRef]

114. Qin, Y.; Liu, X.; Lin; J.; Huang, J.; Jiang, X.; Mo, T.; Xu, Z.; Li, J.; Yang, R. Two new phthalide derivatives from the endophytic fungus Penicillium vilpinum isolated from Sophora tonkienensis. Nat. Prod. Res. 2021, 35, 421–427. [CrossRef]

115. Xu, Y.; Wang, L.; Zhu, C.; Zuo, M.; Gong, Q.; He, W.; Li, M.; Yuan, C.; Hao, X.; Zhu, W. New phenylpyridone derivatives from the Penicillium sumatrense GZWMJZ-313, a fungal endophyte of Carcinsa multiflora. Chin. Chem. Lett. 2019, 30, 431–434. [CrossRef]

116. Zhao, T.; Xu, L.L.; Zhang, Y.; Lin, Z.H.; Xia, T.; Yang, D.F.; Chen, Y.M.; Yang, X.L. Three new α-pyrones from the plant endophytic fungus Penicillium ochrochloronthe and their antibacterial, antifungal, and cytotoxic activities. J. Asian Nat. Prod. Res. 2019, 21, 851–858. [CrossRef]

117. Xie, J.; Wu, Y.Y.; Zhang, T.Y.; Zhang, M.Y.; Peng, F.; Lin, B.; Zhang, Y.X. New antimicrobial compounds produced by endophytic Penicillium janthinellum isolated from IFB nothofagi sp. CAM64 against multi-drug resistant Gram-negative bacteria. Afr. Health Sci. 2018, 18, 786–790. [CrossRef]

118. Feng, Z.W.; Lv, M.M.; Li, X.S.; Zhang, L.; Liu, C.X.; Guo, Z.Y.; Deng, Z.S.; Zou, K.; Proksch, P. Penicitroamide, an antimicrobial metabolite with high carbonylization from the endophytic fungus Penicillium janthinellum isolated from Panax notoginseng. Molecules 2019, 24, 4132–4146. [CrossRef]

119. Yang, M.H.; Li, T.X.; Wang, Y.; Liu, R.H.; Luo, J.; Kong, L.Y. Antimicrobial metabolites from the plant endophytic fungus Penicillium sp. Fitoterapia 2017, 116, 72–76. [CrossRef]

120. Ma, Y.M.; Qiao, K.; Kong, Y.; Li, M.Y.; Guo, L.X.; Miao, Z.; Fan, C. A new isoquinolone alkaloid from an endophytic fungus R22 of Nerium indicum. Nat. Prod. Res. 2017, 31, 951–958. [CrossRef]

121. Feng, Z.W.; Lv, M.M.; Li, X.S.; Zhang, L.; Liu, C.X.; Guo, Z.Y.; Deng, Z.S.; Zou, K.; Proksch, P. Penicitroamide, an antimicrobial metabolite with high carbonylization from the endophytic fungus Penicillium sp. (No. 24). Molecules 2016, 21, 1438. [CrossRef]

122. Jouda, J.B.; Mbazoza, C.D.; Sarkar, P.; Bag, P.K.; Wandji, J. Anticancer and antibacterial secondary metabolites from the endophytic fungus Penicillium sp. CM64 against multi-drug resistant Gram-negative bacteria. Afr. Health Sci. 2016, 16, 734–743. [CrossRef]

123. Lenta, B.N.; Ngatchou, J.; Frese, M.; Ladoh-Yemeda, F.; Voundi, S.; Nardella, F.; Michalek, C.; Wibberg, D.; Ngouela, S.; Tsampo, E.; et al. Purpurocine, an antileishmanial ergochromone from the endophytic fungus Purpurococcum lilacinum. Z. Naturforsch. B. 2016, 71, 1159–1167. [CrossRef]

124. Klomchit, A.; Calderin, J.D.; Jaidee, W.; Watla-Iad, K.; Brooks, S. Naphthoquinones from Neocosmospora sp.—Antibiotic Activity against Acidovorax citrulli, the Causative Agent of Bacterial Fruit Blotch in Watermelon and Melon. J. Fungi 2021, 7, 370. [CrossRef]

125. Ibrahim, S.R.M.; Mohamed, G.A.; Khayat, M.T.; Al Haidari, R.A.; El-Kholy, A.A.; Zayed, M.F. A new antifungal aminobenzamide derivative from the endophytic fungus Neocosmospora sp. Pharmacogn. Mag. 2019, 15, 204–207. [CrossRef]

126. Jiang, C.X.; Li, J.; Zhang, J.M.; Jin, X.J.; Yu, B.; Fang, J.G.; Wu, Q.X. Isolation, identification, and activity evaluation of chemical constituents from soil fungus Fusariumavenaceum SF-1502 and endophytic fungus Fusarium proliferatum AF-04. J. Agric. Food Chem. 2019, 67, 1839–1846. [CrossRef]

127. Shi, S.; Li, Y.; Ming, Y.; Li, C.; Li, Z.; Chen, J.; Luo, M. Biological activity and chemical composition of the endophytic fungus Fusarium sp. TP-G1 obtained from the root of Dendrobium officinale Kimura et Migo. Rec. Nat. Prod. 2018, 12, 549–556. [CrossRef]

128. Yan, C.; Liu, W.; Li, J.; Deng, Y.; Chen, S.; Liu, H. Bioactive terpenoids from Santalum album derived endophytic fungus Fusarium sp. YD-2. RSC Adv. 2018, 8, 14823–14828. [CrossRef]

129. Ibrahim, S.R.; Mohamed, G.A.; Al Haidari, R.A.; Zayed, M.F.; El-Kholy, A.A.; Elkhayat, E.S.; Ross, S.A. Fusaritioamide B, a new benzamide derivative from the endophytic fungus Fusariumchlamydosporium with potent cytotoxic and antimicrobial activities. Bioorg. Med. Chem. 2018, 26, 786–790. [CrossRef]

130. Shah, A.; Rather, M.A.; Hassan, Q.P.; Aga, M.A.; Mushtaq, S.; Shah, A.M.; Hussain, A.; Baba, S.A.; Ahmad, Z. Discovery of anti-microbial and anti-tubercular molecules from Fusarium solani: An endophyte of Glycerrhiza glabra. J. Appl. Microbiol. 2017, 122, 1168–1176. [CrossRef]

131. Ibrahim, S.R.M.; Elkhayat, E.S.; Mohamed, G.A.A.; Fat’hi, S.M.; Ross, S.A. Fusaritioamide A, a new antimicrobial and cytotoxic benzamide derivative from the endophytic fungus Fusariumchlamydosporium. Biochem. Biophys. Res. Commun. 2016, 479, 211–216. [CrossRef][PubMed]
132. Alvin, A.; Kalaitzis, J.A.; Sasia, B.; Neilan, B.A. Combined genetic and bioactivity-based prioritization leads to the isolation of an endophyte-derived antimycobacterial compound. *J. Appl. Microbiol.* 2016, 120, 1229–1239. [CrossRef]

133. Liang, X.A.; Ma, Y.M.; Zhang, H.C.; Liu, R. A new helvolic acid derivative from an endophytic *Fusarium sp.* of *Ficus carica*. *Nat. Prod. Res.* 2016, 30, 2407–2412. [CrossRef]

134. Hussain, H.; Drogies, K.H.; Al-Harrasi, A.; Hassan, Z.; Shah, A.; Rana, U.A.; Green, I.R.; Draeger, S.; Schulz, B.; Krohn, K. Antimicrobial constituents from endophytic fungus *Fusarium sp.* *Asian Pac. J. Trop. Dis.* 2015, 5, 186–189. [CrossRef]

135. Ratnaweera, P.B.; de Silva, E.D.; Williams, D.E.; Andersen, R.J. Antimicrobial activities of endophytic fungi obtained from the arid zone invasive plant *Opuntia dillenii* and the isolation of equisetin, from endophytic *Fusarium sp.* *BMC Complement. Altern. Med.* 2015, 15, 1–7. [CrossRef]

136. Harwoko, H.; Daletos, G.; Stuhlbreider, F.; Lee, J.; Wesselborg, S.; Müller, W.E.; Kalscheuer, R.; Ancheeva, E.; Proksch, P. Dithiodiketopiperazine derivatives from endophytic fungis *Trichoderma harzianum* and *Epococcum nigrum*. *Nat. Prod. Res.* 2021, 35, 257–265. [CrossRef] [PubMed]

137. Wang, Y.L.; Hu, B.Y.; Qian, M.A.; Wang, Z.H.; Zou, J.M.; Sang, X.Y.; Li, L.; Luo, X.D.; Zhao, L.X. Koninginin W, a new polyketide from the endophytic fungus *Trichoderma koningiopsis* PH30002. *Chem. Biodivers.* 2021, 18, e2100460. [CrossRef]

138. Shi, X.S.; Song, Y.P.; Meng, L.H.; Yang, S.Q.; Wang, D.J.; Zhou, X.W.; Ji, N.Y.; Wang, B.G.; Li, X.M. Isolation and Characterization of antibacterial carotene sesquiterpenes from *Artemisia argyi* associated endophytic *Trichoderma virens* QA-8. *Antibiotics* 2021, 10, 213. [CrossRef]

139. Shi, X.S.; Meng, L.H.; Li, X.; Wang, D.J.; Zhou, X.W.; Du, F.Y.; Wang, B.G.; Li, X.M. Polyketides and Terpenoids with Potent Antibacterial Activities from the *Artemisia argyi*-Derived Fungus *Trichoderma koningiopsis* QA-3. *Chem. Biodivers.* 2020, 17, e2000566. [CrossRef]

140. Shi, X.S.; Li, H.L.; Li, X.M.; Wang, D.J.; Li, X.; Meng, L.H.; Zhou, X.W.; Wang, B.G. Highly oxygenated polyketides produced by *Trichoderma koningiopsis* QA-3, an endophytic fungus from the fresh roots of the medicinal plant *Artemisia argyi*. *Bioorg. Chem.* 2020, 94, 103448. [CrossRef]

141. Li, W.Y.; Liu, Y.; Lin, Y.T.; Liu, Y.C.; Guo, K.; Li, X.N.; Luo, S.H.; Li, S.H. Antibacterial harziane diterpenoids from a fungal symbiont *Trichoderma atroviride* isolated from *Colquhounia cocinea var. mullis*. *Phytochemistry* 2020, 170, 112198. [CrossRef]

142. Sarsaiya, S.; Jain, A.; Fan, X.; Jia, Q.; Xu, Q.; Shu, F.; Zhou, Q.; Shi, J.; Chen, J. New insights into detection of Front Microbiol, 11a dendrobine compound from a novel endophytic *Trichoderma longibrachiatum* strain and its toxicity against phytopathogenic bacteria. *Front. Microbiol.* 2020, 11, 337. [CrossRef]

143. Shi, X.S.; Meng, L.H.; Li, X.M.; Li, X.; Wang, D.J.; Li, H.L.; Zhou, X.W.; Wang, B.G. Trichocadinins B–G: Antimicrobial cadinane sesquiterpenes from *Trichoderma virens* QA-8, an endophytic fungus obtained from the medicinal plant *Artemisia argyi*. *J. Nat. Prod.* 2019, 82, 2470–2476. [CrossRef]

144. Chen, S.; Li, H.; Chen, Y.; Li, S.; Xu, J.; Guo, H.; Liu, Z.; Zhu, S.; Liu, H.; Zhang, W. Three new diterpenes and two new sesquiterpenoids from the endophytic fungus *Trichoderma koningiopsis* A729. *Bioorg. Chem.* 2019, 86, 368–374. [CrossRef]

145. Shi, X.S.; Wang, D.J.; Li, X.M.; Li, H.L.; Meng, L.H.; Li, X.; Pi, Y.; Zhou, X.W.; Wang, B.G. Antimicrobial polyketides from *Trichoderma koningiopsis* QA-3, an endophytic fungus from the medicinal plant *Artemisia argyi*. *Rsc. Adv.* 2017, 7, 51335–51342. [CrossRef]

146. Zhao, S.; Wang, B.; Tian, K.; Ji, W.; Zhang, T.; Ping, C.; Yan, W.; Ye, Y. Novel metabolites from the *Cinchis chinensis* derived endophytic fungus *Alternaria alternata* ZHJG5 and their antibacterial activities. *Pest Manag. Sci.* 2021, 77, 2264–2271. [CrossRef] [PubMed]

147. Kong, F.D.; Yi, T.F.; Ma, Q.Y.; Xie, Q.Y.; Zhou, L.M.; Chen, J.P.; Dai, H.F.; Wu, Y.G.; Zhao, Y.X. Biphenyl metabolites from the patchouli endophytic fungus *Alternaria sp.* *Phytoph. J.* 2020, 146, 104708. [CrossRef] [PubMed]

148. Zhao, S.; Xiao, C.; Wang, J.; Tian, K.; Ji, W.; Yang, T.; Khan, B.; Qian, G.; Yan, W.; Ye, Y. Discovery of natural FabH inhibitors using an immobilized enzyme column and their antibacterial activity against *Xanthomonas oryzae* pv. *oryzae*. *J. Agric. Food Chem.* 2020, 68, 14204–14211. [CrossRef]

149. Palanichamy, P.; Kannan, S.; Murugan, D.; Alagusundaram, P.; Marudhamuthu, M. Purification, crystallization and anticancer activity evaluation of the compound alternariol methyl ether from endophytic fungis *Alternaria alternata*. *J. Appl. Microbiol.* 2019, 127, 1468–1478. [CrossRef]

150. Deshidi, R.; Devari, S.; Kushwaha, M.; Gupta, A.P.; Sharma, R.; Chib, R.; Khan, I.A.; Jaglan, S.; Shah, B.A. Isolation and quantification of alternariol and alternariol methyl ether from endophytic fungi, *Alternaria alternata*: LC-ESI-MS/MS analysis. *ChemistrySelect* 2017, 2, 364–368. [CrossRef]

151. Tian, J.; Fu, L.; Zhang, Z.; Dong, X.; Xu, D.; Mao, Z.; Liu, Y.; Lai, D.; Zhou, L. Dibenzo-α-pyrones from the endophytic fungus *Alternaria sp.* Samif01: Isolation, structure elucidation, and their antibacterial and antioxidant activities. *Nat. Prod. Res.* 2017, 31, 387–396. [CrossRef]

152. Lou, J.; Yu, R.; Wang, X.; Mao, Z.; Fu, L.; Liu, Y.; Zhou, L. Alternariol 9-methyl ether from the endophytic fungus *Alternaria sp.* Samif01 and its bioactivities. *Braz. J. Microbiol.* 2016, 47, 96–101. [CrossRef]

153. Kellogg, J.J.; Todd, D.A.; Egan, J.M.; Raja, H.A.; Oberlies, N.H.; Kvalheim, O.M.; Cech, N.B. Biochemometrics for natural products research: Comparison of data analysis approaches and application to identification of bioactive compounds. *J. Nat. Prod.* 2016, 79, 376–386. [CrossRef]
154. Rukachaisirikul, V.; Chinpha, S.; Saetang, P.; Phongpaichit, S.; Jungsuttiwong, S.; Hadsadee, S.; Sakayaroj, J.; Preedanon, S.; Temkitthawon, P.; Ingkaninan, K. Depsidones and a dihydroxanthone from the endophytic fungi Simplicillium lansonitum (FJH Beyma) Zare & W. Gams PSU-H168 and PSU-H261. *Phytoparasitica* 2019, 138, 104266.

155. Saetang, P.; Rukachaisirikul, V.; Phongpaichit, S.; Preedanon, S.; Sakayaroj, J.; Borwornpinyo, S.; Seemakhan, S.; Muanprasat, C. Depsidones and an α-pyrone derivative from *Simplicillium* sp. PSU-H41, an endophytic fungus from *Hevea brasiliensis* leaf. *Phytochemistry* 2017, 143, 115–123. [CrossRef]

156. Zhao, S.; Chen, S.; Wang, B.; Niu, S.; Wu, W.; Guo, L.; Che, Y. Four new tetramic acid and one new furanone derivatives from the endophytic fungus *Phoma* sp., an endophyte of *Rhizopycnis vagum* and their antibacterial, cytotoxic, and phytotoxic activities. *J. Antibiot.* 2015, 68, 139–141. [CrossRef]

157. De Medeiros, L.S.; Abreu, L.M.; Nielsen, A.; Ingmer, H.; Larsen, T.O.; Nielsen, K.F.; Rodrigues-Filho, E. Dereplication-guided isolation of depsides thielavins S–T and lecanorins D–F from the endophytic fungus *Stemphylium lycopersici* and their antibacterial activity. *Fitoterapia* 2019, 134, 296–302. [CrossRef]

158. Khan, M.I.H.; Sohrab, M.H.; Rony, S.R.; Tareq, F.S.; Hasan, C.M.; Mazid, M.A. Cytotoxic and antibacterial naphthoquinones from an endophytic fungus, *Cladosporium* sp. *Toxicol. Rep.* 2016, 3, 861–865. [CrossRef]

159. Wang, W.X.; Kusari, S.; Laatsch, H.; Golz, C.; Kusari, P.; Strohmann, C.; Kayser, O.; Spiteller, M. Antibacterial azaphilones from an endophytic fungus *Cladosporium* sp. WBS017. *Toxins* 2020, 12, 591. [CrossRef] [PubMed]

160. Beattie, K.D.; Ellwood, N.; Kumar, R.; Yang, X.; Healy, P.C.; Choomuenwai, V.; Quinn, R.J.; Elliott, A.G.; Huang, J.X.; Chitty, J.L.; et al. Antibacterial and antifungal screening of natural products sourced from Australian fungi and characterisation of pestalactams D–F. *Phytochemistry* 2016, 124, 79–85. [CrossRef]

161. Zhao, S.; Chen, S.; Wang, B.; Niu, S.; Wu, W.; Guo, L.; Che, Y. Four new tetramic acid and one new furanone derivatives from the plant endophytic fungus *Neopesstalotiopsis* sp. *Phytoparasitica* 2015, 103, 106–112. [CrossRef]

162. Xia, X.; Kim, S.; Bang, S.; Lee, H.J.; Liu, C.; Park, C.I.; Shim, S.H. Barceloneic acid C, a new polyketide from an endophytic fungus *Phoma* sp. J5752 and its antibacterial activities. *J. Antibiot.* 2015, 68, 139–141. [CrossRef]

163. De Medeiros, L.S.; Abreu, L.M.; Nielsen, A.; Ingmer, H.; Larsen, T.O.; Nielsen, K.F.; Rodrigues-Filho, E. Dereplication-guided isolation of depsides thielavins S–T and lecanorins D–F from the endophytic fungus *Epicoccum nigrum* and their antibacterial, cytotoxic, and phytotoxic activities. *Molecules* 2016, 21, 155–162. [CrossRef] [PubMed]

164. Arora, P.; Wani, Z.A.; Nalli, Y.; Ali, A.; Riyaz-Ul-Hassan, S. Antimicrobial potential of thiodiketopiperazine derivatives produced by *Colletotrichum* sp. *Fitoterapia* 2019, 137, 104243. [CrossRef]

165. Pan, F.; El-Kashef, D.H.; Kalscheuer, R.; Müller, W.E.; Lee, J.; Feldbrügge, M.; Mändi, A.; Kurtán, T.; Liu, Z.; Wu, W.; et al. Cladosinos LO, new hybrid polyketides from the endophytic fungus *Cladosporium sphaerospermum* WBS017. *Eur. J. Med. Chem.* 2020, 191, 112159. [CrossRef]

166. Beattie, K.D.; Ellwood, N.; Kumar, R.; Yang, X.; Healy, P.C.; Choomuenwai, V.; Quinn, R.J.; Elliott, A.G.; Huang, J.X.; Chitty, J.L.; et al. Antibacterial and antifungal screening of natural products sourced from Australian fungi and characterisation of pestalactams D–F. *Phytochemistry* 2016, 124, 79–85. [CrossRef]

167. Wang, A.; Yin, R.; Zhou, Z.; Gu, G.; Dai, J.; Lai, D.; Zhou, L. Eremophilane-type sesquiterpenoids from the endophytic fungus *Colletotrichum gloeosporioides* Phytochem. Lett. 2019, 33, 90–93. [CrossRef]

168. Wang, W.X.; Kusari, S.; Laatsch, H.; Gölz, C.; Kusari, P.; Strohmann, C.; Kayser, O.; Spittel, M. Antibacterial azaphilones from an endophytic fungus, *Colletotrichum* sp. *BSA*. J. Nat. Prod. 2016, 79, 704–710. [CrossRef]

169. Zhao, A.; Yin, R.; Zhou, Z.; Gu, G.; Dai, J.; Lai, D.; Zhou, L. Eremophilane-type sesquiterpenoids from the endophytic fungus *Rhizopus oryzae* and their antibacterial, cytotoxic, and phytotoxic activities. *Front. Chem.* 2020, 8, 980. [CrossRef]

170. Wang, A.; Li, P.; Zhang, X.; Han, P.; Lai, D.; Zhou, L. Two new anisic acid derivatives from endophytic fungus *Rhizopus oryzae* Nita22 and their antibacterial activity. *Molecules* 2018, 23, 591. [CrossRef] [PubMed]

171. Lai, D.; Wang, A.; Cao, Y.; Zhou, K.; Mao, Z.; Dong, X.; Tian, J.; Xu, D.; Dai, J.; Peng, Y.; et al. Bioactive dibenzo-α-pyrone derivatives from the endophytic fungus *Rhizopus nigricans* Nita22. *J. Nat. Prod.* 2016, 79, 2022–2031. [CrossRef] [PubMed]

172. Chen, H.Y.; Liu, T.K.; Shi, Q.; Yang, X.L. Sesquiterpenoids and diterpenes with antimicrobial activity from *Leptosphaeria sp.* JL026, an endophytic fungus in *Panicum notatum*. *Toxins* 2019, 11, 104243. [CrossRef]

173. Mao, Z.; Zhang, W.; Wu, C.; Feng, H.; Peng, Y.; Shahid, H.; Cui, Z.; Ding, P.; Shan, T. Diversity and antibacterial activity of fungal endophytes from *Eucalyptus exserta*. *BMC Microbiol.* 2021, 21, 1–12. [CrossRef] [PubMed]

174. Mou, Q.L.; Yang, S.X.; Xiang, T.; Liu, W.W.; Yang, J.; Guo, L.P.; Wang, W.J.; Yang, X.L. New cytotoxic and antibacterial dimer from an endophytic fungus *Cytospora chrysosperma* in *Hippophae rhamnoides* and their antimicrobial activities. *Tetrahedron Lett.* 2021, 87, 153207. [CrossRef]

175. Mao, Z.; Xue, M.; Gu, G.; Wang, W.; Li, D.; Lai, D.; Zhou, L. Lophiostilbomin A-D: New 3,4-dihydroisocoumarin derivatives from the endophytic fungus *Lophiostilbus* sp. Sigfr10. *RSC Adv.* 2020, 10, 6985–6991. [CrossRef]

176. Hussain, H.; Root, N.; Jabeen, F.; Al-Harrasi, A.; Ahmad, M.; Mabood, F.; Hassan, Z.; Shah, A.; Green, I.R.; Schulz, B.; et al. Microsphaerol and seimatorone: Two new compounds isolated from the endophytic fungus, *Microsphaeropsis* sp. and *Seimatosporium* sp. *Chem. Biodivers.* 2015, 12, 289–294. [CrossRef]

177. Harwoko, H.; Lee, J.; Hartmann, R.; Mándi, A.; Kurtán, T.; Müller, W.E.; Feldbrügge, M.; Kalscheuer, R.; Ancheeva, E.; Daletos, G.; et al. Azacoccones FH, new flavipin-derived alkaloids from an endophytic fungus *Epicoccum nigrum* MK214079. *Phytoparasitica* 2020, 446, 104698. [CrossRef]

178. Dzoyem, J.P.; Melong, R.; Tsono, A.T.; Maffo, T.; Kapche, D.G.; Ngadjui, B.T.; McGaw, L.J.; Ellof, J.N. Cytotoxicity, antioxidant and antibacterial activity of four compounds produced by an endophytic fungus *Epicoccum nigrum* associated with *Entada abyssinica*. *Rev. Bras. Farmacogn.* 2017, 27, 251–253. [CrossRef]

179. Xu, Z.L.; Zheng, N.; Cao, S.M.; Li, S.T.; Mo, T.X.; Qin, Y.Y.; Li, J.; Yang, R.Y. Secondary metabolites from the endophytic fungus *Stemphylum lycopersici* and their antimicrobial activities. *Chem. Nat. Compd.* 2020, 56, 1162–1165. [CrossRef]
178. Liu, Y.; Marmann, A.; Abdel-Aziz, M.S.; Wang, C.Y.; Müller, W.E.; Lin, W.H.; Mándi, A.; Kurtán, T.; Daletos, G.; Proksch, P. Tetrahydroxyantherine derivatives from the endophytic fungus Stemonitis globuliferum. Eur. J. Org. Chem. 2015, 2015, 2646–2653. [CrossRef]

179. Mai, P.Y.; Levasseur, M.; Buisson, D.; Touboul, D.; Epavlier, V. Identification of antimicrobial compounds from Sandwirthia guayanas-c-associated endophyte using molecular network approach. Plants 2020, 9, 47. [CrossRef]

180. Ramesha, K.P.; Mohana, N.C.; Nuthan, B.R.; Rakshit, D.; Satis, S. Antimicrobial metabolite profiling of Nigrospora sphaerica from Adiantum philippense. L. J. Genet. Eng. Biotechnol. 2018, 17, 1–9. [CrossRef]

181. Kaaniche, F.; Hamed, A.; Abdel-Razek, A.S.; Wibberg, D.; Abdissa, N.; El Euch, I.Z.; Allouche, N.; Mellouli, L.; Shaaban, M.; Sewald, N. Bioactive secondary metabolites from new endophytic fungus Curvularia sp. isolated from Rauwolfia macrophylla. PLoS ONE 2019, 14, e0217627. [CrossRef]

182. Hilario, F.; Polinário, G.; de Amorim, M.R.; de Sousa Batista, V.; do Nascimento Júnior, N.M.; Araújo, A.R.; Bauab, T.M.; Dos Santos, L.C. Spiroyclic lactams and curvulinic acid derivatives from the endophytic fungus Curvularia lunata and their antibacterial and antifungal activities. Fitoterapia 2020, 141, 104466. [CrossRef]

183. Long, Y.; Tang, T.; Wang, L.Y.; He, B.; Gao, K. Absolute configuration and biological activities of meroterpenoids from an endophytic fungus of Lyceum barbarum. J. Nat. Prod. 2019, 82, 2229–2237. [CrossRef]

184. He, J.; Li, Z.H.; Ai, H.L.; Feng, T.; Liu, J.K. Anti-bacterial chromones from cultures of the endophytic fungus Bipolaris eulesea. Nat. Prod. Res. 2019, 33, 3515–3520. [CrossRef]

185. Huang, H.; Yang, D.S.; Li, G.H.; Pu, X.J.; Mo, M.H.; Zhao, P.J. Antibacterial diketopiperazines from an endophytic fungus Biopectrum sp. Y1085. J. Antibiot. 2019, 72, 752–758. [CrossRef]

186. Yang, Y.H.; Yang, D.S.; Li, G.H.; Pu, X.J.; Mo, M.H.; Zhao, P.J. Antibacterial diketopiperazines from an endophytic fungus Biopectrum sp. Y1085. J. Antibiot. 2019, 72, 752–758. [CrossRef]

187. Kamdem, R.S.; Pascal, W.; Rehberg, N.; van Geelen, L.; Höfert, S.P.; Knedel, T.O.; Janiak, C.; Sureechatchaiyan, P.; Kassack, M.U.; Lin, W.; et al. Metabolites from the endophytic fungus Cylindrocarpon sp. isolated from tropical plant Sapium ellipticum. Fitoterapia 2018, 128, 175–177. [CrossRef]

188. Lin, G.; Kusari, S.; Golz, C.; Laatsch, H.; Strohmann, C.; Spiteller, M. Epigenetic modulation of endophytic Dendrothyrium variisporum potential. J. Nat. Prod. 2018, 81, 983–988. [CrossRef]

189. Pan, Y.; Zheng, W.; Yang, S. Chemical and activity investigation on metabolites produced by an endophytic fungi Psathyrella candolleana from the seed of Ginkgo biloba. Nat. Prod. Res. 2020, 34, 3103–3133. [CrossRef]

190. Peponio, F.; Noumeur, S.R.; Helay, S.E.; Huttel, S.; Harzallah, D.; Stancl, M. Furanones and anthranilic acid derivatives from the endophytic fungus Distylium chinense. ACS Infect. Dis. 2020, 6, 1371–1378. [CrossRef]

191. Pina, J.R.S.; Silva-Silva, J.V.; Carvalho, J.M.; Bitencourt, H.R.; Watanabe, L.A.; Fernandes, J.M.P.; Aguiar, A.C.C.; Teponno, R.B.; Noumeur, S.R.; Helaly, S.E.; Hüttel, S.; Harzallah, D.; Stadler, M. Furanones and anthranilic acid derivatives from the endophytic fungus Distylium chinense. ACS Infect. Dis. 2020, 6, 1371–1378. [CrossRef]

192. Pan, Y.; Zheng, W.; Yang, S. Chemical and activity investigation on metabolites produced by an endophytic fungi Psathyrella candolleana from the seed of Ginkgo biloba. Nat. Prod. Res. 2020, 34, 3103–3133. [CrossRef]

193. Duan, X.X.; Qin, D.; Song, H.C.; Gao, T.C.; Zuo, S.H.; Yan, X.; Wang, J.Q.; Ding, X.; Di, Y.T.; Dong, J.Y. Irpex lacte A-D, four new bioactive metabolites of endophytic fungus Irpex lacteus DR10-1 from the waterlogging tolerant plant Distylidium chinense. Phytochem. Lett. 2019, 32, 151–156. [CrossRef]

194. Rehberg, N.; Akone, H.S.; Ioerger, T.R.; Erlenkamp, G.; Daletos, G.; Gohlke, H.; Proksch, P.; Kalscheuer, R. Chlorflavonin targets acetohydroxyacid synthase catalytic subunit IlvB1 for synergistic killing of Mycoschizus yezoensis. ACS Infect. Dis. 2021, 7, 123–134. [CrossRef] [PubMed]

195. Schulz, S.; Dickshat, J.S. Bacterial volatiles: The smell of small organisms. Nat. Prod. Rep. 2007, 24, 814–842. [CrossRef] [PubMed]

196. Sapium ellipticum. ACS Infect. Dis. 2018, 4, 123–134. [CrossRef] [PubMed]

197. Weisskopf, L.; Schulz, S.; Garbeva, P. Microbial volatile organic compounds in intra-kingdom and inter-kingdom interactions. Nat. Rev. Microbiol. 2021, 19, 391–404. [CrossRef] [PubMed]

198. Chen, J.J.; Feng, X.; Xia, C.Y.; Kong, D.; Qi, Z.Y.; Liu, F.; Chen, D.; Lin, F.; Zhang, C. Confirming the phylogenetic position of the genus Muscodor and the description of a new Muscodor species. Mycosphere 2019, 10, 187–201. [CrossRef]

199. Saxena, S.; Strobel, G.A. Marvellous Muscodor spp.: Update on Their Biology and Applications. Microb. Ecol. 2020, 82, 5–20. [CrossRef]

200. Ezra, D.; Hess, W.; Strobel, G. Unique wild type endophytic isolates of Muscodor albus, a volatile antibiotic producing fungus. Microbiology 2004, 150, 4023–4031. [CrossRef]

201. Attembulo, I.; Castillo, U.; Hess, W.M.; Sears, J.; Strobel, G. Isolation and characterization of M. albus I-41.3 s, a volatile antibiotic producing fungus. Plant Sci. 2010, 169, 854–861. [CrossRef] [PubMed]

202. Mitchell, A.M.; Strobel, G.A.; Moore, E.; Robison, R.; Sears, J. Volatile antimicrobials from Muscodor crispsans, a novel endophytic fungus. Microbiology 2010, 156, 270–277. [CrossRef] [PubMed]
231. Poças-Fonseca, M.J.; Cabral, C.G.; Manfrão-Netto, J.H.C. Epigenetic manipulation of filamentous fungi for biotechnological applications: A systematic review. *Biotechnol. Lett.* **2020**, *42*, 885–904. [CrossRef]

232. Mao, X.M.; Xu, W.; Li, D.; Yin, W.B.; Chooi, Y.H.; Li, Y.Q.; Tang, Y.; Hu, Y. Epigenetic genome mining of an endophytic fungus leads to the pleiotropic bio-synthesis of natural products. *Angew. Chem. Int. Ed.* **2015**, *54*, 7592–7596. [CrossRef]

233. Strauss, J.; Reyes-Dominguez, Y. Regulation of secondary metabolism by chromatin structure and epigenetic codes. *Fungal Genet. Biol.* **2011**, *48*, 62–69. [CrossRef]

234. Gacek, A.; Strauss, J. The chromatin code of fungal secondary metabolite gene clusters. *Appl. Microbiol. Biotechnol.* **2012**, *95*, 1389–1404. [CrossRef]

235. Aghcheh, R.K.; Kubicek, C.P. Epigenetics as an emerging tool for improvement of fungal strains used in biotechnology. *Appl. Microbiol. Biotechnol.* **2015**, *99*, 6167–6181. [CrossRef]

236. Li, C.Y.; Chung, Y.M.; Wu, Y.C.; Hunyadi, A.; Wang, C.C.; Chang, F.R. Natural products development under epigenetic modulation in fungi. *Phytochem. Rev.* **2020**, *19*, 1323–1340. [CrossRef]

237. Kim, J.H.; Lee, N.; Hwang, S.; Kim, W.; Lee, Y.; Cho, S.; Palsson, B.O.; Cho, B.K. Discovery of novel secondary metabolites encoded in actinomyete genomes through coculture. *J. Ind. Microbiol. Biotechnol.* **2021**, *48*, kuaa001. [CrossRef]

238. Tomm, H.A.; Ucciferri, L.; Ross, A.C. Advances in microbial culturing conditions to activate silent biosynthetic gene clusters for novel metabolite production. *J. Ind. Microbiol. Biotechnol.* **2019**, *46*, 1381–1400. [CrossRef]

239. Gonciarz, J.; Bizukojc, M. Adding talc microparticles to *Aspergillus terreus* ATCC 20542 preculture decreases fungal pellet size and improves lovastatin production. *Eng. Life Sci.* **2014**, *14*, 190–200. [CrossRef]

240. Timmermans, M.L.; Picott, K.J.; Ucciferri, L.; Ross, A.C. Culturing marine bacteria from the genus Pseudoalteromonas on a cotton scaffold alters secondary metabolite production. *Microbiologyopen* **2019**, *8*, e00724. [CrossRef]

241. Boruta, T.; Bizukojc, M. Application of aluminum oxide nanoparticles in *Aspergillus terreus* cultivations: Evaluating the effects on lovastatin production and fungal morphology. *Biomed. Res. Int.* **2019**, *2019*, 1–11. [CrossRef]

242. Bode, H.B.; Bethe, B.; Hof, R.; Zeeck, A. Big effects from small changes: Possible ways to explore nature’s chemical diversity. *Chembiochemistry* **2002**, *3*, 619–627. [CrossRef]

243. Scherlach, K.; Hertweck, C. Discovery of aspoquinolones A–D, prenylated quinoline-2-one alkaloids from *Aspergillus nidulans*, motivated by genome mining. *Org. Biomol. Chem.* **2006**, *4*, 3517–3520. [CrossRef]

244. Scherlach, K.; Schuemann, J.; Dahlse, H.M.; Hertweck, C. Aspernidine A and B, prenylated isoindolobrane alkaloids from the model fungus *Aspergillus nidulans*. *J. Antibiot.* **2010**, *63*, 375–377. [CrossRef]