Review

Structural Diversity and Biological Activities of Cyclic Depsipeptides from Fungi

Xiaohan Wang, Xiao Gong, Peng Li, Daowan Lai and Ligang Zhou *

Department of Plant Pathology, College of Plant Protection, China Agricultural University, Beijing 100193, China; wangxiaohan99@126.com (X.W.); gongxiao1994@163.com (X.G.); ytmuyue1989@163.com (P.L.); dwlai@cau.edu.cn (D.L.)

* Correspondence: lgzhou@cau.edu.cn; Tel.: +86-10-6273-1199

Received: 29 November 2017; Accepted: 10 January 2018; Published: 15 January 2018

Abstract: Cyclic depsipeptides (CDPs) are cyclopeptides in which amide groups are replaced by corresponding lactone bonds due to the presence of a hydroxylated carboxylic acid in the peptide structure. These peptides sometimes display additional chemical modifications, including unusual amino acid residues in their structures. This review highlights the occurrence, structures and biological activities of the fungal CDPs reported until October 2017. About 352 fungal CDPs belonging to the groups of cyclic tri-, tetra-, penta-, hexa-, hepta-, octa-, nona-, deca-, and tridecadepsipeptides have been isolated from fungi. These metabolites are mainly reported from the genera Acremonium, Alternaria, Aspergillus, Beauveria, Fusarium, Isaria, Metarhizium, Penicillium, and Rosellina. They are known to exhibit various biological activities such as cytotoxic, phytotoxic, antimicrobial, antiviral, anthelmintic, insecticidal, antimalarial, antitumoral and enzyme-inhibitory activities. Some CDPs (i.e., PF1022A, enniatins and destruxins) have been applied as pharmaceuticals and agrochemicals.

Keywords: cyclodepsipeptides; fungi; biological activities; occurrence; applications

1. Introduction

Cyclic depsipeptides (CDPs), also known as cyclodepsipeptides or peptolides, are cyclooligomers in which one or more amino acid is replaced by a hydroxylated carboxylic acid, resulting in the formation of at least one lactone bond in the core ring. They are biosynthesized by non-ribosomal peptide synthetases (NRPS) in combination with either polyketide synthase (PKS) or fatty acid (FA) synthase enzyme systems [1–3]. CDPs are widely distributed in bacteria [4], fungi [1], plants [5,6], algae [7], sponges [8], and other marine organisms [9–13]. Here, we focus on fungal CDPs which include cyclic tri-, tetra-, penta-, hexa-, hepta-, octa-, nona-, deca-, and tridecadepsipeptides though fungi can produce large amounts of cyclic peptides without any lactone bond in the core ring [14,15]. Some fungal CDPs such as beauvericins, destruxins, enniatins have been well characterized [16–19]. Special reviews covering chemical synthesis [16], biosynthesis [20], chemical classification [3], as well as applications [21,22] of fungal CDPs are also available. In this review, we describe the occurrence, biological activities, and structures of all hitherto reported fungal CDPs to assess which of them merit further study for purposes of drug development as well as for clarification of their physiological and ecological functions. We still classify fungal CDPs based on the total amounts of amino and hydroxylated carboxylic acids though a review about the classification of CDPs based on the hydroxylated carboxylic acid(s) involved in the ring lacone has just been published [3].

2. Cyclic Tridepsipeptides

Cyclic tridepsipeptides usually contain two amino acids and one hydroxylated carboxylic acid. They were found in the genera Acremonium, Calcarisporium, Fusarium, Phonopsis and Ramalina.

Molecules 2018, 23, 169; doi:10.3390/molecules23010169 www.mdpi.com/journal/molecules
The occurrence and biological activities of fungal cyclic tridepsipeptides are listed in Table 1, and their structures are shown in Figure 1.

Ten cyclic tridepsipeptides have been isolated from fungi so far. Acremolides A–D (1–4) were isolated from an Australian marine-derived *Acremonium* sp. MST-MF588a obtained from a sediment sample [23]. Calcaripeptides A (5), B (6), and C (7) were identified from *Calcarisporium* sp. strain KF525, which was isolated from German Wadden Sea [24]. HA23 (8), a cyclic tridepsipeptide of mixed peptide-polyketide origins, was isolated from *Fusarium* sp. CANU-HA23 [25].

PM181110 (9) was identified from the endophytic fungus *Phomopsis glabrae* isolated from the leaves of *Pongamia pinnata*, and exhibited anticancer activity against 40 human cancer cell lines with a mean IC$_{50}$ value of 0.089 µM. The structure of this compound has a disulfide ring, which possibly contributed to the biological activity [26].

Stereocalpin A (10) was isolated from the endophytic fungus *Ramalina terebrata* associated with the Antarctic lichen *Stereocaulon alpinum*. This CDP is unique in that its structure contains a 5-hydroxy-2,4-dimethyl-3-oxo-octanoic acid. It showed moderate cytotoxic activity against three human solid tumor cell lines (i.e., colon carcinoma cell line HT-29, skin carcinoma cell line B16/F10, and liver carcinoma cell line HepG2), and weak inhibitory activity against protein tyrosine phosphatase 1B (PTP1B) [27]. Further investigation of the mechanism showed that stereocalpin A (10) inhibited the expression of adhesion molecules in activated muscle cells. These results suggest that this compound has the potential to exert a protective effect by modulating inflammation within the atherosclerotic lesion [28].

### Table 1. Fungal cyclic tridepsipeptides and their biological activities.

| Name               | Fungus and Its Origin                                                                 | Biological Activity | References |
|--------------------|---------------------------------------------------------------------------------------|---------------------|------------|
| Acremolide A (1)   | Marine-derived fungus *Acremonium* sp. MST-MF588a from an estuarine sediment sample  | -                   | [23]       |
| Acremolide B (2)   | Marine-derived fungus *Acremonium* sp. MST-MF588a from an estuarine sediment sample  | -                   | [23]       |
| Acremolide C (3)   | Marine-derived fungus *Acremonium* sp. MST-MF588a from an estuarine sediment sample  | -                   | [23]       |
| Acremolide D (4)   | Marine-derived fungus *Acremonium* sp. MST-MF588a from an estuarine sediment sample  | -                   | [23]       |
| Calcaripeptide A (5)| Marine-derived fungus *Calcarisporium* sp. KF525 from a water sample collected in the German Wadden Sea | -                   | [24]       |
| Calcaripeptide B (6)| Marine-derived fungus *Calcarisporium* sp. KF525 from a water sample collected in the German Wadden Sea | -                   | [24]       |
| Calcaripeptide C (7)| Marine-derived fungus *Calcarisporium* sp. KF525 from a water sample collected in the German Wadden Sea | -                   | [24]       |
| HA 23 (8)          | *Fusarium* sp. CANU-HA23                                                              | -                   | [25]       |
| PM181110 (9)       | Endophytic fungus *Phomopsis glabrae* from the leaves of *Pongamia pinnata*           | Cytotoxic activity  | [26]       |
| Stereocalpin A (10)| Endophytic fungus *Ramalina terebrata* from the Antarctic lichen *Stereocaulon alpinum* | Cytotoxic activity  | [27]       |
Aspergillus clavatus C2WU. The fungus was isolated from the crab *Alternaria alternata* apple pathotype [32–34]. They showed moderate antifungal activity against the plant pathogenic fungi in greenhouse tests and human fungal pathogens in vitro. Microscopic examination of treated fungi suggested that the compounds displayed inhibition on cell wall biosynthesis [31].

AM-toxins I (14), II (15) and III (16), which were host-specific phytotoxins, were isolated from *Alternaria alternata* apple pathotype [32–34].

Aspergillipeptides A (18), B (19), and C (20) were obtained from *Aspergillus* sp. SCSGAF 41501 from China South Sea gorgonian *Melitodes squamata*. Aspergillipeptide C (20) showed strong antifouling activity against *Bugula neritina* larvae settlement [35].

Beauveriolides I-VIII (21–28) were isolated from *Beauveria* sp. [36–38]. Among them, beauveriolide I (21) displayed insecticidal activity on *Spodoptera litura* and *Callosobruchus chinensis* [36]. Beauveriolide III (23) selectively inhibited steroid O-acyltransferase 1 (SOAT1) in a cell-based assay [39].

Clavatustides A (49) and B (50) were identified from the cultured mycelia and broth of *Aspergillus clavatus* C2WU. The fungus was isolated from the crab *Xenograpsus testudinatus*, which lived at extreme, toxic habitat around the sulphur-rich hydrothermal vents in Taiwan Kueishantao. Both compounds suppressed the proliferation of hepatocellular carcinoma (HCC) cell lines (HepG2, SMMC-7721 and Bel-7402), and induced an accumulation of HepG2 cells in G1 phase and reduction of cells in S phase [40]. CCNE2 (cyclin E2) was proved to be the key regulator of clavatustide B-induced G1-S transition blocking in several cancer cell lines by using real-time PCR [41].

Fusaristatins A (51) and B (52) were identified in the endophytic fungus *Fusarium* sp. YG-45. Both compounds showed a moderate inhibitory effect on topoisomerases I and II. They also showed the growth-inhibitory activity toward lung cancer cells LU 65 [42]. Fusaristatin A (51) also displayed an inhibitory effect on the fungus *Glomerella acutata* [43].

A series of stevastelins were obtained from *Penicillium* sp. NK374186 which was isolated from the soil collected in Niigata of Japan [44–46]. They inhibited interleukin-2 or interleukin-6 dependent gene expression but did not inhibit the phosphatase activity of calcineurin. Stevastelins were considered as the potential immunosuppressants [47].

### 3. Cyclic Tetradepsipeptides

Forty nine cyclic tetradepsipeptides have been isolated from fungi so far. They have been found mainly in the genera *Alternaria*, *Aspergillus*, *Beauveria*, *Fusarium*, *Hypoxylon*, and *Penicillium*. Their occurrences in fungi, and biological activities are listed in Table 2, and the structures are provided in Figure 2.

15G256y (11), δ (12) and ε (13) were isolated from the marine fungus *Hypoxylon oceanicum* (LL-15G256) [29,30]. They showed moderate antifungal activity against the plant pathogenic fungi in greenhouse tests and human fungal pathogens in vitro. Microscopic examination of treated fungi suggested that the compounds displayed inhibition on cell wall biosynthesis [31].

AM-toxins I (14), II (15) and III (16), which were host-specific phytotoxins, were isolated from *Alternaria alternata* apple pathotype [32–34].

Aspergillipeptides A (18), B (19), and C (20) were obtained from *Aspergillus* sp. SCSGAF 41501 from China South Sea gorgonian *Melitodes squamata*. Aspergillipeptide C (20) showed strong antifouling activity against *Bugula neritina* larvae settlement [35].

Beauveriolides I-VIII (21–28) were isolated from *Beauveria* sp. [36–38]. Among them, beauveriolide I (21) displayed insecticidal activity on *Spodoptera litura* and *Callosobruchus chinensis* [36]. Beauveriolide III (23) selectively inhibited steroid O-acyltransferase 1 (SOAT1) in a cell-based assay [39].

Clavatustides A (49) and B (50) were identified from the cultured mycelia and broth of *Aspergillus clavatus* C2WU. The fungus was isolated from the crab *Xenograpsus testudinatus*, which lived at extreme, toxic habitat around the sulphur-rich hydrothermal vents in Taiwan Kueishantao. Both compounds suppressed the proliferation of hepatocellular carcinoma (HCC) cell lines (HepG2, SMMC-7721 and Bel-7402), and induced an accumulation of HepG2 cells in G1 phase and reduction of cells in S phase [40]. CCNE2 (cyclin E2) was proved to be the key regulator of clavatustide B-induced G1-S transition blocking in several cancer cell lines by using real-time PCR [41].

Fusaristatins A (51) and B (52) were identified in the endophytic fungus *Fusarium* sp. YG-45. Both compounds showed a moderate inhibitory effect on topoisomerases I and II. They also showed the growth-inhibitory activity toward lung cancer cells LU 65 [42]. Fusaristatin A (51) also displayed an inhibitory effect on the fungus *Glomerella acutata* [43].

A series of stevastelins were obtained from *Penicillium* sp. NK374186 which was isolated from the soil collected in Niigata of Japan [44–46]. They inhibited interleukin-2 or interleukin-6 dependent gene expression but did not inhibit the phosphatase activity of calcineurin. Stevastelins were considered as the potential immunosuppressants [47].
Table 2. Fungal cyclic tetradepsipeptides and their biological activities.

| Name                      | Fungus and Its Origin                                                                 | Biological Activity                                      | References                              |
|---------------------------|--------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------|
| 15G256γ (11)              | Hypoxylon oceanicum LL-15G256                                                        | Antifungal activity                                      | [29,30]                                 |
| 15G256δ (12)              | Hypoxylon oceanicum LL-15G256                                                        | Antifungal activity                                      | [29,30]                                 |
| 15G256ε (13)              | Hypoxylon oceanicum LL-15G256                                                        | Antifungal activity                                      | [29,30]                                 |
| AM-toxin I (14)            | Alternaria mali                                                                       | Phytotoxic activity                                      | [32,34]                                 |
| AM-toxin II (15)           | Alternaria mali                                                                       | Phytotoxic activity                                      | [33,34]                                 |
| AM-toxin III (16)          | Alternaria mali                                                                       | Phytotoxic activity                                      | [32–34]                                 |
| Angolide (17)              | Pithomyces sp. IMM 101184                                                             | -                                                       | [48]                                    |
| Aspergilipeptide A (18)    | Aspergillus sp. SCSGAF 0076 from China South Sea gorgonian Melitodes squamata        | -                                                       | [35]                                    |
| Aspergilipeptide B (19)    | Aspergillus sp. SCSGAF 0076 from China South Sea gorgonian Melitodes squamata        | -                                                       | [35]                                    |
| Aspergilipeptide C (20)    | Aspergillus sp. SCSGAF 0076 from China South Sea gorgonian Melitodes squamata        | Antifouling activity against Bugula neritina larvae settlement | [35]                                    |
| Beauveriolide I (21)       | Beauveria sp.                                                                         | Insecticidal activity on Spodoptera litura and Callosobruchus Chinensis | [36]                                    |
| Beauveriolide II (22)      | Beauveria sp.                                                                         | -                                                       | [36]                                    |
| Beauveriolide III (23)     | Beauveria sp. FO-6979                                                                | -                                                       | [37]                                    |
| Beauveriolide IV (24)      | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauveriolide V (25)       | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauveriolide VI (26)      | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauveriolide VII (27)     | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauveriolide VIII (28)    | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauverolonelide A (29)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide B (30)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide Ra =      | Beauveria bassana                                                                    | -                                                       | [50]                                    |
| Beauverolonelide A (31)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Anti-aging activity; Insecticidal activity              | [51,52]                                 |
| Beauverolonelide C (32)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide Ca (33)   | Beauveria bassana                                                                    | -                                                       | [50]                                    |
| Beauverolonelide D (34)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide E (35)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide Ea (36)   | Beauveria bassana                                                                    | -                                                       | [49]                                    |
| Beauverolonelide F (37)    | Entomopathogenic fungus Beauveria bassana from a pupa of the Gum Emperor moth Antheraea eucalpti | Insecticidal activity                                  | [49]                                    |
| Beauverolonelide Fa =      | Beauveria bassana                                                                    | -                                                       | [49]                                    |
| Beauverolonelide IX (38)   | Beauveria sp. FO-6979                                                                | -                                                       | [38]                                    |
| Beauverolonelide H (39)    | Beauveria bassana                                                                    | -                                                       | [53]                                    |
| Beauverolonelide I (40)    | Beauveria bassana                                                                    | -                                                       | [53]                                    |
| Beauverolonelide J (41)    | Beauveria bassana                                                                    | -                                                       | [50]                                    |
| Name              | Fungus and Its Origin                                           | Biological Activity                          | References |
|-------------------|-----------------------------------------------------------------|----------------------------------------------|------------|
| Beauverolide Ka   | Beauveria bassiana - [50]                                      | -                                            |            |
| Beauverolide L    | Beauveria tenella and Paecilomyces fumosoroseus - [54]         | -                                            |            |
| Beauverolide M    | Beauveria tenella and Paecilomyces fumosoroseus - [54]         | -                                            |            |
| Beauverolide N    | Beauveria bassiana - [55]                                      | -                                            |            |
| Beauverolide P    | Beauveria bassiana - [55]                                      | -                                            |            |
| Chaetomiamide A   | Endophytic fungus Chaetomium sp. from the roots of Cymbidium goeringii - [56] | -                                            |            |
| Clavatustide A    | Aspergillus clavatus Cytotoxic activity [40]                  | -                                            |            |
| Clavatustide B    | Aspergillus clavatus Cytotoxic activity [40,41]                | -                                            |            |
| Fusaristatin A    | Endophytic fungus Fusarium sp. YG-45 Cytotoxic activity [42]   | -                                            |            |
| Fusaristatin B    | Endophytic fungus Fusarium sp. YG-45 Weak activity against toposomerases I and II; Cytotoxic activity [42] | -                                            |            |
| Stevastelin A     | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [44–46] | -                                            |            |
| Stevastelin A2    | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [46] | -                                            |            |
| Stevastelin B     | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [44,45,57] | -                                            |            |
| Stevastelin B3    | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [44,45] | -                                            |            |
| Stevastelin C3    | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [44] | -                                            |            |
| Stevastelin D3    | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [46] | -                                            |            |
| Stevastelin E3    | Penicillium sp. NK374186 from the soil collected in Niigata of Japan Immunosuppressant by inhibiting dual-specificity protein phosphatase [46] | -                                            |            |

Figure 2. Cont.
Cyclic Pentadepsipeptides

Penicillium brasilianum, a Floridian marine sediment-derived fungus, was found to induce adipocyte differentiation and mRNA expression of adiponectin in murine ST-3 preadipocyte cells.

Cyclic pentadepsipeptides have been isolated from the genera Penicillium, Aspergillus, and Microascus. For example, Beauveriolide I (21) illustrated significant cytotoxic activity against SF-268 and RXF 393 cell lines.

Structures of the cyclic tetradepsipeptides isolated from fungi are provided in Figure 3.

Figure 2. Structures of the cyclic tetradepsipeptides isolated from fungi.
4. Cyclic Pentadepsipeptides

Cyclic pentadepsipeptides have been isolated from the genera *Acremonium, Alternaria, Fusarium, Hapsidospora,* and *Penicillium.* Their occurrences and biological activities are listed in Table 3, and their structures are provided in Figure 3.

Alternaramide (60) was identified in the marine-derived fungus *Alternaria* sp. SF-5016, and showed weak antibiotic activity on *Bacillus subtilis* and *Staphylococcus aureus* [58]. This compound also had inhibitory effects on inflammatory mediator expression through TLR4-MyD88-mediated inhibition of NF-κB and MAPK pathway signaling in lipopolysaccharide-stimulated RAW264.7 and BV2 cells [59].

Aselacins A (61), B (62) and C (63) were obtained in *Acremonium* spp. from the soil samples collected in Asela (Ethiopia). They had inhibitory activity on the binding of endothelin to its receptor. Among them, aselacin A (61) inhibited binding to receptors in both atrial and cerebral membranes with IC\textsubscript{50} values of 20 µg/mL, approximately [60,61].

By means of epigenetic manipulation of the fungal metabolome, EGM-556 (66) was identified by addition of histone deacetylase inhibitor suberoylanilide hydroxamic acid into the culture of the Floridian marine sediment-derived fungus *Microascus* sp. [62].

Hikiamides A (67), B (68) and C (69) were obtained from *Fusarium* sp. TAMA 456 from a rotten wood sample collected in Hiki county of Japan, and induced adipocyte differentiation and mRNA expression of adiponectin in murine ST-3 preadipocyte cells [63].

JBIR-113 (70), JBIR-114 (71), and JBIR-115 (72) were identified in the marine-derived *Penicillium* sp. fS36 from an unidentified sponge collected near Takarajima Island of Japan [64]. Copper and manganese cations induced production of JBIR-113 (70), JBIR-114 (71), and JBIR-115 (72) in the endophytic fungus *Penicillium brasiliannum* from *Melia azedarach.* JBIR-113 (70) exhibited weak antiparasitary activity against *Leishmania amazonensis* [65].

Leualacin (73) was first isolated from *Hapsidospora irregularis.* This compound inhibited the binding of H-nitrendipine to porcine heart membranes in vitro and lowered the blood pressure of spontaneous hypertensive rats to show its potential application as the calcium channel blocker for treatment of hypertension, angina, myocardial infarction, and arrhythmia [66,67]. Afterwards, six other analogues, leualacins B–G (74–79) were obtained from this fungal species. Leualacin F (78) elicited the calcium influx in primary human lobar bronchial epithelial cells involving the TRPA1 channel [68].

Phomalide (85) was isolated from the pathogen *Phoma lingam* (teleomorph: *Leptosphaeria maculans*) of the blackleg disease of brassica crops. This compound showed host-selective phytotoxicity [69,70].

Sansalvamide A (87) was isolated from a marine fungus *Fusarium* sp. [71]. This compound possessed marked antitumor activity against 60 cancer cell lines such as human prostate cancer PC3, human breast cancer MDA-MB-231, and human melanoma WM-115 by inhibiting topoisomerase I [72]. N-Methylation of sansalvamide A (87) enhanced its antitumor potency and selectivity [73]. Its derivative H-10 exhibited antiproliferative effects against murine melanoma B16 cells and induced cell apoptosis [74]. Zygosporamide (88) was isolated from the marine-derived fungus *Zygosporium masonii.* This compound illustrated significant cytotoxic activity against SF-268 and RXF 393 cell lines [75].
Table 3. Fungal cyclic pentadepsipeptides and their biological activities.

| Name | Fungus and Its Origin | Biological Activity | References |
|------|------------------------|----------------------|------------|
| Alternaramide (60) | Marine-derived Alternaria sp. SF-5016 | Weak antibiotic activity | [58] |
| - | - | Anti-inflammatory activity | [59] |
| Aselacin A (61) | Acremonium sp. | Inhibitory activity on binding of endothelin to its receptor | [60,61] |
| Aselacin B (62) | Acremonium sp. | Inhibitory activity on binding of endothelin to its receptor | [60,61] |
| Aselacin C (63) | Acremonium sp. | Inhibitory activity on binding of endothelin to its receptor | [60,61] |
| Brevigellin (64) | Penicillium brevicompactum | - | [76] |
| Colisporifungin (65) | Colispora carincola | Antifungal activity | [77] |
| EGM-556 (66) | Microascus sp. | Histone deacetylase inhibitor | [62] |
| Hikiamide A (67) | Fusarium sp. TAMA 456 from a rotten wood sample | Induction of adipocyte differentiation and mRNA expression | [63] |
| Hikiamide B (68) | Fusarium sp. TAMA 456 from a rotten wood sample | Induction of adipocyte differentiation and mRNA expression | [63] |
| Hikiamide C (69) | Fusarium sp. TAMA 456 from a rotten wood sample | Induction of adipocyte differentiation and mRNA expression | [63] |
| JBR-113 (70) | Sponge-derived Penicillium sp. fS36 | - | [64] |
| JBR-114 (71) | Sponge-derived Penicillium sp. fS36 | Endophytic fungus Penicillium brevicompactum | Weak antiparasitic activity | [65] |
| JBR-115 (72) | Sponge-derived Penicillium brasilianum | - | [64] |
| Leualacin (73) | Hapsidospora irregularis | Calcium channel blocker | [66,67] |
| Leualacin B (74) | Hapsidospora irregularis | - | [68] |
| Leualacin C (75) | Hapsidospora irregularis | - | [68] |
| Leualacin D (76) | Hapsidospora irregularis | - | [68] |
| Leualacin E (77) | Hapsidospora irregularis | - | [68] |
| Leualacin F (78) | Hapsidospora irregularis | Elicitation of calcium influx | [68] |
| Leualacin G (79) | Hapsidospora irregularis | - | [68] |
| MBJ-0110 (80) | Penicillium sp. f25267 | - | [78] |
| Neo-\textit{N}-methylsansalvamide A (81) | Fusarium solani KCCM90040 | Cytotoxic activity | [79] |
| \textit{N}-methylsansalvamide (82) | Marine-derived fungus Fusarium sp. CNL-619 | Cytotoxic activity | [80] |
| Petrosifungin A (83) | Marine-derived Penicillium brevicompactum | - | [81] |
| Petrosifungin B (84) | Marine-derived Penicillium brevicompactum | - | [81] |
| Phomalide (85) | Phoma lingam | Phytotoxic activity | [70] |
| Pithomycolide (86) | Pithomyces chatatum | - | [82] |
| Sansalvamide A (87) | Marine-derived fungus Fusarium sp. | Cytotoxic, topoisomerase I inhibitory, and antitumor activities | [71,72] |
| Zygosphoramid (88) | Marine-derived fungus Zygosphorium masonii | Cytotoxic activity against SF-268 and RXF 393 cell lines | [75] |
Figure 3. Cont.
Figure 3. Structures of the cyclic pentadepsipeptides isolated from fungi.
5. Cyclic Hexadepsipeptides

Cyclic hexadepsipeptides are mainly distributed in the genera *Acremonium, Aspergillus, Beauveria, Cordyceps, Fusarium, Isaria, Nigrospora, Paecilomyces,* and *Verticillium.* They represent the largest class of CDPs found in fungi. Most of cyclic hexadepsipeptides belong to mycotoxins. Their occurrences and biological activities are shown in Table 4, and their structures are provided in Figure 4. The main groups of cyclic hexadepsipeptides include beauvenniatins, beauvericins, destruxyins, enniatins, isariins and isaridins which have been well reviewed, respectively [16–19].

Six aspergillicins analogs 94–99 were isolated from *Aspergillus* sp. [83,84]. Among them, aspergillicin F (99) showed innate immune-modulating activity [84].

Beauvenniatins A–E (100–104), and beauvericin J (125) from *Acremonium* sp. BCC 28424 showed antimalaria on *Plasmodium falciparum* K1, antituberculosis on *Mycobacterium tuberculosis* H37Ra, and cytotoxic activities on cancer cell lines (KB, MCF-7, and NCI-H187) and Vero cells. Beauvenniatins C (102), D (103), E (104), and beauvericin J (125), containing an N-Me-L-Tyr residue, showed weaker activity [85].

Beauvenniatin F (105) was isolated from an entomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet, and exhibited strong cytotoxicity against K562/A (adriamycin-resistant K562) cells with IC50 value of 3.78 µM, and autophagy-inducing activity at the concentration of 20 µM in GFP-LC3 stable HeLa cells [86]. Beauvenniatins F (105), G1 (106), G2 (107), G3 (108), H1 (109), H2 (110), and H3 (111) from the fungus *Acremonium* sp. BCC 2629 exhibited antibacterial activity against *Mycobacterium tuberculosis* H37Ra with MIC values in the range of 1.07–4.45 µM, and proliferation inhibitions against the human malaria parasite (*Plasmodium falciparum* K1) with IC50 values in the range of 3.6–3.9 µM. They also displayed cytotoxic activity toward cancer cell-lines (KB, BC, NCI-H187 cell-lines) with IC50 values ranging from 1.00 to 2.29 µM, as well as Vero cells with IC50 values in the range of 1.9–5.5 µM [87].

Beauvericins and allobeauvericins are a class of cyclohexadepsipeptides with core structures made of three N-methyl-L-phenylalanine units connected alternately with three 2-hydroxy-d-isovaleric acid residues. They were first isolated from the culture of the insect-pathogenic fungus *Beauverina bassiana* [88]. They consisted of alternating 2-hydroxy-3-methylbutanoic acid and amino acid units. The three amino acid residues are aromatic N-methyl-L-phenylalanines. Beauvericin (BEA, 112) was found in many entomopathogenic fungi such as *Beauveria bassiana, Isaria tenuipes* (formerly *Paecilomyces tenuipes*), *Isaria fumosorosea* (formerly *Paecilomyces fumosoroseus*), *Cordyceps cicadae,* all of these species are members of family Cordycipitaceae. *BEA* (112) has also been isolated from many *Fusarium* species (i.e., *F. acuminatum, F. acutatum, F. anthophilum, F.avenaceum, F. beoniforme, F. circinatum, F. concentricum, F. dlamini, F. equiseti, F. fujikuroi, F. globosum, F. guttiforme, F. konzum, F. langsethiae, F. longipes, F. nygamai, F. oxysprum, F. poae, F. proliferatum, F. pseudoanthonophilum, F. sambucinum, F. semitectum, F. sporotrichioides, F. subglutinans, F. tricinctum, and F. verticilloides*). BEA was suggested as a chemotaxonomic marker of the fungi in genus *Fusarium* [17] and family Cordycipitaceae [89].

Destruxins are mainly isolated from the entomopathogenic fungus *Metarhizium anisopliae.* More than 35 destruxin analogs have been identified in this fungus [19]. Destruxin A (141) can induce and bind heat shock proteins (HSPs) in *Bombyx mori* Bm12 cells [90]. Most of destruxins exhibit insecticidal and phytotoxic activities. Other biological activities include antimicrobial, antitrypanosomal, cytotoxic, immunosuppressant, antiproliferative and antiviral activities. Destruxins act as V-ATPase inhibitors and provide a basis for the development of new drugs to against osteoporosis, cancer, or as the biological control agents [16,19]. Destruxins cause an initial tetanic paralysis, which is attributed to muscle depolarization by direct opening of Ca2+ channels in the membrane [16]. They can act as V-ATPase inhibitors, and modulate the antiapoptotic function of Bcl-xL through their inherent ability to inhibit the V-ATPase activity as a result of a caspase-independent pathway [19].

Enniatins have been isolated largely from *Fusarium* species, although they were isolated from other fungal genera, such as *Verticillium* and *Halosarphoea* [18]. About 30 enniatins have been isolated and characterized, either as a single compound or mixtures of inseparable homologs. Structurally,
these depsipeptides are biosynthesized by a multifunctional enzyme, termed enniatin synthetase, and composed of six residues that alternate between N-methyl amino acids and hydroxylated carboxylic acids [18].

Enniatins A (177), A₁ (178), B (180), B₁ (181), D (184), E₁ (186), E₂ (187) and F (188) were isolated from the culture broth of Fusarium sp. FO-1305 [91]. In an enzyme assay using rat liver microsomes, they were found to inhibit acyl-CoA:cholesterol acyltransferase (ACAT) activity with IC₅₀ values of 22 to 110 µM [92]. Enniatins A₁ (178) and B₁ (181) were found to induce apoptotic cell death and disrupt extracellular-regulated protein kinase, a mitogen-activated protein kinase associated with cell proliferation. They incorporate easily into the cell membrane as a passive channel and form action selective pores. By forming complexes with cations like K⁺, Na⁺ and Ca²⁺, enniatins evoke changes in intracellular ion concentration, disrupting cell function [18].

Enniatins H (190), I (191), and MK1688 (199), and beauvericin (112) were purified from Fusarium oxysporum KFCC 11363. Enniatins I (191) and MK1688 (199) inhibited the growth of cancer cell lines most strongly and had similar cytotoxic effects on the tested human cancer cell cultures [93].

Hirsutellide A (218), isolated from the entomopathogenic fungus Hirsutella kobayasi, showed antimiycobacterial activity (IC₅₀, 6–12 µg/mL) and antimalarial activity (IC₅₀, 2.8 µg/mL) on Plasmodium falciparum [94].

Isarfelins A (225/226) and B (228) were isolated from the mycelia of Isaria felina. They were later identified as isarridins Cl (225)/C2 (226) and E (228), respectively, and exhibited antifungal activity on Rhizoctonia solani and Sclerotinia sclerotiorum, and insecticidal activity on Leucania separata [95].

Isoisarriin B (240) was isolated from the entomopathogenic fungus Beauveria felina. This compound was active against the pest-insect Sitophilus spp. with an LD₅₀ value of 10 µg/mL [96]. Other isarriin analogs including isariins A (231), B (232), C (233), C₂ (234), D (235), E (236), F₂ (237), G₁ (238), G₂ (239), and isoisarriin D (241) were identified in the fungus Beauveria felina [96–99].

Nodupeptide (242) was isolated from the gut of the insect Riptortus pedestris. This compound displayed insecticidal activity against rice brown planthopper (Nilaparvata lugens) with an LD₅₀ value of 70 ng/larva, and inhibitory activity towards the drug-resistant human pathogenic bacterium Pseudomonas aeruginosa with the MIC value (5.0 µM) comparable to that (3.2 µM) of the positive control ciprofloxacin [100].

Paecilodepsipeptide A (also namely gliotide, 248) was first obtained from the marine-derived fungus Gliocladium sp. from the alga Durvillaea antarctica [101], and later isolated from the insect pathogenic fungus Paecilomyces cinnamomeus BCC 9616 [102]. This compound exhibited antimalarial activity on Plasmodium falciparum K1 and cytotoxic activity on KB and BC cell lines [102].

Pseudodestruxins A (249) and B (250) were obtained from the coprophilous fungus Nigrosabulum globosum isolated from sheep dung. Both had antibacterial activity on Bacillus subtilis and Staphylococcus aureus [103].

Roseotoxin B (259) from Trichothecium roseum improved allergic contact dermatitis through a unique anti-inflammatory mechanism involving excessive activation of autophagy in activated T lymphocytes [104].

Trichodespsipeptides A (272) and B (273), and guangomide A (214) were isolated from the filamentous fungus Trichothecium sp. (MSX 51320) [105]. Guangomide A (214) showed weak antibacterial activity on Staphylococcus epidermidis and Enterococcus durans [106].

Trichomides A (274) and B (275) were isolated from Trichothecium roseum. Trichomide A (274) decreased the expression of Bcl-2 and increased that of Bax, with mild or negligible effects on the levels of p-Akt, CD25, and CD69. It provided valuable information for lead structure optimization of the novel immunosuppressant [107].
### Table 4. Fungal cyclic hexadepsipeptides and their biological activities.

| Name                  | Fungus and Its Origin                          | Biological Activity                                                                 | References         |
|-----------------------|------------------------------------------------|--------------------------------------------------------------------------------------|--------------------|
| 1962A (89)            | Unidentified fungus from *Kandelia candel* leaf | Weak activity against human breast cancer MCF-7 cells                                | [108]              |
| 1962B (90)            | Unidentified fungus from *Kandelia candel* leaf | -                                                                                    | [108]              |
| Allebeauvericin A (91)| *Paecilomyces tenuipes* BCC 1614               | -                                                                                    | [109]              |
| Allebeauvericin B (92)| *Paecilomyces tenuipes* BCC 1614               | -                                                                                    | [109]              |
| Allebeauvericin C (93)| *Paecilomyces tenuipes* BCC 1614               | -                                                                                    | [109]              |
| Aspergillicin A (94)  | *Aspergillus carneus* from an estuarine sediment | -                                                                                    | [83]               |
| Aspergillicin B (95)  | *Aspergillus carneus* from an estuarine sediment | -                                                                                    | [83]               |
| Aspergillicin C (96)  | *Aspergillus carneus* from an estuarine sediment | -                                                                                    | [83]               |
| Aspergillicin D (97)  | *Aspergillus carneus* from an estuarine sediment | -                                                                                    | [83]               |
| Aspergillicin E (98)  | *Aspergillus carneus* from an estuarine sediment | -                                                                                    | [83]               |
| Aspergillicin F (99)  | *Aspergillus* sp.                               | Innate immune-modulating activity                                                   | [84]               |
| Beauvenniatin A (100) | *Acremonium* sp. BCC 28424                      | Antimalaria, antituberculosis and cytotoxic activities                              | [85]               |
| Beauvenniatin B (101) | *Acremonium* sp. BCC 28424                      | Antimalaria, antituberculosis and cytotoxic activities                              | [85]               |
|                       | Entomogenous fungus *Fusarium proliferatum*    | from the cadaver of an unidentified insect collected in Tibet                       | [86]               |
| Beauvenniatin C (102) | *Acremonium* sp. BCC 28424                      | Antimalaria, antituberculosis and cytotoxic activities                              | [85]               |
| Beauvenniatin D (103) | *Acremonium* sp. BCC 28424                      | -                                                                                    | [85]               |
| Beauvenniatin E (104) | *Acremonium* sp. BCC 28424                      | Antimalaria, antituberculosis and cytotoxic activities                              | [85]               |
| Beauvenniatin F (105) | *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
|                       | Entomogenous fungus *Fusarium proliferatum*    |                                                                                  | [86]               |
| Beauvenniatin G_1 (106)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvenniatin G_2 (107)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvenniatin G_3 (108)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvenniatin H_1 (109)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvenniatin H_2 (110)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvenniatin H_3 (111)| *Acremonium* sp. BCC 2629                      | Antituberculosis, anti-human malaria, and cytotoxic activities                      | [87]               |
| Beauvericin (112)     | *Acremonium* sp. BCC 28424                      | Antimalaria, antituberculosis and cytotoxic activities                              | [85]               |
|                       | *Aspergillus terreus* No. GX7-3B                | *In vitro* acetylcholinesterase inhibitory activity with an IC_{50} value of 3.09 µM | [110]              |
| Beauverina bassiana   | -                                              |                                                                                  | [88]               |
| Beauverina bassiana ATCC 7159 | -                                          |                                                                                  | [111]              |
| Parasitic fungus *Cordyceps cicadae* on the larvae of *Cicada flammata* | Anti-hepatoma activity                   |                                                                                  | [112]              |
| Endophytic fungus *Fusarium realdus* from the rhizomes of *Dioscorea zingiberensis* | Antibacterial activity                   |                                                                                  | [113]              |
| Beauvericin A (113)   | Insect pathogenic fungus *Paecilomyces tenuipes* BCC 1614 | Antimycobacterial and antiplasmodial activities                                      | [109,114]          |
| Parasitic fungus *Cordyceps cicadae* on the larvae of *Cicada flammata* | Anti-hepatoma activity                   |                                                                                  | [112]              |
| Beauvericin B (114)   | *Paecilomyces tenuipes* BCC 1614                | -                                                                                    | [109]              |
Table 4. Cont.

| Name                      | Fungus and Its Origin | Biological Activity                          | References |
|---------------------------|-----------------------|----------------------------------------------|------------|
| Beauvericin C (115)       | Peacilomyces tenuipes BCC 1614 | -                                             | [109]      |
| Beauvericin D (116)       | Beauveria sp. FKI-1366 | Antifungal activity                           | [115]      |
| Beauvericin E (117)       | Parasitic fungus Cordyceps cicadae on the larvae of Cicada flammat | Anti-hepatoma activity                        | [112]      |
| Beauvericin F (118)       | Beauveria sp. FKI-1366 | Antifungal activity                           | [115]      |
| Beauvericin G₁ (119)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antihaptotic activities         | [111]      |
| Beauvericin G₂ (120)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antihaptotic activities         | [111]      |
| Beauvericin G₃ (121)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antihaptotic activities         | [111]      |
| Beauvericin H₁ (122)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antihaptotic activities         | [111]      |
| Beauvericin H₂ (123)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antiapoptotic activities        | [111]      |
| Beauvericin H₃ (124)      | Beauveria bassiana ATCC 7159 | Cytotoxic and antiapoptotic activities        | [111]      |
| Beauvericin J (125)       | Acremonium sp. BCC 28424 | -                                             | [85]       |
| Bursaphelocide A (126)    | Unidentified fungus strain D1084 | Nematicidal activity                        | [116]      |
| Bursapheloxide B (127)    | Unidentified fungus strain D1084 | Nematicidal activity                        | [116]      |
| Cardinalisamide A (128)   | Insect pathogenic fungus Cordyceps cardinalis NBRC 103832 | Antitrypanosomal activity         | [117]      |
| Cardinalisamide B (129)   | Insect pathogenic fungus Cordyceps cardinalis NBRC 103832 | Antitrypanosomal activity         | [117]      |
| Cardinalisamide C (130)   | Insect pathogenic fungus Cordyceps cardinalis NBRC 103832 | Antitrypanosomal activity         | [117]      |
| Conioideocrellide A (131) | Insect pathogenic fungus Conioideocrella tenuis BCC 18627 | -                                             | [118]      |
| Cordycecin A (132)        | Parasitic fungus Cordyceps cicadae on the larvae of Cicada flammat | -                                             | [112]      |
| Desmethyldestruxin A (133) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity                        | [119]      |
| Desmethyldestruxin B (134) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity                        | [120]      |
| Alternaria brassica       | -                                             | Suppressing hepatitis B virus surface antigen production in human hepatoma cells | [121]      |
| Desmethyldestruxin B₂ (135) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity                        | [121]      |
| Desmethyldestruxin C (136) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity                        | [119]      |
| Desmethyilsaradin C₁ (137) | Beauveria felina EN-135 | Antibacterial activity on Escherichia coli with an MIC value of 8 µg/mL | [99]       |
| Desmethyilsaradin C₂ (138) | Beauveria felina | Anti-inflammatory activity                      | [123]      |
| Desmethyilsaradin E (139) | Beauveria felina | Anti-inflammatory activity                      | [123]      |
| Desmethyilsaradin G (140) | Beauveria felina EN-135 | -                                             | [99]       |
| Destruxin A (141)         | Alternaria linicola | Phytotoxic activity                           | [124]      |
| Beauveria felina          | -                                             | Anti-inflammatory activity                      | [123]      |
| Beauveria felina EN-135   | -                                             | Anti-inflammatory activity                      | [123]      |
| Entomopathogenic fungus Metarhizium anisopliae | -                                             | [126,127] |
| Insect pathogenic fungus Ophiocordyceps coccidicola NBRC 100683 | Antitrypanosomal activity on Trypanosoma brucei with an IC₅₀ value of 0.33 µg/mL | [128]      |
| Destruxin A₁ (142)        | Entomopathogenic fungus Metarhizium anisopliae | -                                             | [126]      |
| Destruxin A₂ (143)        | Entomopathogenic fungus Metarhizium anisopliae | -                                             | [126]      |
| Destruxin A₃ (144)        | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity                        | [119]      |
Table 4. Cont.

| Name | Fungus and Its Origin | Biological Activity | References |
|------|-----------------------|---------------------|------------|
| Destruxin A$_4$ (145) | Aschersonis sp. | Insecticidal activity | [129] |
| Destruxin A$_4$ chlorohydrin (146) | Unidentified fungus OS-F68576 | Induction of erythropoietin gene expression | [130] |
| Destruxin A$_5$ (147) | Aschersonis sp. | Insecticidal activity | [129] |
| Destruxin B (148) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [127] |
| - | - | Inhibitory on Helicobacter pylori | [131] |
| Destruxin A$_4$ chlorohydrin (146) | Unidentified fungus OS-F68576 | Induction of erythropoietin gene expression | [130] |
| Destruxin A$_5$ (147) | Aschersonis sp. | Insecticidal activity | [129] |
| Destruxin B (148) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [127] |
| - | - | Inhibitory on Helicobacter pylori | [131] |
| Insect pathogenic fungus Ophiocordyceps coicidiicola | | Antitrypanosomal activity on Trypanosoma brucei with an IC$_{50}$ value of 0.16 µg/mL | [128] |

[β-Me-Pro] Destruxin B (149) | Beauveria felina | - | [132] |
| Destruxin B$_2$ (150) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Destruxin B$_2$ (151) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Alternaria brassicae | - | | [133] |
| Destruxin B$_4$ | Alternaria brassicae | - | [121] |
| - | Aschersonis sp. | - | [129] |
| Destruxin C (153) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [120,126] |
| Destruxin C$_1$ (154) | Metarhizium brunneum | - | [134] |
| Destruxin D (156) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Destruxin D$_1$ (157) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Destruxin D$_2$ (158) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Destruxin E (159) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [126] |
| Destruxin E$_2$ (160) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [127] |
| Insect pathogenic fungus Ophiocordyceps coicidiicola | | Antitrypanosomal activity on Trypanosoma brucei with an IC$_{50}$ value of 0.061 µg/mL | [128] |

[Destruxin E$_2$ chlorohydrin (164) | Marine-derived fungus Beauveria felina | - | [135] |
| Destruxin E$_2$ chlorohydrin (164) | Marine-derived fungus Beauveria felina | - | [135] |
| - | Beauveria felina EN-135 | - | [125] |
| Destruxin E$_2$ (162) | Entomopathogenic fungus Metarhizium anisopliae | - | [126] |
| Destruxin E$_2$ (163) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [127] |
| Destruxin E$_2$ chlorohydrin (164) | Metarhizium anisopliae | Weak suppressive activity on the production of hepatitis B virus antigen | [136] |
| Destruxin Ed (165) | Metarhizium anisopliae | Insecticidal activity | [119] |
| Destruxin Ed$_1$ (166) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [137] |
| Destruxin Ed$_2$ (167) | Metarhizium brunneum | - | [134] |
| Destruxin F (168) | Entomopathogenic fungus Metarhizium anisopliae | Insecticidal activity | [119] |
| Destruxin G (169) | Metarhizium brunneum | - | [134] |
| Destruxin G$_2$ (170) | Metarhizium brunneum | - | [134] |
| Emericellamide A (171) | Aspergillus nidulans | - | [138] |
| Emericellamide B (172) | Marine-derived fungus Emericella sp. from the surface of a green alga of the genus Hamlima | Antibacterial activity | [139] |
| Emericellamide B (172) | Marine-derived fungus Emericella sp. from the surface of a green alga of the genus Hamlima | Antibacterial activity | [139] |
| Emericellamide C (173) | Aspergillus nidulans | - | [138] |
| Emericellamide D (174) | Aspergillus nidulans | - | [138] |
| Emericellamide E (175) | Aspergillus nidulans | - | [138] |
| Emericellamide F (176) | Aspergillus nidulans | - | [138] |
| Name          | Fungus and Its Origin                                                                 | Biological Activity                                                                 | References |
|--------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------|
| Enniatin A (177) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
|              | Endophytic fungus *Fusarium tricinctum* isolated from the fruits of *Hordeum sativum* | Insecticidal activity                                                               |            |
| Enniatin A (177) | *Fusarium tricinctum*                                                                 | Inducing an increase in the mitochondrial respiration                            | [142]      |
| Enniatin A (177) | -                                                                                     | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29                                      | [143]      |
| Enniatin A (178) | *Fusarium tricinctum*                                                                 | Cytotoxicity in human hepatocarcinoma cell line HepG2                               | [144]      |
| Enniatin A1 (178) | *Fusarium tricinctum*                                                                 | -                                                                                   |            |
| Enniatin A2 (179) | *Fusarium acuminatum* DAOM 196490                                                    | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29                                      | [143,145]  |
| Enniatin B (180) | *Acremonium* sp. BCC 28424                                                           | Antimalaria, antituberculosis and cytotoxic activities                             | [85]       |
| Enniatin B (180) | Endophytic fungus *Fusarium sp. strain F31 from the needles of *Pinus sylvestris*    | Inhibition on *Botrytis cinerea* spore germination                                  | [146]      |
| Enniatin B (180) | *Fusarium tricinctum*                                                                 | Inducing an increase in the mitochondrial respiration                            | [142]      |
| Enniatin B (180) | -                                                                                     | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29                                      | [143]      |
| Enniatin B (180) | -                                                                                     | Cytotoxicity in human hepatocarcinoma cell line HepG2                               | [144]      |
| Halosarpheia sp. strain 732 | -                                                                                   |                                                                                     |            |
| Enniatin B (181) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin B (181) | Entomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet | -                                                                                   | [86]       |
| Enniatin B (181) | *Fusarium tricinctum* isolated from the fruits of *Hordeum sativum*                  | Insecticidal activity                                                               | [141]      |
| Enniatin B1 (181) | *Verticillium hemipterigenum*                                                         | -                                                                                   | [148]      |
| Enniatin B (181) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin B (181) | Endophytic fungus *Fusarium sp. strain F31 from the needles of *Pinus sylvestris*      | Inhibition on *Botrytis cinerea* spore germination                                  | [146]      |
| Enniatin B (181) | -                                                                                     | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29                                      | [143]      |
| Enniatin B (182) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin B (182) | Endophytic fungus *Fusarium sp. strain F31 from the needles of *Pinus sylvestris*      | Inhibition on *Botrytis cinerea* spore germination                                  | [146]      |
| Enniatin B (182) | Endophytic fungus *Fusarium tricinctum* isolated from the fruits of *Hordeum sativum* | Insecticidal activity                                                               | [141]      |
| Enniatin B2 (183) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin B (183) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin B4 = Enniatin D(184) | *Fusarium sp. FO-1305*                                                                | ACAT inhibition                                                                      | [81]       |
| Enniatin D (184) | *Fusarium acuminatum*                                                                 | -                                                                                   | [140]      |
| Enniatin D (184) | *Fusarium tricinctum*                                                                 | Inducing an increase in the mitochondrial respiration                            | [142]      |
| Enniatin D (184) | Endophytic fungus *Fusarium sp. strain F31 from the needles of *Pinus sylvestris*      | Inhibition on *Botrytis cinerea* spore germination                                  | [146]      |
| Name | Fungus and Its Origin | Biological Activity | References |
|------|-----------------------|---------------------|------------|
| -    | -                     | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29 | [143]      |
| Halosarpheia sp. strain 732 | - | | [147] |
| Verticillium hemipterigenum | - | | [148] |
| Enniatin C (185) | Verticillium hemipterigenum | - | [148] |
| Enniatin E₁ (186) | Fusarium sp. FO-1305 | ACAT inhibition | [91] |
| Enniatin E₂ (187) | Fusarium sp. FO-1305 | ACAT inhibition | [91] |
| Enniatin F (188) | Fusarium sp. FO-1305 | ACAT inhibition | [91] |
| Enniatin G (189) | Halosarpheia sp. strain 732 | Cytotoxic activity on HepG2, with an ED₅₀ of 12 µg/mL | [147] |
| Verticillium hemipterigenum | - | | [148] |
| Enniatin H (190) | Fusarium oxysporum KFCC 11363P | Cytotoxic activity | [93] |
| Verticillium hemipterigenum | - | | [148] |
| Enniatin I (191) | Fusarium oxysporum KFCC 11363P | Cytotoxic activity | [93] |
| Verticillium hemipterigenum | - | | [148] |
| Enniatin J₁ (192) | Endophytic fungus Fusarium sp. strain F31 from the needles of Pinus sylvestris | Inhibition on Botrytis cinerea spore germination | [146] |
| Fusarium solani | Antibacterial effects on pathogenic and lactic acid bacteria | [149] |
| Fusarium tricinctum | Inducing an increase in the mitochondrial respiration | [142] |
| Enniatin J₂ (193) | Endophytic fungus Fusarium sp. strain F31 from the needles of Pinus sylvestris | Inhibition on Botrytis cinerea spore germination | [146] |
| Fusarium solani | Antibacterial effects on pathogenic and lactic acid bacteria | [149] |
| Endophytic fungus Fusarium sp. strain F31 from the needles of Pinus sylvestris | Inhibition on Botrytis cinerea spore germination | [146] |
| - | Cytotoxicity on Caco-2 cells, Hep-G2 and HT-29 | [143] |
| Enniatin K₁ (195) | Endophytic fungus Fusarium sp. strain F31 from the needles of Pinus sylvestris | Inhibition on Botrytis cinerea spore germination | [146] |
| Entomogenous fungus Fusarium proliferatum from the cadaver of an unidentified insect collected in Tibet | - | | [86] |
| Enniatin L (196) | Entomogenous fungus Fusarium proliferatum from the cadaver of an unidentified insect collected in Tibet | Antimalarial, antituberculous and cytotoxic activities | [86] |
| Acremonium sp. BCC 2629 | - | | [150] |
| Enniatin M₁ (197) | Acremonium sp. BCC 2629 | Antimalarial, antituberculous and cytotoxic activities | [150] |
| Enniatin M₂ (198) | Acremonium sp. BCC 2629 | Antimalarial, antituberculous and cytotoxic activities | [150] |
| Enniatin MK1688 (199) | Fusarium oxysporum KFCC 11363P | Cytotoxic activity | [93] |
| Fsarium oxysporum FB1501 | Cytotoxic effects on several adenocarcinoma cell lines | [151] |
| Fsarium oxysporum | - | | [152] |
| Verticillium hemipterigenum | - | | [148] |
| Enniatin N (200) | Acremonium sp. BCC 2629 | Antimalarial, antituberculous and cytotoxic activities | [150] |
| Enniatin O₁ (201) | Verticillium hemipterigenum BCC 1449 | Antimalarial, antituberculous and cytotoxic activities | [153] |
| Enniatin O₂ (202) | Verticillium hemipterigenum BCC 1449 | Antimalarial, antituberculous and cytotoxic activities | [153] |
Table 4. Cont.

| Name          | Fungus and Its Origin                                                                 | Biological Activity                                      | References |
|---------------|---------------------------------------------------------------------------------------|----------------------------------------------------------|------------|
| Enniatin O_{3} (203) | *Verticillium hemipterigenum* BCC 1449                                                 | Antimalarial, antituberculous and cytotoxic activities    | [153]      |
| Enniatin P_{1} (204) | *Fusarium* sp. VI 03441 -                                                           |                                                          |            |
| Enniatin P_{2} (205) | *Fusarium* sp. VI 03441 -                                                           |                                                          |            |
| Enniatin Q (206) | Endomogenous fungus *Fusarium tricinctum* isolated from the fruits of *Hordeum sativum* | Insecticidal activity                                    | [141]      |
| Enniatin R (207) | Endomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet |                                                          | [86]       |
| Enniatin S (208) | Endomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet |                                                          | [86]       |
| Enniatin T (209) | Endomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet |                                                          | [86]       |
| Enniatin U (210) | Endomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet |                                                          | [86]       |
| Enniatin V (211) | Endomogenous fungus *Fusarium proliferatum* from the cadaver of an unidentified insect collected in Tibet |                                                          | [86]       |
| Exumolide A (212) | Marine-derived fungus *Scytalidium* sp. obtained from decaying plant material in the Exuma Islands, Bahamas | Antimicroalgal activity                                  | [155]      |
| Exumolide B (213) | Marine-derived fungus *Scytalidium* sp. obtained from decaying plant material in the Exuma Islands, Bahamas | Antimicroalgal activity                                  | [155]      |
| Guangomide A (214) | Endophytic fungus *Acremonium* sp. PSU-MA70 from a mangrove *Rhizophora apiculata* |                                                          | [156]      |
| Guangomide B (215) | Endophytic fungus *Acremonium* sp. PSU-MA70 from a mangrove *Rhizophora apiculata* |                                                          | [156]      |
| Guangomide B (215) | Endophytic fungus *Acremonium* sp. PSU-MA70 from a mangrove *Rhizophora apiculata* |                                                          | [156]      |
| Hirsutatin A (216) | Insect pathogenic fungus *Hirsutella nivea* BCC 2594 from a Homoptera leaf-hoppper |                                                          | [157]      |
| Hirsutatin B (217) | Insect pathogenic fungus *Hirsutella nivea* BCC 2594 from a Homoptera leaf-hoppper | Antimalarial activity on *Plasmodium falciparum* K1 with an IC_{50} value of 5.8 µg/mL | [157]      |
| Hirsutellide A (218) | Entomopathogenic fungus *Hirsutella kobayasii* | Antimycobacterial activity; antimalarial activity on *Plasmodium falciparum* | [94]       |
| Homodestcardin (219) | Unidentified fungus 001314c from *Ianthella* sp.                                          |                                                          | [106]      |
| Hydroxysterigmatrin B (220) | *Alternaria brassicae*                                                                  | Phytotoxic activity                                       | [158]      |
| Hydroxyhomoderigmatrin B (221) | *Alternaria brassicae*                                                                  |                                                          | [158]      |
| IB-01212 (222) | *Clonostachys* sp. ESNA-A009                                                          | Cytotoxic activity                                        | [159]      |
| IB-01212 (222) | *Clonostachys* sp.                                                                    | Antitumoral activity                                     | [160]      |
| Isaridin A (223) | *Beauveria* sp. Lr89                                                                   |                                                          | [161]      |
| Isaridin B (224) | *Beauveria* felina EN-135                                                               |                                                          | [99]       |
| Isaridin B (224) | *Beauveria* felina EN-135                                                               |                                                          | [99]       |


Table 4. Cont.

| Name             | Fungus and Its Origin                  | Biological Activity                        | References |
|------------------|----------------------------------------|--------------------------------------------|------------|
| Isaridin C₁ (225) | Isaria sp. from soil                   | -                                          | [98]       |
| Isaridin C₂ (226) | Isaria sp. from soil                   | -                                          | [98]       |
|                  | Beauveria felina                       | -                                          | [123]      |
| Isaridin C₁ (225)/C₂ (226) = Isarlein A | Isaria felina                         | Antifungal and insecticidal activities     | [95]       |
| Isaridin D (227)  | Isaria sp. from soil                   | -                                          | [98]       |
| Isaridin E = Isarlein B (228) | Isaria felina                    | Antifungal and insecticidal activities     | [95]       |
|                  | Isaria felina KMM 4639                  | -                                          | [163]      |
|                  | Beauveria felina EN-135                 | -                                          | [99]       |
|                  | Beauveria felina                        | -                                          | [123]      |
| Isaridin F (229)  | Beauveria felina                       | -                                          | [123]      |
| Isaridin G (230)  | Beauveria felina EN-135                 | -                                          | [99]       |
| Isarin A = Isarin (231) | Isaria felina                | Insecticidal activity                      | [98]       |
| Isarin B (232)    | Isaria felina                          | Insecticidal activity                      | [97]       |
| Isarin C (233)    | Isaria felina                          | Insecticidal activity                      | [97]       |
| Isarin C₂ (234)   | Isaria felina                          | Insecticidal activity                      | [98]       |
| Isarin D (235)    | Isaria felina                          | Insecticidal activity                      | [97]       |
| Isarin E (236)    | Isaria felina                          | Insecticidal activity                      | [98]       |
| Isarin F₂ (237)   | Isaria felina                          | Insecticidal activity                      | [98]       |
| Isarin G₁ (238)   | Isaria felina                          | Insecticidal activity                      | [98]       |
| Isarin G₂ (239)   | Isaria felina                          | Insecticidal activity                      | [98]       |
| Isosiarin B (240) | Isaria felina KMM 4639                 | -                                          | [163]      |
|                  | Beauveria felina                        | Insecticidal activity                      | [98]       |
| Isosiarin D (241) | Beauveria felina EN-135                | Brine-shrimp lethality activity            | [125]      |
| Nodupetide (242)  | Nodulisporium sp. IFB-A163 residing in the gut of insect Riptortus pedestris | Insecticidal and antimicrobial activities | [160]      |
| Oryzamide A (243) | Marine-derived fungus Nigrospora oyzae from the sponge Phakellia fusca | -                                          | [164]      |
| Oryzamide B (244) | Marine-derived fungus Nigrospora oyzae from the sponge Phakellia fusca | -                                          | [164]      |
| Oryzamide C (245) | Marine-derived fungus Nigrospora oyzae from the sponge Phakellia fusca | -                                          | [164]      |
| Oryzamide D (246) | Marine-derived fungus Nigrospora oyzae from the sponge Phakellia fusca | -                                          | [164]      |
| Oryzamide E (247) | Marine-derived fungus Nigrospora oyzae from the sponge Phakellia fusca | -                                          | [164]      |
| Paecilodepsipeptide A = Gliotide (248) | Marine-derived fungus Gloiocladium sp. from the alga Durvillaea antarctica | -                                          | [101]      |
|                  | Insect pathogenic fungus Paecilomyces cinnamomeus BCC 9616 | Antimarial and cytotoxic activities         | [102]      |
| Pseudodestruxin A (249) | Coprophilous fungus Nigrosabulum globosum | Antibacterial activity                     | [103]      |
| Pseudodestruxin B (250) | Coprophilous fungus Nigrosabulum globosum | Antibacterial activity                     | [103]      |
| Pseudodestruxin C (251) | Marine-derived fungus Beauveria felina | -                                          | [135]      |
| Pullularin A (252) | Pullularia sp. BCC 8613                | Antimarial, antiviral and cytotoxic activities | [165]      |
|                  | Bionectria ochrolena                    | Cytotoxic activity on L5178Y cell line      | [166]      |
| Pullularin B (253) | Pullularia sp. BCC 8613                | -                                          | [165]      |
| Pullularin C (254) | Pullularia sp. BCC 8613                | -                                          | [165]      |
| Verticillium F04W2166 |                                      | Inhibitory activity on proteasome; Cytotoxic activity on human colon cell line HT-29 and human breast cancer cell line MDA-MB-231 | [167]      |
Table 4. Cont.

| Name | Fungus and Its Origin | Biological Activity | References |
|------|-----------------------|---------------------|------------|
| - | Bionectria ochroleuca | Cytotoxic activity on human PC-3 cells | [168] |
| Pullularin D (255) | Pullularia sp. BCC 8613 | - | [165] |
| Pullularin E (256) | Endophytic fungus Bionectria ochroleuca from the mangrove plant Sonneratia caseolaris | Cytotoxic activity on L5178Y cell line | [166] |
| Roseocardin (257) | Beauveria felina | Antibacterial activity | [123] |
| Trichothecium roseum TT103 | | Positive inotropic effect on rat heart muscles | [169] |
| Roseotoxin A (258) | Trichothecium roseum | - | [170] |
| Roseotoxin B (259) | Beauveria felina | - | [123] |
| Roseotoxin EN-135 | Beauveria felina | Lethality against brine shrimp with an LD$_{50}$ value of 0.73 µM | [125] |
| Trichothecium roseum TT1031 | | | |
| Trichothecium roseum | | Phototoxic activity | [172] |
| Scopularide A (261) | Marine sponge-derived Scopularia brevicaulis from Tethya aurantium | Cytotoxic activity | [173] |
| Scopularide B (262) | Marine sponge-derived Scopularia brevicaulis from Tethya aurantium | Cytotoxic activity | [173] |
| Spicellamide A (263) | Marine-derived fungus Spicellum roseum from the sponge Ectyplasia perox | Cytotoxic activity | [174] |
| Spicellamide B (264) | Marine-derived fungus Spicellum roseum from the sponge Ectyplasia perox | Cytotoxic activity | [174] |
| Sporidesmolide I (265) | Pithomyces chartarum | - | [175] |
| Sporidesmolide II (266) | Pithomyces chartarum | - | [175] |
| Sporidesmolide III (267) | Pithomyces chartarum | - | [175] |
| Sporidesmolide IV (268) | Pithomyces chartarum | - | [176] |
| Sporidesmolide V (269) | Pithomyces chartarum | - | [177] |
| T987A (270) | Cladobotryum sp. | Cytotoxic activity | [178] |
| T987B (271) | Cladobotryum sp. | Cytotoxic activity | [178] |
| Trichodepsipeptide A (272) | Trichothecium sp. MSX 51320 | - | [108] |
| Trichodepsipeptide B (273) | Trichothecium sp. MSX 51320 | - | [108] |
| Trichomide A (274) | Trichothecium roseum | Immunosuppressive activity | [107] |
| Trichomide B (275) | Trichothecium roseum | Immunosuppressive activity | [107] |
| Verticilide B1 (276) | Verticillium sp. FKI-2679 from soil | Inhibition of ACAT1 and ACAT2 | [179] |

Note. ACAT, acyl-CoA: cholesterol acyltransferase; ED$_{50}$, median effective dose; IC$_{50}$, median inhibitory concentration. LD$_{50}$, median lethal dose.
Figure 4. Cont.
Figure 4. Cont.
Figure 4. Cont.
| Compound       | R₁  | R₂  | R₃  | R₄  | R₅  | R₆  | R₇  | R₈  |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Enniatin A (177) | sBu | sBu | sBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin A₁ (178) | sBu | iPr | sBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin A₂ (179) | sBu | iBu | sBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin B (180) | iPr | iPr | iPr | iPr | iPr | iPr | Me  | Me  |
| Enniatin B₁ (181) | iPr | sBu | iPr | iPr | iPr | iPr | Me  | Me  |
| Enniatin B₂ (182) | iPr | iPr | iPr | iPr | iPr | iPr | H   | Me  |
| Enniatin B₃ (183) | iPr | iPr | iPr | iPr | iPr | iPr | H   | H   |
| Enniatin B₄ (184) | iPr | iPr | iBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin C (185) | iPr | iPr | iPr | iPr | iPr | iPr | Me  | Me  |
| Enniatin C₁ (186) | sBu | iBu | iBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin C₂ (187) | iBu | iBu | iBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin D (188) | sBu | sBu | iBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin D₁ (189) | iBu | iBu | iBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin E (190) | iPr | iPr | iPr | iPr | sBu | iPr | iPr | Me  |
| Enniatin E₁ (191) | iPr | iPr | iPr | iPr | sBu | sBu | iPr | Me  |
| Enniatin E₂ (192) | iPr | iPr | Me  | iPr | iPr | iPr | Me  | Me  |
| Enniatin E₃ (193) | sBu | iPr | iPr | Me  | iPr | iPr | Me  | Me  |
| Enniatin F (194) | Me  | iPr | sBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin G (195) | iPr | iPr | Et  | iPr | iPr | iPr | Me  | Me  |
| Enniatin H (196) | iPr | iPr | iPr | iPr | iPr | Hy-sBu | Me  | Me  |
| Enniatin J (197) | iPr | iPr | iPr | sBu | iPr | Hy-sBu | Me  | Me  |
| Enniatin J₁ (198) | iPr | iPr | iPr | sBu | Hy-sBu | iPr | Me  | Me  |
| Enniatin MK1688 (199) | iPr | iPr | iPr | sBu | sBu | sBu | Me  | Me  |
| Enniatin N (200) | iPr | iPr | iPr | sBu | sBu | Hy-sBu | Me  | Me  |
| Enniatin O₁ (201) | iBu | iPr | iPr | sBu | iPr | iPr | Me  | Me  |
| Enniatin O₂ (202) | iBu | iPr | iPr | iPr | sBu | iPr | Me  | Me  |
| Enniatin O₃ (203) | iBu | iPr | iPr | iPr | iPr | sBu | Me  | Me  |
| Enniatin P₁ (204) | iPr | iPr | Hy-Et | iPr | iPr | iPr | Me  | Me  |
| Enniatin P₂ (205) | iBu | iPr | Hy-Et | iPr | iPr | iPr | Me  | Me  |
| Enniatin Q (206) | sBu | sBu | sBu | iPr | iPr | iPr | Me  | Me  |
| Enniatin R (207) | iPr | iPr | iPr | Hy-iPr | iPr | iPr | Me  | Me  |
| Enniatin S (208) | iPr | iPr | iPr | sBu | Hy-iPr | sBu | Me  | Me  |
| Enniatin T (209) | iPr | iPr | iPr | Hy-sBu | Hy-sBu | Hy-sBu | Me  | Me  |
| Enniatin U (210) | iPr | iPr | iPr | Hy-sBu | Hy-sBu | Hy-sBu | iPr | Me  | Me  |
| Enniatin V (211) | iPr | iPr | iPr | Hy-sBu | Hy-sBu | Hy-sBu | Me  | Me  |

Note. a Enniatins B₂ and B₃ have one and two N-methyls. b The stereochemistry of the Hy-Et side chain was not determined.
Figure 4. Cont.
Figure 4. Cont.
6. Cyclic Heptadepsipeptides

The occurrences and biological activities of fungal cyclic heptadepsipeptides are shown in Table 5, and their structures are provided in Figure 5.

Cordycommunin (277) was obtained from the insect pathogenic fungus *Ophiocordyceps communis* BCC16475. This compound exhibited inhibitory activity on *Mycobacterium tuberculosis* H37Ra. It also showed weak cytotoxic activity on KB cells [180].

Fusaripeptide A (278) was obtained from the endophytic fungus *Fusarium* sp. from the roots of *Mentha longifolia* L. growing in Saudi Arabia. It exhibited antifungal, anti-malarial and cytotoxic activities [181].

Simplicilliumtides J (280), K (281), L (282) and verlamelins A (283) and B (284) were isolated from the deep-sea-derived fungus *Simplicillium obclavatum* EIODSF 020. Simplicilliumtides J (280), and verlamelins A (283) and B (284) showed antifungal activity toward *Aspergillus versicolor* and *Curvularia australiensis*, and also had obvious antiviral activity on HSV-1 with IC\(_{50}\) values of 14.0, 16.7, and 15.6 \(\mu M\), respectively [182]. Verlamelins A (283) and B (284) were obtained from the entomopathogenic fungus *Lecanicillium* sp. (formerly *Verticillium lecanii*) isolated from a chillie trips cadaver. They showed antifungal activity against plant pathogenic fungi [183].

W493 A (285), B (286), C (287) and D (288) were obtained from the endophytic fungus *Fusarium* sp. isolated from the mangrove plant *Ceriops tagal*. Both W493 A (285) and B (286) exhibited moderate activity against the fungus *Cladosporium cladosporiodes* and weak antitumor activity against the human ovarian cancer cell line A2780 [184]. W493 A and B were also isolated from *Fusarium* sp. and showed strong antifungal activity against *Venturia inaequalis, Monilinia mali*, and *Cochliobolus miyabeanus* [185].
Table 5. Fungal cyclic heptadepsipeptides and their biological activities.

| Name                   | Fungus and Its Origin                  | Biological Activity                                      | References |
|------------------------|----------------------------------------|----------------------------------------------------------|------------|
| Cordycommunin (277)    | *Ophiocordyceps communis* BCC16475     | Antimycobacterial activity;                               | [180]      |
|                        |                                        | Cytotoxic activity                                        |            |
| Fusaripeptide A (278)  | Endophytic fungus *Fusarium* sp. from *Mentha longifolia* sp. | Antifungal, anti-malarial and cytotoxic activities         | [181]      |
| HUN-7293 (279)         | Unidentified fungus                    | Inhibition of inducible cell adhesion molecule expression  | [186]      |
| Simplicilliumtide J (280) | Deep-sea derived fungus *Simplicillium obclavatum* | Antifungal and antiviral activities                       | [182]      |
| Simplicilliumtide K (281) | Deep-sea derived fungus *Simplicillium obclavatum* | -                                                        | [182]      |
| Simplicilliumtide L (282) | Deep-sea derived fungus *Simplicillium obclavatum* | -                                                        | [182]      |
| Verlamelin A (283)     | Entomopathogenic fungus *Lecanicillium* sp. | Antifungal activity                                       | [183]      |
|                        |                                        | Deep-sea derived fungus *Simplicillium obclavatum*       | [182]      |
| Verlamelin B (284)     | Entomopathogenic fungus *Lecanicillium* sp. | Antifungal activity                                       | [183]      |
| W493 A (285)           | Endophytic fungus *Fusarium* sp. from *Ceriops tagal* | Antifungal activity                                       | [185]      |
| W493 B (286)           | Endophytic fungus *Fusarium* sp. from *Ceriops tagal* | Antifungal activity                                       | [185]      |
| W493 C (287)           | *Fusarium* sp. CANU-HA23               | Antifungal activity                                       | [25]       |
| W493 D (288)           | Endophytic fungus *Fusarium* sp. from *Ceriops tagal* | -                                                        | [184]      |

Figure 5. Cont.
7. Cyclic Octadepsipeptides

The occurrences and biological activities of reported fungal cyclic octadepsipeptides are listed in Table 6, and their structures are shown in Figure 6.

Bassianolide (289) was isolated from Beauveria bassiana, Lecanicilium sp. (formerly Verticillium lecanii), and Xylaria sp. BCC1067 to display insecticidal, cytotoxic and anthelmintic activities [187–189]. Synthesis of bassianolide (289) was succeeded, and this compound showed antitumor activity by inducing G0/G1 arrest in MDA-MB 231 breast cancer cells [190].

The broad-spectrum anthelmintic cyclic octadepsipeptides PF1022A (293), PF1022B (294), PF1022C (295), PF1022D (296), PF1022E (297), PF1022F (298), PF1022G (299) and PF1022H (300) were isolated from the endophytic fungus Rosellinia sp. PF1022 from the leaves of Camellia japonica [191,192]. The action mode of PF1022A (293) appeared to be complex, having at least two different targets, a latrophilin-like receptor, and a Ca\(^{2+}\)-activated K\(^+\) channel [193]. The synthesis and biosynthesis of PF1022A (293) have also been studied in detail [194,195]. These metabolites were used as starting points to generate semisynthetic derivatives among which emodepside has been developed as the commercial anthelmintic agent Emodepside against gastrointestinal and extraintestinal parasites [193].

Phaeoefungin (301), which was isolated from the endophytic fungus Phaeosphaeria sp. from living stems and leaves of Sedum sp. (Crassulaceae), was discovered by application of reverse genetics technology, using the Candida albicans fitness test (CaFT). This compound caused ATP release in wild-type Candida albicans strains. It showed modest antifungal activity with the MICs for Candida albicans, Aspergillus fumigatus, and Trichophyton mentagrophytes as 16, 8 and 4 µg/mL, respectively [196].

Verticilides A\(_1\) (302), A\(_2\) (303) and A\(_3\) (304) were isolated from Verticillium sp. FKI-2679. These compounds showed inhibitory activity on acyl-CoA:cholesterol acyltransferase (ACAT) in a cell-based assay using ACAT1- and ACAT2-expressing CHO cells [179].
Table 6. Fungal cyclic octadepsipeptides and their biological activities.

| Name                  | Fungus and Its Origin                                                                 | Biological Activity                                | References          |
|-----------------------|---------------------------------------------------------------------------------------|----------------------------------------------------|---------------------|
| Bassianolide (289)    | 
Beauveria bassiana; Lecanicillum sp. (formerly Verticillium lecanii)                  | Insecticidal, cytotoxic and anthelmintic activities | [187,188]           |
| Xylaria sp. BCC1067  | -                                                                                     |                                                    | [189]               |
| BZR-cotoxin IV (290)  | 
Plant pathogenic fungus Bipolaris zeicola (formerly Bipolaris sorokiniana) LK12      | -                                                  | [197]               |
| Glomosporin (291)     | Glomospora sp. BAUA 2825                                                               | Antifungal activity                                | [199,200]           |
| Halobacillin (292)    | Trichoderma asperellum                                                                 | Antibacterial activity                             | [201]               |
| PF1022A (293)         | Endophytic fungus Rosellina sp. PF1022                                               | Anthelmintic activity on Ascaridia galli in chicken| [191]               |
| Mycelia sterilia PF1022 |                                                                                     | Anthelmintic activity                              | [192]               |
| PF1022B (294)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022C (295)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022D (296)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022E (297)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022F (298)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022G (299)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| PF1022H (300)         | Mycelia sterilia PF1022                                                               | Anthelmintic activity                              | [192]               |
| Phaeofungin (301)     | Endophytic fungus Phaeophaeria sp. from Sedum sp.                                    | Causing ATP release in wild-type Candida albicans strains; Modest antifungal activity | [196]               |
| Verticilide = Verticilide A1 (302) | 
Verticillium sp. FKI-1033 from soil                                                    | Selectively binding to the insect ryanodine receptor| [202]               |
| Verticilide A2 (303)  | 
Verticillium sp. FKI-2679 from soil                                                   | ACAT inhibition                                    | [179]               |
| Verticilide A3 (304)  | 
Verticillium sp. FKI-2679 from soil                                                   | ACAT inhibition                                    | [179]               |

Note. Abbreviations: ACAT, acyl-CoA: cholesterol acyltransferase.
The origins and biological activities of fungal cyclic nonadepsipeptides are listed in Table 7, and their structures are provided in Figure 7. Aureobasins were isolated from the black yeast *Aureobasidium pullulans* R106 from the leaf collected at Tsushima of Japan. They are composed of one hydroxylated carboxylic acid and eight amino acids, and 29 aureobasidin analogs (305–333) have been isolated from this fungus [203–206]. They showed good in vitro activity against all *Candida* species and *Cryptococcus neoformans*, in vivo activity against murine systemic candidiasis, and had low toxicity. They also showed inhibitory activity on inositol phosphorylceramide synthase [207].

BZR-cotoxin I (334) was isolated from plant pathogenic fungus *Bipolaris zeicola* [208] and endophytic fungus *Bipolaris sorokiniana* LK12 [198]. It had moderate anti-lipid peroxidation and urease activities [198]. Pleofungins A (338), B (339), C (340) and D (341) were identified from *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan. It is a rare case where a CDP contains three subsequent lactone bonds. These CDPs showed inhibitory activity on inositol phosphorylceramide synthase [209,210].

### Table 7. Fungal cyclic nonadepsipeptides and their biological activities.

| Name             | Fungus and Its Origin                        | Biological Activity                                                                 | References        |
|------------------|----------------------------------------------|-------------------------------------------------------------------------------------|-------------------|
| Aureobasidin A   | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity; Inhibitory activity on *Candida* planktonic and biofilm cells | [203,211,212]    |
| Aureobasidin B   | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity                                                                | [204,213]        |
| Aureobasidin C   | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity                                                                | [204,213]        |
| Aureobasidin D   | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity                                                                | [204,213]        |
Table 7. Cont.

| Name         | Fungus and Its Origin                      | Biological Activity           | References       |
|--------------|--------------------------------------------|--------------------------------|------------------|
| Aureobasidin E (309) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin F (310) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin G (311) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin H (312) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin I (313) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin J (314) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin K (315) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin L (316) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin M (317) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin N (318) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin O (319) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin P (320) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin Q (321) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin R (322) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [204,213] |
| Aureobasidin S1 (323) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [205] |
| Aureobasidin S2a (324) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [205] |
| Aureobasidin S2b (325) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [205] |
| Aureobasidin S3 (326) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [205] |
| Aureobasidin S4 (327) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [205] |
| Aureobasidin T1 (328) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| Aureobasidin T2 (329) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| Aureobasidin T3 (330) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| Aureobasidin T4 (331) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| Aureobasidin U1 (332) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| Aureobasidin U2 (333) | *Aureobasidium pullulans* from a leaf collected at Tsushima of Japan | Antifungal activity | [206] |
| BZR-cotoxin I (334) | Plant pathogenic fungus *Bipolaris zeicola* | - | [208] |
| BZR-cotoxin II (335) | Plant pathogenic fungus *Bipolaris sorokiniana* LK12 | Moderate anti-lipid peroxidation and uease activities | [198] |
| BZR-cotoxin III (336) | Plant pathogenic fungus *Bipolaris zeicola* | - | [214] |
Table 7. Cont.

| Name                        | Fungus and Its Origin                                      | Biological Activity                                      | References  |
|-----------------------------|-----------------------------------------------------------|----------------------------------------------------------|-------------|
| Phomafungin (337)           | *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan | Inhibitory activity on inositol phosphorylceramide synthase | [209,210]   |
| Pleofungin A (338)          | *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan | Inhibitory activity on inositol phosphorylceramide synthase | [209,210]   |
| Pleofungin B (339)          | *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan | Inhibitory activity on inositol phosphorylceramide synthase | [209,210]   |
| Pleofungin C (340)          | *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan | Inhibitory activity on inositol phosphorylceramide synthase | [209,210]   |
| Pleofungin D (341)          | *Phoma* sp. SANK 13899 from a soil sample collected at Tokyo of Japan | Inhibitory activity on inositol phosphorylceramide synthase | [209,210]   |

![Diagram](image_url)

**Figure 7. Cont.**
9. Cyclic Decadepsipeptides

The occurrences and biological activities of fungal cyclic decadepsipeptides are shown in Table 8, and their structures are provided in Figure 8. Only eight cyclic decadepsipeptides have been identified in fungi. Clavariopsins A (342) and B (343) were produced by an aquatic hyphomycetes, *Clavariopsis aquatic* [217]. Both showed antifungal activity by inhibiting fungal cell wall biosynthesis [218]. Four tachykinin (NK₂) receptor inhibitors, SCH 217048 (346), SCH 378161 (348), SCH 378167 (349) and SCH 378199 (350) were isolated from a taxonomically unidentified fungus. They were selective and competitive receptor antagonists of the human NK₂ receptor [219]. Both Sch 217048 (346) and Sch 378161 (348) were also isolated from the freshwater fungus *Clothesomyces aquaticus* [220].

Table 8. Fungal cyclic decadepsipeptides and their biological activities.

| Name                | Fungus and Its Origin                              | Biological Activity                  | References  |
|---------------------|---------------------------------------------------|--------------------------------------|-------------|
| Clavariopsin A (342)| Aquatic hyphomycetes *Clavariopsis aquatic*       | Antifungal activity                  | [217,218]   |
| Clavariopsin B (343)| Aquatic hyphomycetes *Clavariopsis aquatic*       | Antifungal activity                  | [217,218]   |
| Eujavanicin A (344) | *Eupenicillium javanicum*                         | Antifungal activity                  | [221]       |
| Pleosporin A (345)  | Unidentified elephant dung fungus of the family Pleosporaceae | Antimalarial activity               | [222]       |
| Sch 217048 (346)    | Unidentified fungus                               | Neurokinin antagonist activity       | [223]       |
|                     |                                                   | Inhibition on tachykinin receptor    | [219]       |
| Sch 218157 (347)    | Unidentified elephant dung fungus of the family Pleosporaceae | Antimalarial activity on *Plasmodium falciparum* K1 | [222]       |
| Freshwater fungus *Clothesomyces aquaticus* | -                                               | -                                    | [220]       |
| Sch 378161 (348)    | Unidentified elephant dung fungus of the family Pleosporaceae | Antimalarial activity on *Plasmodium falciparum* K1 | [222]       |
| Freshwater fungus *Clothesomyces aquaticus* | -                                               | -                                    | [220]       |
| Sch 378167 (349)    | Unidentified fungus                               | Inhibition on tachykinin receptor    | [219]       |
| Sch 378199 (350)    | Unidentified fungus                               | Inhibition on tachykinin receptor    | [219]       |
10. Cyclic Tridecadepsipeptides

Up to now, only two tridecadepsipeptides namely FR901469 (351) and petriellin A (352) have been identified in fungi [224]. Their structures are shown in Figure 9. FR901469 (351) was isolated from an unidentified fungus No.11243. This compound displayed antifungal activity by inhibiting 1,3-β-glucan synthase with an IC$_{50}$ value of 0.05 µg/mL [224]. Petriellin A (352) was obtained from the coprophilous fungus Petriella sordida. It exhibited antifungal activity against Ascobolus furfuraceus (NRRL 6460) and Sordaria fimicola (NRRL 6459) [225].
11. Conclusions and Future Perspectives

In this review, we describe the chemistry and biology of the CDPs discovered from fungi during the past 50 years. It is worth mentioning that more and more CDPs have been isolated from plant endophytic and marine-derived fungi which indicate that plant-derived endophytic and marine-driven fungi are the mines of biologically active natural products [10,13,226–228]. Some invertebrate derived CDPs (e.g., from sponge origin) are actually synthesized by the symbiotic microorganisms [229]. In addition, some minor or new CDPs have been identified in fungi with the application of new techniques such as LC-MS/MS [230], reverse genetics [196], genomics [138], epigenetic manipulation [62], and combinatorial biosynthesis [231,232].

Fungal CDPs are mainly reported from the genera *Acremonium*, *Alternaria*, *Aspergillus*, *Beauveria*, *Fusarium*, *Isaria*, *Metarhizium*, *Penicillium*, and *Rosellina*. Among the CDPs, cyclic hexadepsipeptides account for the largest proportion. Most of them are mycotoxins such as beauvenniatins, beauvericins, destruxins, and enniatins [16–19]. Compared to the cyclic peptides only with amide bonds [14,15], the ring size of CDPs seems to be smaller.

Many fungal CDPs such as aureobasidins (305–333), beauvericin (112), paecilodepsipeptide A (248) and sansalvamide A (87), show an interesting spectrum of biological activities, can be used as
either drug candidates or lead compounds for drug development [21]. Their potential applications as antitumor agents, herbicides, antimicrobials, and insecticides have attracted considerable interest within the pharmaceutical and agrochemical companies [19,233–235]. Chemical syntheses have been achieved for many bioactive CDPs such as aspergillicin F (99) [84], enniatin B (180) [236], PF1022A (293) [194], and zygosporamide (88) [237]. The biosynthetic pathways of some fungal CDPs such as beauvericin (112) [238], enniatin (177) [239], fusaristatin A (51) and W493 B (286) [240], verlamelin (283) [241] have also been revealed. They were considered to be biosynthesized by the non-ribosomal peptide synthetases (NRPS) [231].

Some fungal CDPs are currently in clinical use or have entered human clinical trials as antibiotic or anticancer agents. Some have been developed into commercial products [18,19,22]. The noteworthy example is the antihelmintic agent emodepside which is a semisynthetic derivative of PF1022A (293), a cyclic octadepsipeptide from the endophytic fungus Rosellina sp. PF1022 derived from the leaves of Camellia japonica [191]. Emodepside binds to a presynaptic latrophilin receptor and interacts with a calcium-activated potassium channel. Both modes of action cause paralysis and death of the nematode [242]. It is employed against gastrointestinal and extraintestinal parasites such as nematodes in veterinary medicine [193]. Another example is fusafungine, a mixture of enniatins, which is an antibacterial for the treatment of rhinosinusitis in nasal spray [18]. However, fusafungine has been recently withdrawn from the EU market since enniatins have been previously identified as mycotoxins which pose a potential health hazard on humans or animals [243–245]. The third example is the direct application of destruxins as insecticidal agents [19]. Destruxins were isolated from a variety of fungi such as Metarrhizium anisopliae [16], Beauveria felina [123], and Ophiocordyceps coccidiicola [128]. With the increasing understanding of the biosynthetic pathways of some fungal CDPs, we can rationally design bioengineering approaches such as chemoenzymatics, mutasynthesis, site-directed mutagenesis, and combinatorial biosynthesis. We may be able to effectively not only increase the yields of bioactive CDPs, but also block the biosynthesis of some toxic depsipeptides [231,246].

Acknowledgments: This work was co-financed by the grants from the National Key R & D Program of China (2017YFD0201105), and the National Natural Science Foundation of China (31271996).

Author Contributions: Xiaohan Wang performed bibliographic research, drafted and corrected the manuscript. Xiao Gong and Peng Li retrieved literature, participated in the discussions and supported manuscript corrections. Daowan Lai reviewed the manuscript and helped to revise it. Ligang Zhou conceived the idea, designed the review structure, supervised manuscript drafting, and revised the manuscript. All authors read and approved the final manuscript.

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

References
1. Sivanathan, S.; Scherkenbeck, J. Cyclodepsipeptides: A rich source of biologically active compounds for drug research. Molecules 2014, 19, 12368–12420. [CrossRef] [PubMed]
2. Taevernier, L.; Wynendaele, E.; De Vreese, L.; Burvenich, C.; De Spiegeleer, B. The mycotoxin definition reconsidered towards fungal cyclic depsipeptides. J. Environ. Sci. Health C 2016, 34, 114–135. [CrossRef] [PubMed]
3. Taevernier, L.; Wynendaele, E.; Gevaert, B.; De Spiegeleer, B. Chemical classification of cyclic depsipeptides. Curr. Protein Pept. Sci. 2017, 18, 425–452. [CrossRef] [PubMed]
4. Ye, X.; Anjum, K.; Song, T.; Wang, W.; Liang, Y.; Chen, M.; Huang, H.; Lian, X.-Y.; Zhang, Z. Antiproliferative cyclodepsipeptides from the marine actinomycete Streptomyces sp. P11-23B downregulating the tumor metabolic enzymes of glycolysis, glutaminolysis, and lipogenesis. Phytochemistry 2017, 135, 151–159. [CrossRef] [PubMed]
5. Fujioka, M.; Koda, S.; Morimoto, Y.; Biemann, K. Structure of FR900359, a cyclic depsipeptide from Ardisia crenata Sims. J. Org. Chem. 1988, 53, 2820–2825. [CrossRef]
6. Yang, G.-Z.; Li, Y.-C. Cyclopeptide and terpenoids from Tripterygium wilfordii Hook. F. Helv. Chim. Acta 2002, 85, 168–174. [CrossRef]
30. Schlingmann, G.; Milne, L.; Williams, D.R.; Carter, G.T. Cell wall active antifungal compounds produced by the marine fungus Hypoxylon oceanicum LL-15G256. II. Isolation and structure determination. J. Antibiot. 1998, 51, 303–316. [CrossRef] [PubMed]

31. Albaugh, D.; Albert, G.; Bradford, P.; Cotter, V.; Froyd, J.; Gaughran, D.R.; Lai, M.; Rehnig, A.; Sieverding, E.; et al. Cell wall active antifungal compounds produced by the marine fungus Hypoxylon oceanicum LL-15G256. III. Biological properties of 15G256. J. Antibiot. 1998, 51, 317–322. [CrossRef] [PubMed]

32. Ueno, T.; Nakashima, T.; Hayashi, Y.; Fukami, H. Structures of AM-toxin I and II, host specific phytotoxic metabolites produced by Alternaria mali. Agric. Biol. Chem. 1975, 39, 1115–1122. [CrossRef]

33. Ueno, T.; Nakashima, T.; Hayashi, Y.; Fukami, H. Isolation and structure of AM-toxin III, a host specific phytotoxic metabolite produced by Alternaria mali. Agric. Biol. Chem. 1975, 39, 2081–2082. [CrossRef]

34. Miyashita, M.; Nakamori, T.; Miyagawa, H.; Akamatsu, M.; Ueno, T. Inhibitor activity of analogs of AM-toxin, a host-specific phytotoxin from the Alternaria alternata apple pathotype, on photosynthetic O2 evolution in apple leaves. Biosci. Biotechnol. Biochem. 2003, 67, 635–638. [CrossRef] [PubMed]

35. Bao, J.; Zhang, X.-Y.; Xu, X.-Y.; He, F.; Nong, X.-H.; Qi, S.-H. New cyclic tetrapeptides and asteltoxins from gorgonian-derived fungus Aspergillus sp. SCSAF 0076. Tetrahedron 2013, 69, 2113–2117. [CrossRef]

36. Mochizuki, K.; Ohmori, K.; Tamura, H.; Shizuri, Y.; Nichiyama, S.; Miyoshi, E.; Yamamura, S. The structures of biactive cyclodepsipeptides, beauveriolides I and II, metabolites of entomopathogenic fungi Beauveria sp. Bull. Chem. Soc. Jpn. 1993, 66, 3041–3046. [CrossRef]

37. Namatame, I.; Tomoda, H.; Tabata, N.; Si, S.; Omura, S. Structure elucidation of fungal beauveriolide III, a novel inhibitor of lipid droplet formation in mouse macrophages. J. Antibiot. 1999, 52, 7–12. [CrossRef] [PubMed]

38. Matsuda, D.; Namatame, I.; Tomoda, H.; Kobayashi, S.; Zocher, R.; Kleinkauf, H.; Omura, S. New beauveriolides produced by amino acid-supplemented fermentation of Beauveria sp. FO-6979. J. Antibiot. 2004, 57, 1–9. [CrossRef] [PubMed]

39. Ohshiro, T.; Kobayashi, K.; Ohba, M.; Matsuda, D.; Rudel, L.L.; Takahashi, T.; Doi, T.; Tomoda, H. Selective inhibition of sterol O-acyltransferase 1 isozyme by beauveriolide III in intact cells. Sci. Rep. 2017, 7, 4163. [CrossRef] [PubMed]

40. Jiang, W.; Ye, P.; Chen, C.-T.A.; Wang, K.; Liu, P.; He, S.; Wu, X.; Gan, L.; Ye, Y.; Wu, B. Two novel hepatocellular carcinoma cycle inhibitory cyclodepsipeptides from a hydrothermal vent carab-associated fungus Aspergillus clavatus C2WU. Mar. Drugs 2013, 11, 4761–4772. [CrossRef] [PubMed]

41. Ye, P.; Shen, L.; Jiang, W.; Ye, L.; Chen, C.A.; Wu, X.; Wang, K.; Wu, B. Zn-driven discovery of a hydrothermal vent fungal metabolite clavatustide C, and an experimental study of the anti-cancer mechanism of c.avatustide B. Mar. Drugs 2014, 12, 3023–3027. [CrossRef] [PubMed]

42. Shiono, Y.; Tsuchinari, M.; Shimanuki, K.; Miyajima, T.; Murayama, T.; Koseki, T.; Laatsch, H.; Funakoshi, T.; Takanami, K.; Suzuki, K. Fusarstatins A and B, two new cyclic lipopeptides from an endophytic Fusarium sp. Mar. Drugs 2013, 11, 1795–1799. [CrossRef]

43. Li, G.; Kusari, S.; Christopher, G.; Strohmann, C.; Spiteller, M. Three cyclic pentapeptides and a cyclic lipopeptide produced by endophytic Fusarium decemcellulare LG53. RSC Adv. 2016, 6, 54092–54098. [CrossRef]

44. Morino, T.; Masuda, A.; Yamada, M.; Nishimoto, M.; Nishikiori, T.; Saito, S.; Shimada, N. Stevastelins, novel immunosuppressants produced by Penicillium. J. Antibiot. 1994, 47, 1341–1343. [CrossRef] [PubMed]

45. Morino, T.; Shimada, K.; Masuda, A.; Yamashita, N.; Nishimoto, M.; Nishikiori, T.; Saito, S. Structural determination of stevastelins, novel depsipeptides from Penicillium sp. J. Antibiot. 1996, 49, 564–568. [CrossRef] [PubMed]

46. Morino, T.; Shimada, K.; Masuda, A.; Nishimoto, M.; Saito, S. Stevastelins, novel congeners from a high producing mutant of Penicillium sp. J. Antibiot. 1996, 49, 1049–1051. [CrossRef] [PubMed]

47. Hamaguchi, T.; Masuda, A.; Morino, T.; Osada, H. Stevastelins, a novel of immunosuppressants, inhibit dual-specificity protein phosphatases. Chem. Biol. 1997, 4, 279–286. [CrossRef]

48. Russell, D.W. Angolide, a naturally-occurring cyclotetradepsipeptide with twelve-membered ring, J. Chem. Soc. 1965, 1965, 4664–4668. [CrossRef]

49. Elsworth, J.F.; Grove, J.F. Cyclodepsipeptides from Beauveria bassiana. Part 2. Beauveriolides A to F and their relationship to isarolide. J. Chem. Soc. Perkin Trans. I 1980, 8, 1795–1799. [CrossRef]
50. Grove, J.F. Cyclodepsipeptides from *Beauveria bassiana*. Part 3. The isolation of beauverolides Ba, Ca, Ja, and Ka. *J. Chem. Soc. Perkin Trans. 1* 1980, 12, 2878–2880. [CrossRef]

51. Isogai, A.; Kanaoka, M.; Matsuda, H.; Horii, Y.; Suzuki, A. Structure of a new cyclodepsipeptide, beauverilide A from *Beauveria bassiana*. *Agric. Biol. Chem.* 1978, 42, 1797–1798. [CrossRef]

52. Nakaya, S.; Mizuno, S.; Ishigami, H.; Yamakawa, Y.; Kawagishi, H.; Ushimaru, T. New rapid screening method for anti-aging compounds using budding yeast and identification of beauveriolide I as a potent active compound. *Biosci. Biotechnol. Biochem.* 2012, 76, 1226–1228. [CrossRef] [PubMed]

53. Elsworth, J.F.; Grove, J.F. Cyclodepsipeptides from *Beauveria bassiana*. Part 1. Beauverolides H and I. *J. Chem. Soc. Perkin Trans. 1* 1977, 3, 270–273. [CrossRef]

54. Jegorov, A.; Sedmera, P.; Matha, V.; Simek, P.; Zhradnickova, H.; Landa, Z.; Eyal, J. Beauverolides L and La from *Beauveria tenella* and *Paecilomyces fumosoroseus*. *Phytochemistry* 1994, 37, 1301–1303. [CrossRef]

55. Kuzma, M.; Jegorov, A.; Kacer, P.; Havlicek, V. Sequencing of new beauverolides by high-performance liquid chromatography and mass spectrometry. *J. Mass Spectrom.* 2001, 36, 1108–1115. [CrossRef] [PubMed]

56. Wang, F.; Jiang, J.; Hu, S.; Ma, H.; Zhu, H.; Tong, Q.; Cheng, L.; Hao, X.; Zhang, G.; Zhang, Y. Secondary metabolites form endophytic fungus *Chaetomium* sp. induce colon cancer cell apoptotic death. *Fitoterapia* 2017, 121, 86–93. [CrossRef] [PubMed]

57. Shimada, K.; Morino, T.; Masuda, A.; Sato, M.; Kitagawa, M.; Saito, S. Absolute structural determination of stevastelin B. *J. Antibiot.* 1996, 49, 569–574. [CrossRef] [PubMed]

58. Kim, M.; Sohn, J.; Ahn, J.; Oh, H. Alternaramide, a cyclic depsipeptide from the marine-derived fungus *Alternaria* sp. SF-5016. *J. Nat. Prod.* 2009, 72, 2065–2068. [CrossRef] [PubMed]

59. Ko, W.; Sohn, J.H.; Jang, J.-H.; Ahn, J.S.; Kang, D.G.; Lee, H.S.; Kim, J.-S.; Kim, Y.-C.; Oh, H. Inhibitory effects of alternaramide on inflammatory mediator expression through TLR4-MyD88-mediated inhibition of NF-κB and MAPK pathway signaling in lipopolysaccharide-stimulated RAW264.7 and BV2 cells. *Chem.-Biol. Interact.* 2016, 244, 16–26. [CrossRef] [PubMed]

60. Jackson, M.; Burren, N.S.; Karwowsky, J.P.; Alder, L.A.; Humphrey, P.E.; Hohl, W.L.; McAlpine, J.B. Aselacins, novel compounds that inhibit binding of endothelin to its receptor. I. The production organism, fermentation and biological activity. *J. Antibiot.* 1994, 47, 523–527. [CrossRef] [PubMed]

61. Hochlowski, J.E.; Hill, P.; Whittern, D.N.; Scherr, M.H.; Rasmussen, R.R.; Dorwin, S.A.; McAlpine, J.B. Aselacins, novel compounds that inhibit binding of endothelin to its receptor. II. Isolation and elucidation of structures. *J. Antibiot.* 1994, 47, 528–535. [CrossRef] [PubMed]

62. Vervoort, H.C.; Draskovic, M.; Crews, P. Histone deacetylase inhibitors as a tool to up-regulate new fungal biosynthetic products: Isolation of EGM-556, a cyclodepsipeptide, from *Microascus* sp. *Org. Lett.* 2011, 13, 410–413. [CrossRef] [PubMed]

63. Fukuda, T.; Sudoh, Y.; Tsuchiya, Y.; Okuda, T.; Matsuura, N.; Motojima, A.; Oikawa, T.; Igashiri, Y. Hikiamides A–C, cyclic pentadepsipeptides from *Fusarium* sp. TAMA 456. *J. Nat. Prod.* 2015, 78, 797–802. [CrossRef] [PubMed]

64. Kawahara, T.; Takagi, M.; Shin-ya, K. Three new depsipeptides, JBIR-113, JBIR-114 and JRIR-115, isolated from a marine sponge-derived *Penicillium* sp. *J. Antibiot.* 2012, 65, 147–150. [CrossRef] [PubMed]

65. Fill, T.P.; Pallini, H.F.; Amaral, L.S.; Silva, J.V.; Bidoia, D.L.; Peron, F.; Garcia, F.P.; Nakamura, C.V.; Rodrigues-Filho, E. Copper and manganese cations alter secondary metabolism in the fungus *Paecilomyces fumosoroseus*. *Fitoterapia* 2013, 84, 350–355. [CrossRef] [PubMed]

66. Hamano, K.; Kinoshita, M.; Furuuya, K.; Miyamoto, M.; Takamatsu, Y.; Hemmi, A.; Tanaka, K. Leualacin, a novel calcium blocker from *Hapsidospora irregularis*. I. Taxonomy, fermentation, isolation, physio-chemical and biological properties. *J. Antibiot.* 1992, 45, 899–905. [CrossRef] [PubMed]

67. Hamano, K.; Kinoshita, M.; Tanaka, K.; Yoda, K.; Ohki, Y.; Nakamura, T.; Kinoshita, T. Leualacin, a novel calcium blocker from *Hapsidospora irregularis*. II. Structure determination. *J. Antibiot.* 1992, 45, 906–913. [CrossRef] [PubMed]

68. Zhang, S.; Qiu, Y.; Kakule, T.B.; Lu, Z.; Xu, F.; Lamb, J.G.; Reilly, C.A.; Zheng, Y.; Sham, S.W.S.; Xuan, L.; et al. Identification of cyclic depsipeptides and their dedicated synthetase from *Hapsidospora irregularis*. *J. Nat. Prod.* 2017, 80, 363–370. [CrossRef] [PubMed]

69. Ward, D.E.; Vazquez, A.; Pedras, M.S.C. Probing host-selective phytotoxicity: Synthesis and biological activity of phomalide, isophomalide, and dihydrophomalide. *J. Org. Chem.* 1999, 64, 1657–1666. [CrossRef] [PubMed]
Luangsa-Ard, J.J.; Berkaew, P.; Ridkaew, R.; Hywel-Jones, N.L.; Isaka, M. A beauvericin hot spot in the genus Fusarium. *Tetrahedron Lett.* **1999**, *40*, 2913–2916. [CrossRef]  
Hwang, Y.; Rowley, D.; Rhodes, D.; Gertsch, J.; Fenical, W.; Bushman, F. Mechanism of inhibition of a poxvirus topoisomerase by the marine natural product sansalvamide A. *Mol. Pharmacol.* **1999**, *55*, 1049–1053. [CrossRef] [PubMed]  
Liu, S.; Gu, W.; Lo, D.; Ding, X.-Z.; Ujiki, M.; Adrian, T.E.; Soff, G.A.; Silverman, R.B. N-Methylsansalvamide A peptide analogues. Potent new antitumor agents. *J. Med. Chem.* **2005**, *48*, 3630–3638. [CrossRef] [PubMed]  
Zhang, G.; Liu, S.; Liu, Y.; Wang, F.; Ren, J.; Gu, J.; Zhou, K.; Shan, B. A novel cyclic pentapeptide, H-10, inhibits B16 cancer cell growth and induces cell apoptosis. *Oncol. Lett.* **2014**, *8*, 248–252. [CrossRef] [PubMed]  
Oh, D.; Jensen, P.R.; Fenical, W. Zygosporamidine, a cytotoxic cyclic depsipeptide from the marine-derived fungus *Zygosporium nasonii*. *Tetrahedron Lett.* **2006**, *47*, 8625–8628. [CrossRef]  
McCorkindale, N.J.; Baxter, R.L. Brevigellin, a benzoylated cyclodepsipeptide from *Penicillium brevicompactum*. *Tetrahedron* **1981**, *37*, 1795–1801. [CrossRef]  
Ortiz-López, F.J.; Monteiro, M.C.; González-Menéndez, V.; Tormo, J.R.; Geniloud, O.; Bills, G.F.; Vicente, F.; Zhang, C.; Roemer, T.; Singh, S.B.; et al. Cyclic colisporifungin and linear cavinafungins, antifungal lipopeptides isolated from *Colispora cavincia*. *J. Nat. Prod.* **2015**, *78*, 468–475. [CrossRef] [PubMed]  
Kawahara, T.; Itoh, M.; Kozone, I.; Izumikawa, M.; Sakata, N.; Tsuchida, T.; Shin-ya, K. MBJ-0110, a novel cyclopeptide isolated from the fungus *Penicillium sp.* i25267. *J. Antibiot.* **2016**, *69*, 66–68. [CrossRef] [PubMed]  
Song, H.; Lee, H.; Lee, C. A new cytotoxic cyclic pentadepsipeptide, neo-N-methylsansalvamide produced by *Fusarium solani* KCCM90040, isolated from potato. *Food Chem.* **2011**, *126*, 472–478. [CrossRef]  
Cueto, M.; Jensen, P.R.; Fenical, W. N-methylsansalvamide, a cytotoxic cyclic depsipeptide from a marine fungus of the genus *Fusarium*. *Phytochemistry* **2000**, *55*, 223–226. [CrossRef]  
Bringmann, G.; Lang, G.; Steffens, S.; Schaumann, K. Petrosifungins A and B, novel cyclodepsipeptides from a sponge-derived strain of *Penicillium brevicompactum*. *J. Nat. Prod.* **2004**, *67*, 311–315. [CrossRef] [PubMed]  
Rahman, R.; Taylor, A.; Das, B.C.; Verpoorte, J.A. A new depsipeptide from *Pithomyces chartarum*. *Can. J. Chem.* **1976**, *54*, 1360–1364. [CrossRef]  
Capon, R.J.; Skene, C.; Stewart, M.; Ford, J.; O’Hair, R.A.J.; Williams, L.; Lacey, E.; Gill, J.H.; Friedel, T. Aspergillicins A–E: Five novel depsipeptides from the marine-drived fungus *Aspergillus carneus*. *Org. Biomol. Chem.* **2003**, *1*, 1856–1862. [CrossRef]  
Kikuchi, H.; Hoshikawa, T.; Fujimura, S.; Sakata, N.; Kurata, S.; Katou, Y.; Oshima, Y. Isolation of a cyclic depsipeptide, aspergillicin F, and synthesis of aspergillicins with innate immune-modulating activity. *J. Nat. Prod.* **2015**, *78*, 1949–1956. [CrossRef] [PubMed]  
Isaka, M.; Yangchum, A.; Sappan, M.; Suvannakad, R.; Srikitikulchai, P. Cyclohexadepsipeptides from *Acremonium* sp. BBC 28424. *Tetrahedron* **2011**, *67*, 7929–7935. [CrossRef]  
Tian, J.; Han, J.-J.; Zhang, X.; He, L.-W.; Zhang, Y.-J.; Bao, L.; Liu, H.-W. New cyclohexadepsipeptides from an entomogenous fungus *Fusarium proliferatum* and their cytotoxicity and autophagy-inducing activity. *Chem. Biodivers.* **2016**, *13*, 852–860. [CrossRef] [PubMed]  
Bunyapaiboonsri, T.; Yongvilai, P.; Auncharoen, P.; Isaka, M. Cyclohexadepsipeptides from the filamentous fungus *Acremonium* sp. BBC 6292. *Helv. Chim. Acta* **2012**, *95*, 963–972. [CrossRef]  
Hamill, R.L.; Higgens, C.E.; Boaz, H.E.; Gorman, M. The structure of beauvericin, a new depsipeptide antibiotic toxic to *Artemia salina*. *Tetrahedron Lett.* **1969**, *49*, 4255–4258. [CrossRef]  
Laungs-Ard, J.J.; Berkaw, P.; Ridkaew, R.; Hywel-Jones, N.L.; Isaka, M. A beauvericin hot spot in the genus *Isaria*. *Mycol. Res.* **2009**, *113*, 1389–1395. [CrossRef] [PubMed]  
Zhang, H.; Hu, W.; Xiao, M.; Ou, S.; Hu, Q. Destruxin A induces and binds HSPs in *Bombbyx mori* Bm12 cells. *J. Agric. Food Chem.* **2017**, *65*, 9849–9853. [CrossRef] [PubMed]  
Tomoda, H.; Nishida, H.; Huang, X.-H.; Masuma, R.; Kim, Y.K.; Omura, S. New cyclohexadepsipeptides, enniatins D, E and F produced by *Fusarium* sp. FO-1305. *J. Antibiot.* **1992**, *45*, 1207–1215. [CrossRef] [PubMed]  
Tomoda, H.; Huang, X.-H.; Cao, J.; Nishida, H.; Nagao, R.; Okuda, S.; Tanaka, H.; Omura, S.; Arai, H.; Inoue, K. Inhibition of acyl-CoA:cholesterol acyltransferase activity by cyclohexadepsipeptide antibiotics. *J. Antibiot.* **1992**, *45*, 1626–1632. [CrossRef] [PubMed]
106. Amagata, T.; Morinaka, B.I.; Amagata, A.; Tenney, K.; Valeriote, F.A.; Lobkovsky, E.; Clardy, J.; Crews, P.
102. Isaka, M.; Palasarn, S.; Lapanun, S.; Striklung, K. Peacilodepsipeptide A, an antimalarial and antitumor
97. Deffieux, G.; Merlet, D.; Baute, R.; Bourgeois, G.; Baute, M.A.; Neveu, A. New insecticidal cyclodepsipeptides
93. Lee, H.-S.; Song, H.-H.; Jeong, J.-H.; Shin, C.-G.; Choi, S.-U.; Lee, C. Cytotoxicities of enniatins H, I, and
108. Huang, H.; She, Z.; Lin, Y.; Vrijmoed, L.L.P.; Lin, W. Cyclic peptides from an endophytic fungus obtained
107. Zhang, A.H.; Wang, X.Q.; Han, W.B.; Sun, Y.; Guo, Y.; Wu, Q.; Ge, H.M.; Song, Y.C.; Ng, S.W.; Xu, Q.; et al.
105. Sy-Cordero, A.A.; Graf, T.N.; Adcock, A.F.; Kroll, D.J.; Shen, Q.; Swanson, S.M.; Wani, M.C.; Pearce, C.J.;
104. Wang, X.; Hu, C.; Wang, S.; Zhang, A.; Chen, W.; Shen, Y.; Tan, R.; Wu, X.; Sun, Y.; et al. Anti-inflammatory mechanism involving excessive activation of autophagy in activated T lymphocytes. J. Investig. Dermatol. 2016, 136, 1636–1646. [CrossRef] [PubMed]
103. Che, Y.; Swenson, D.C.; Gloer, J.B.; Koster, B.; Malloch, D. Pseudodestruxins A and B: New cyclic depsipeptides from the coprophilous fungus Nigrosabulum globosum. J. Nat. Prod. 2001, 64, 555–558. [CrossRef] [PubMed]
102. Isaka, M.; Palasarn, S.; Lapanun, S.; Striklung, K. Peacilodepsipeptide A, an antimalarial and antitumor cyclodepsipeptide from the insect pathogenic fungus Peacilomyces cinnamomeus Bacillus BCC 9616. J. Nat. Prod. 2007, 70, 675–678. [CrossRef] [PubMed]
100. Wu, H.M.; Lin, L.P.; Xu, Q.L.; Han, W.B.; Zhang, S.; Liu, Z.W.; Mei, Y.N.; Yao, Z.J.; Tan, R.X. Nodupetide, a potent insecticide and antimicrobial from Nodulisporium sp. associated with Riptortus pedestris. Tetrahedron Lett. 2017, 58, 663–665. [CrossRef]
101. Lang, G.; Mitova, M.I.; Ellis, G.; van der Sar, S.; Phipps, R.K.; Blunt, J.W.; Cummings, N.J.; Cole, A.L.J.; Munro, M.H.G. Bioactivity profiling using HPLC/microtiter-plate analysis: Application to a New Zealand marine alga-derived fungus, Gliocladium sp. J. Nat. Prod. 2006, 69, 621–624. [CrossRef] [PubMed]
103. Che, Y.; Swenson, D.C.; Gloer, J.B.; Koster, B.; Malloch, D. Pseudodestruxins A and B: New cyclic depsipeptides from the coprophilous fungus Nigrosabulum globosum. J. Nat. Prod. 2001, 64, 555–558. [CrossRef] [PubMed]
104. Wang, X.; Hu, C.; Wu, X.; Wang, S.; Zhang, A.; Chen, W.; Shen, Y.; Tan, R.; Wu, X.; Sun, Y.; et al. Anti-inflammatory mechanism involving excessive activation of autophagy in activated T lymphocytes. J. Investig. Dermatol. 2016, 136, 1636–1646. [CrossRef] [PubMed]
105. Sy-Cordero, A.A.; Graf, T.N.; Adcock, A.F.; Kroll, D.J.; Shen, Q.; Swanson, S.M.; Wani, M.C.; Pearce, C.J.; Oberlies, N.H. Cyclodepsipeptides, sesquiterpenoids, and other cytotoxic metabolites from the filamentous fungus Trichothecium sp. (MSX 51320). J. Nat. Prod. 2011, 74, 2137–2142. [CrossRef] [PubMed]
106. Amagata, T.; Morinaka, B.I.; Amagata, A.; Tenney, K.; Valeriote, F.A.; Lobkovsky, E.; Clardy, J.; Crews, P.
107. Zhang, A.H.; Wang, X.Q.; Han, W.B.; Sun, Y.; Guo, Y.; Wu, Q.; Ge, H.M.; Song, Y.C.; Ng, S.W.; Xu, Q.; et al. Discovery of a new class of immunosuppressants from Trichothecium roseum co-inspired by cross-kindom similarity in innate immunity and pharmacophore motif. Chem. Asian J. 2013, 8, 3101–3107. [CrossRef] [PubMed]
108. Huang, H.; She, Z.; Lin, Y.; Vrijmoed, L.L.P.; Lin, W. Cyclic peptides from an endophytic fungus obtained from a mangrove leaf (Kandelia candel). J. Nat. Prod. 2007, 70, 1696–1699. [CrossRef] [PubMed]
109. Nilanonta, C.; Isaka, M.; Kittakoop, P.; Trakulnaleamsai, S.; Tanticharoen, M.; Thebtaranonth, Y. Precursor-directed biosynthesis of beauvericin analogs by the insect pathogenic fungus Paecilomyces tenuipes BCC 1614. Tetrahedron 2002, 58, 3355–3360. [CrossRef]
110. Deng, C.-M.; Liu, S.-X.; Huang, C.-H.; Pang, J.-Y.; Lin, Y.-C. Secondary metabolites of a mangrove endophytic fungus Aspergillus terreus (No. GX7-3B) from the South China Sea. Mar. Drugs 2013, 11, 2616–2624. [CrossRef] [PubMed]
111. Xu, Y.; Zhan, J.; Wijeratne, E.M.K.; Burns, A.M.; Gunatilaka, A.A.L.; Molnar, I. Cytotoxic and antihaptotactic beauvericin analogues from precursor-directed biosynthesis with the insect pathogen Beauveria bassiana ATCC 7159. J. Nat. Prod. 2007, 70, 1467–1471. [CrossRef] [PubMed]
112. Wang, J.; Zhang, D.-M.; Jia, J.-F.; Peng, Q.-L.; Tian, H.-Y.; Wang, L.; Ye, W.-C. Cyclodepsipeptides from the ascocarps and insect-body portions of fungus Cordyceps cicadae. Fitoterapia 2014, 97, 23–27. [CrossRef] [PubMed]
113. Wang, J.; Zhang, D.-M.; Jia, J.-F.; Peng, Q.-L.; Tian, H.-Y.; Wang, L.; Ye, W.-C. Cyclodepsipeptides from the ascocarps and insect-body portions of fungus Cordyceps cicadae. Fitoterapia 2014, 97, 23–27. [CrossRef] [PubMed]
114. Nilanonta, C.; Isaka, M.; Kittakoop, P.; Palittapongarnpim, P.; Kamonvongpaisan, S.; Pitayakajhatorn, D.; Tanticharoen, M.; Thebtaranonth, Y. Antimycobacterial and antiplasmodial cyclodepsipeptides from the insect pathogenic fungus Paecilomyces tenuipes BCC 1614. Planta Med. 2000, 66, 756–758. [CrossRef] [PubMed]
115. Fukuda, T.; Arai, M.; Tomoda, H.; Omura, S. New beauvericins, potentiators of antifungal miconazole activity, produced by Beauveria sp. FKI-1366. II. Structure elucidation. J. Antibiot. 2004, 57, 117–124. [CrossRef] [PubMed]
116. Kawazu, K.; Murakami, T.; Ono, Y.; Kanzaki, H.; Kobayashi, A.; Mikawa, T.; Yoshikawa, N. Isolation and characterization of two novel nematicidal depsipeptides from an imperfect fungus, strain D1084. Biosci. Biotechnol. Biochem. 1993, 57, 98–101. [CrossRef] [PubMed]
117. Umeyama, A.; Takahashi, K.; Grudniewska, A.; Shimizu, M.; Hayashi, S.; Kato, M.; Okamoto, Y.; Suenaga, M.; Ban, S.; Kumada, T.; et al. In vitro antitrypanosomal activity of the cyclodepsipeptides, cardinalisamides A–C, from the insect pathogenic fungus Cordyceps cardinalis NBRC 103832. J. Antibiot. 2014, 67, 163–166. [CrossRef] [PubMed]
118. Isaka, M.; Palasarn, S.; Supothina, S.; Komwijit, S.; Luangsa-ard, J. Bioactive compounds from the scale insect pathogenic fungus Cordyceps cardinalis ATCC 7159. J. Nat. Prod. 1987, 50, 400–407. [CrossRef] [PubMed]
119. Wahlman, M.; Davidson, B.S. New destruxins from the entomopathogenic fungus Metarhizium anisopliae. J. Nat. Prod. 1993, 56, 643–647. [CrossRef] [PubMed]
120. Suzuki, A.; Yeh, S.F.; Ong, G.-T.; Tian, H.-Y.; Wang, L.; Ye, W.-C. Cyclodepsipeptides from the ascocarps and insect-body portions of fungus Cordyceps cicadae. Fitoterapia 2014, 97, 23–27. [CrossRef] [PubMed]
121. Ayer, W.A.; Pena-Rodriguez, L.M. Metabolites produced by Alternaria brassicae, the black spot pathogen of canola. Part I, the phytotoxic components. J. Nat. Prod. 1987, 50, 400–407. [CrossRef] [PubMed]
122. Krasnoff, S.B.; Gibson, D.M. New destruxins from the entomopathogenic fungus Aschersonia sp. J. Nat. Prod. 1996, 59, 485–489. [CrossRef]
130. Cai, P.; Smith, D.; Katz, B.; Pearce, C.; Venables, D.; Houck, D. Dextruxin-A4 chlorohydrin, a novel destruxin from fungus OS-F68576: Isolation, structure determination, and biological activity as an inducer of erythropoietin. J. Nat. Prod. 1998, 61, 290–293. [CrossRef] [PubMed]

131. Kao, M.-C.; Rao, Y.K.; Hsieh, Y.-W.; Weng, S.-H.; Lu, T.-L.; Tzeng, D.T.W.; Liu, J.-J.; Lin, C.-J.; Lai, C.-H.; Tzeng, Y.-M. A cyclohexadepsipeptide from entomogenous fungi Metarhizium anisopliae inhibits the Helicobacter pylori induced pathogenesis through attenuation of vacuolating cytotoxin-A activity. Process Biochem. 2015, 50, 134–139. [CrossRef]

132. Kim, H.S.; Jung, M.H.; Ahn, S.; Lee, C.W.; Kim, S.N.; Ok, J.H. Structure elucidation of a new cyclic destruxin antibiotic from Alternaria brassicae in culture and leaves of Brassica napus. Phytochemistry 1991, 30, 2311–2316. [CrossRef]

133. Buchwaldt, L.; Jensen, J.S. HPLC purification of destruxins produced by Verticillium hemipterigenum. Phytochemistry 1998, 49, 1815–1817. [CrossRef]

134. Jegorov, A.; Sedmera, P.; Havlicek, V.; Mat‘haa, V. Destruxin Ed1, a cyclopeptide from the fungus Metarhizium anisopliae. Phytochemistry 1998, 49, 1805–1811. [CrossRef]

135. Lira, S.P.; Vita-Marques, A.M.; Selegalhim, M.H.R.; Bugini, T.S.; LaBarbera, D.V.; Sette, L.D.; Sponchiado, S.R.P.; Ireland, C.M.; Berlinck, R.G.S. New destruxins from the marine-derived fungus Beauveria felina. J. Antibiot. 2006, 59, 553–563. [CrossRef] [PubMed]

136. Yeh, S.F.; Pan, W.; Ong, G.; Chiou, A.; Chuang, C.; Chiou, S.; Wu, S. Study of structure-activity correlation in destruxins, a class of cyclodepsipeptides possessing suppressive effect on the generation of hepatitis B virus surface antigen in human hepatoma cells. Biochem. Biophys. Res. Commun. 1996, 229, 65–72. [CrossRef] [PubMed]

137. Jegorov, A.; Sedmera, P.; Havlicek, V.; Mat‘haa, V. Destruxin Ed1, a cyclopeptide from the fungus Metarhizium anisopliae. Phytochemistry 1998, 49, 1815–1817. [CrossRef]

138. Chiang, Y.-M.; Szewczyk, E.; Nayak, T.; Davidson, A.D.; Sanchez, J.F.; Lo, H.-C.; Wen-Yueh, H.; Simityan, H.; Kuo, E.; Praseuth, A.; et al. Molecular genetic mining of the Aspergillus secondary metabolome: Discovery of the emericellamide biosynthetic pathway. Chem. Biol. 2008, 15, 527–532. [CrossRef] [PubMed]

139. Oh, D.; Kauffmann, C.A.; Jensen, P.R.; Fenical, W. Induced production of emericellamides A and B from the marine-derived fungus Emericella sp. in competing co-culture. J. Nat. Prod. 2007, 70, 515–520. [CrossRef] [PubMed]

140. Visconti, A.; Blais, L.A.; ApSimon, J.W.; Greenhalgh, R.; Miller, J.D. Production of enniatins by Fusarium acuminatum and Fusarium compactum in liquid culture: Isolation and characterization of three new enniatins, B2, B3, and B4. J. Agric. Food Chem. 1992, 40, 1076–1082. [CrossRef]

141. Zaher, A.M.; Makboul, M.A.; Moharram, A.M.; Tekwani, B.L.; Quesada-Moraga, E.; De Saeger, S. Analytical strategy for determination of known and unknown destruxins using hybrid quadrupole-orbitrap high-resolution mass spectrometry. Anal. Bioanal. Chem. 2017, 409, 3349–3357. [CrossRef] [PubMed]

142. Cuomo, V.; Randazzo, A.; Meca, G.; Moretti, A.; Cascone, A.; Eriksson, O.; Novellino, E.; Ritienni, A. Production of enniatins A, A1, B, B1, B4 j1 by Fusarium tricinctum in solid corn culture: Structural analysis and effects on mitochondrial respiration. Food Chem. 2013, 140, 784–793. [CrossRef] [PubMed]

143. Meca, G.; Font, G.; Ruiz, M.J. Comparative cytotoxicity study of enniatins A, A1, A2, B, B1, B4 and J3 on Caaco-2 cells, Hep-G2 and HT-29. Food Chem. Toxicol. 2011, 49, 2464–2469. [CrossRef] [PubMed]

144. Juan-Garcia, A.; Manyes, L.; Ruiz, M.-J.; Font, G. Involvement of enniatins-induced cytotoxicity in human HepG2 cells. Toxicol. Lett. 2013, 218, 166–173. [CrossRef] [PubMed]

145. Blais, L.A.; ApSimon, J.W.; Blackwell, B.A.; Greenhalgh, R.; Miller, J.D. Isolation and characterization of enniatins from Fusarium avenaceum DAOM 196490. Can. J. Chem. 1992, 70, 1281–1287. [CrossRef]

146. Pohanka, A.; Capieau, K.; Broberg, A.; Stenlid, J.; Kenne, L. Enniatins of Fusarium sp. strain F31 and their inhibition of Botrytis cinerea spor germination. J. Nat. Prod. 2004, 67, 851–857. [CrossRef] [PubMed]

147. Lin, Y.; Wang, J.; Wu, X.; Zhou, S.; Vrijmoed, L.L.P.; Jones, E.B.G. A novel compound, enniatin G, from the mangrove fungus Halosarphaea sp. (strain 732) form the South China Sea. Aust. J. Chem. 2002, 55, 225–227. [CrossRef] [PubMed]

148. Nilanonta, C.; Isaka, M.; Chanphen, R.; Thong-orn, N.; Tanticharoen, M.; Thebtaranonth, Y. Unusual enniatins produced by the insect pathogenic fungus Verticillium hemipterigenum: Isolation and studies on precursor-directed biosynthesis. Tetrahedron 2003, 59, 1015–1020. [CrossRef] [PubMed]
149. Sebastia, N.; Meca, G.; Soriano, J.M.; Manes, J. Antibacterial effects of enniatins J₁ and J₃ on pathogenic and lactic acid bacteria. Food Chem. Toxicol. 2011, 49, 2710–2717. [CrossRef] [PubMed]

150. Vongvilai, P.; Isaka, M.; Kittakoop, P.; Sritikulchail, P.; Kongsaeeree, P.; Prabpai, S.; Thebtaranonth, Y. Isolation and structure elucidation of enniatins L, M₁, M₂, and N: Novel hydroxy analogs. Helv. Chim. Acta 2004, 87, 2066–2073. [CrossRef]

151. Hyun, U.; Lee, D.-H.; Lee, C.; Shin, C.-G. Apoptosis induced by enniatins H and MK 1688 isolated from Fusarium oxysporum FB1501. Toxicol 2009, 53, 723–728. [CrossRef] [PubMed]

152. Ravindra, G.; Ranganayaki, R.S.; Raghothama, S.; Srinivasan, M.C.; Gilardi, R.D.; Karle, I.L.; Balaram, P. Supothina, S.; Isaka, M.; Kirtikara, K.; Tanticharoen, M.; Thebtaranonth, Y. Enniatin production by the entomopathogenic fungus Verticillium hemipterigenum BCC 1449. J. Antibiot. 2004, 57, 732–738. [CrossRef] [PubMed]

153. Uhlig, S.; Ivanova, L.; Petersen, D.; Kristensen, R. Structural studies on minor enniatins from Fusarium sp. VI03441: Novel N-methyl-threonine containing enniatins. Toxicol 2009, 53, 734–742. [CrossRef] [PubMed]

154. Jenkins, K.M.; Renner, M.K.; Jensen, P.R.; Fenical, W. Exumolides A and B: Antimicroalgal cyclic depsipeptides produced by a marine fungus of the genus Scytalidium. Tetrahedron Lett. 1998, 39, 2463–2466. [CrossRef]

155. Jenkins, K.M.; Renner, M.K.; Jensen, P.R.; Fenical, W. Exumolides A and B: Antimicroalgal cyclic depsipeptides produced by a marine fungus of the genus Scytalidium. Tetrahedron Lett. 1998, 39, 2463–2466. [CrossRef]

156. Pedras, M.S.C.; Zaharia, I.L.; Gai, Y.; Smith, K.C.; Ward, D.E. Metabolism of the host-selective toxins destruxin B and homodestruxin B: Probing a plant disease resistance trait. Org. Lett. 1999, 1, 1655–1658. [CrossRef]

157. Isaka, M.; Palasarn, S.; Sriklung, K.; Kocharin, K. Cyclohexadepsipeptides from the insect pathogenic fungus Hirsutella nivea BCC 2594. J. Nat. Prod. 2005, 68, 1680–1682. [CrossRef] [PubMed]

158. Isaka, M.; Palasarn, S.; Sriklung, K.; Kocharin, K. Cyclohexadepsipeptides from the insect pathogenic fungus Hirsutella nivea BCC 2594. J. Nat. Prod. 2005, 68, 1680–1682. [CrossRef] [PubMed]

159. Isaka, M.; Palasarn, S.; Sriklung, K.; Kocharin, K. Cyclohexadepsipeptides from the insect pathogenic fungus Hirsutella nivea BCC 2594. J. Nat. Prod. 2005, 68, 1680–1682. [CrossRef] [PubMed]

160. Luque-Ortega, J.R.; Cruz, L.J.; Albericio, F.; Rivas, L. The antitumoral depsipeptide IB-01212 kills leishmania through an apoptosis-like process involving intracellular targets. Mol. Pharm. 2010, 7, 1608–1617. [CrossRef] [PubMed]

161. Li, J.; Fu, X.; Zeng, Y.; Wang, Q.; Zhao, P. Two cyclopeptides from endophytic fungus Beauveria sp. LR89 isolated from Maytenus hookeri. Nat. Prod. Res. Dev. 2011, 23, 667–669.

162. Ravindra, G.; Ranganayaki, R.S.; Raghothama, S.; Srinivasan, M.C.; Gilardi, R.D.; Karle, I.L.; Balaram, P. Two novel hexadepsipeptides with several modified amino acid residues isolated from the fungus Isaria. Chem. Biodivers. 2004, 1, 489–504. [CrossRef] [PubMed]

163. Yurchenko, A.N.; Smetanina, O.F.; Kalinovsky, A.I.; Pushilin, M.A.; Khudyakova, Y.V.; Kirichuk, N.N.; Ermakova, S.P.; Dyshlovoy, S.A.; Yurchenko, E.A.; et al. Oxirapentyns F-K from the marine-sediment-derived fungus Isaria felina KMM 4639. J. Nat. Prod. 2014, 77, 1321–1328. [CrossRef] [PubMed]

164. Ding, L.-J.; Yuan, W.; Liao, X.-J.; Han, B.-N.; Wang, S.-P.; Li, Z.-Y.; Xu, S.-H.; Zhang, W.; Lin, H.-W. Oryzamides A-E, cyclopeptides from the sponge-derived fungus Nigrospora oryzae PF18. J. Nat. Prod. 2016, 79, 2045–2052. [CrossRef] [PubMed]

165. Isaka, M.; Berkaew, P.; Intereya, K.; Komwijkit, S.; Sathitkunanon, T. Antiplasmodial and antiviral cyclohexadepsipeptides from the endophytic fungus Pulfalaria sp. BCC 8613. Tetrahedron 2004, 60, 6855–6860. [CrossRef] [PubMed]

166. Ibrahim, W.; Kjer, J.; El Amrani, M.; Wray, V.; Lin, W.; Ebel, R.; Lai, D.; Proksch, P. Pullularins E and F, two new peptides from the endophytic fungus Bionecteria ochroleuca isolated from the mangrove plant Sonneratia caseolaris. Mar. Drugs 2012, 10, 1081–1091. [CrossRef] [PubMed]

167. Wang, Y.; Ke, A.; Wang, F.; Zhang, X.; Fan, Y.; Lu, X.; Zheng, Z.; Jiang, Q.; Zhang, H.; Zhao, B. F04W2166A, a proteasome inhibitor from fungal metabolites. Chin. J. Antibiot. 2011, 9, 662–666.

168. Ni, X.; Zhang, A.; Zhao, Z.; Shi, Q. Inhibitory effect of cyclic hexadepsipeptides on the proliferation activity on human PC-3 cells. Chin. Pharmacol. Bull. 2012, 28, 1527–1530.
169. Tsunoo, A.; Kamijo, M.; Taketomo, N.; Sato, Y.; Ajisaka, K. Roseocardin, a novel cardiotonic cyclodepsipeptide from Trichothecium roseum. J. Antibiot. 1997, 50, 1007–1013. [CrossRef] [PubMed]

170. Jegorov, A.; Paizs, B.; Zabka, M.; Kuzma, M.; Havlicek, V.; Giannakopulos, A.E.; Derrick, P.J. Profiling of cyclic hexadepsipeptides roseotoxins synthesized in vitro and in vivo: A combined tandem mass spectrometry and quantum chemical study. Eur. J. Mass Spectrom. 2003, 9, 105–116. [CrossRef] [PubMed]

171. Engstorn, G.; Delance, J.; Richard, J.; Baetz, A. Purification and characterization of roseotoxin b, a toxic cyclodepsipeptide from Trichothecium roseum. J. Agric. Food Chem. 1975, 23, 244–253. [CrossRef]

172. Zabka, M.; Drastichova, K.; Jegorov, A.; Soukupova, J.; Nedbal, L. Direct evidence of plant-pathogenic activity of fungal metabolites of Trichothecium roseum on apple. Mycopathologia 2006, 162, 65–68. [CrossRef] [PubMed]

173. Yu, Z.; Liang, G.; Kajahn, I.; Schmaljohann, R.; Imhoff, J.F. Scopularides A and B, cyclodepsipeptides from a marine sponge-derived fungus Scopulariopsis brevicaulis. J. Nat. Prod. 2008, 71, 1052–1054. [CrossRef] [PubMed]

174. Russell, D.W. Isolation and structure of sporidesmolide IV, a cyclohexadepsipeptide from Pithomyces chartarum. Can. J. Chem. 1990, 68, 19–21. [CrossRef]

175. Russell, D.W. Effect of stereoisomeric isoleucines on sporidesmolide biosynthesis by Pithomyces chartarum. Can. J. Chem. 1990, 68, 335–346. [CrossRef] [PubMed]

176. Bishop, E.; Russell, D.W. Isolation and structural determination of spirodesmolide IV, a cyclohexadepsipeptide from Pithomyces myadicus. J. Chem. Soc. 1967, 0, 634–638.

177. Gillis, H.A.; Russell, D.W.; Taylor, A.; Walter, J.A. Isolation and structure of sporidesmolide V from cultures of Pithomyces chartarum. Can. J. Chem. 1990, 68, 19–21. [CrossRef]

178. Mohamed, G.A. Fusaripeptode A: New antifungal and anti-malarial cyclodepsipeptide from the endophytic fungus Ophiocordyceps communis BCC 16475. J. Nat. Prod. 2010, 73, 75–78. [CrossRef] [PubMed]

179. Ishidoh, K.; Kinoshita, H.; Igarashi, Y.; Ihara, F.; Nihira, T. Cyclic lipodepsipeptides verlamelins A and B, isolated from entomopathogenic fungus Lecanicillium sp. J. Antibiot. 2014, 67, 459–463. [CrossRef] [PubMed]

180. Liang, X.; Nong, X.-H.; Huang, Z.-H.; Qi, S.-H. Antifungal and antiviral cyclic peptides from the deep-sea-derived fungus Simplicillium obclavatum. J. Agric. Food Chem. 2017, 65, 525–526. [CrossRef] [PubMed]

181. Haritakun, R.; Sappan, M.; Suvannakad, R.; Tasanathai, K.; Isaka, M. An antimycobacterial cyclodepsipeptide from the deep-sea-derived fungus Simplicillium obclavatum EIODSF 020. J. Agric. Food Chem. 2017, 65, 5114–5121. [CrossRef] [PubMed]

182. Ibrahim, S.R.M.; Adbdallah, H.M.; Elkhayat, E.S.; Al Musayeb, N.M.; Asfour, H.Z.; Zayed, M.F.; Mohamed, G.A. Fusaripeptode A: New antifungal and anti-malarial cyclodepsipeptide from the endophytic fungus Fusarium sp. J. Asian Nat. Prod. Res. 2017, 20, 1–11. [CrossRef] [PubMed]

183. Liang, X.; Nong, X.-H.; Huang, Z.-H.; Qi, S.-H. Antifungal and antiviral cyclic peptides from the deep-sea-derived fungus Simplicillium obclavatum. J. Agric. Food Chem. 2017, 65, 525–526. [CrossRef] [PubMed]

184. Ishidoh, K.; Kinoshita, H.; Igarashi, Y.; Ihara, F.; Nihira, T. Cyclic lipodepsipeptides verlamelins A and B, isolated from entomopathogenic fungus Lecanicillium sp. J. Antibiot. 2014, 67, 459–463. [CrossRef] [PubMed]

185. Lu, F.; Daletos, G.; Lin, W.; Proksch, P. Two new cyclic depsipeptides from the endophytic fungus Fusarium sp. Nat. Prod. Commun. 2015, 10, 1667–1670.

186. Kanaoka, M.; Isogai, A.; Murakoshi, S.; Ichinoe, M.; Suzuki, A.; Tamura, S. Bassianolide, a new insecticidal cyclodepsipeptide from Beauveria bassiana and Verticillium lecanii. Agric. Biol. Chem. 1978, 42, 629–635. [CrossRef] [PubMed]

187. Nakajyo, S.; Shimizu, K.; Kometani, A.; Suzuki, A.; Ozaki, H.; Urakawa, N. On the inhibitory mechanism of bassianolide, a cyclodepsipeptide, in acetylcholine-induced contraction in guinea-pig taenia coli. Jpn. J. Pharmacol. 1983, 33, 573–582. [CrossRef] [PubMed]
189. Jirakkakul, J.; Punya, J.; Pangpattanakitshote, S.; Paungmoung, P.; Vorapreeda, N.; Tachaleat, A.; Klomnara, C.; Tanticharoen, M.; Cheevadhanarak, S. Identification of the nonribosomal peptide synthetase gene responsible for bassianolide synthesis in wood-decaying fungus Xylaria sp. BCC1067. *Microbiology 2008*, 154, 995–1006. [CrossRef] [PubMed]

190. Mun, B.; Park, Y.J.; Sung, G.H.; Lee, Y.; Kim, K.H. Synthesis and antitumor activity of (−)-bassianolide in MDA-MB 231 breast cancer cells through cell cycle arrest. *Bioorg. Chem. 2016*, 69, 64–70. [CrossRef] [PubMed]

191. Sasaki, T.; Takagi, M.; Yaguchi, T.; Miyadoh, S.; Okada, T.; Koyama, M. A new anthelmintic cyclodepsipeptide, PF1022A. *J. Antibiot. 1992*, 45, 692–697. [CrossRef] [PubMed]

192. Ohyama, M.; Okada, Y.; Takahashi, M.; Sakanaoka, O.; Matsumoto, M.; Atsumi, K. Structure-activity relationship of anthelmintic cyclooctadepsipeptides. *Biosci. Biotechnol. Biochem. 2011*, 75, 1354–1363. [CrossRef] [PubMed]

193. Kruecken, J.; Harder, A.; Jeschke, P.; Holden-Dye, L.; O’Connor, V.; Welz, C.; Von Samson-Himmelstjerna, G. Anthelmintic cyclooctadepsipeptides: Complex in structure and mode of action. *Trends Parasitol. 2012*, 28, 385–394. [CrossRef] [PubMed]

194. Scherkenbeck, J.; Plant, A.; Harder, A.; Mencke, N. A highly efficient synthesis of the anthelmintic cyclooctadepsipeptide PF1022A. *Tetrahedron 1995*, 51, 8459–8470. [CrossRef]

195. Weckwerth, W.; Miyamoto, K.; Inuma, Y.; Krause, M.; Glnski, M.; Storm, T.; Bonse, G.; Kleinkauf, H.; Zocher, R. Biosynthesis of PF1022A and related cyclooctadepsipeptide. *J. Biol. Chem. 2000*, 275, 17909–17915. [CrossRef] [PubMed]

196. Singh, S.B.; Ondeyka, J.; Harris, G.; Herath, K.; Zink, D.; Vicente, F.; Bills, G.; Collado, J.; Platas, G.; Val, A.G.; et al. Isolation, structure, and biological activity of phaeofungin, a cyclic lipodepsipeptide from *Phaeosphaeria sp.* using the genome-wide *Candida albicans* fitness test. *J. Nat. Prod. 2013*, 76, 334–345. [CrossRef] [PubMed]

197. Ueda, K.; Xiao, J.; Doke, N.; Nakatsuka, S. Isolation and structure of BZR-cotoxin IV produced by *Bipolaris zeicola* race 3, the cause of leaf spot disease in corn. *Tetrahedron Lett. 2010*, 63, 77–82. [CrossRef] [PubMed]

198. Mun, B.; Park, Y.J.; Sung, G.H.; Lee, Y.; Kim, K.H. Synthesis and antitumor activity of (−)-bassianolide in MDA-MB 231 breast cancer cells through cell cycle arrest. *Bioorg. Chem. 2016*, 69, 64–70. [CrossRef] [PubMed]

199. Ishiyama, D.; Sato, T.; Honda, R.; Senda, H.; Konno, H.; Kanazawa, S. Glomosporin, a novel antifungal cyclic depsipeptide from *Glomospora* sp. II. Structure elucidation. *J. Antibiot. 2000*, 53, 525–531. [CrossRef] [PubMed]

200. Sasaki, T.; Takagi, M.; Yaguchi, T.; Miyadoh, S.; Okada, T.; Koyama, M. A new anthelmintic cyclodepsipeptide, PF1022A. *J. Antibiot. 1992*, 45, 692–697. [CrossRef] [PubMed]

201. Ding, G.; Chen, A.J.; Lan, J.; Zhang, H.; Chen, X.; Liu, X.; Zou, Z. Sesquiterpenes and cyclopeptides from the *Bipolaris sorokiniana* LK12. *BMC Microbiol. 2016*, 16, 103. [CrossRef] [PubMed]

202. Ishiyama, D.; Sato, T.; Honda, R.; Senda, H.; Konno, H.; Kanazawa, S. Glomosporin, a novel antifungal cyclic depsipeptide from *Glomospora* sp. II. Structure elucidation. *J. Antibiot. 2000*, 53, 525–531. [CrossRef] [PubMed]

203. Ikai, K.; Takesako, K.; Shiomi, K.; Moriguchi, M.; Umeda, Y.; Yamamoto, J.; Kato, I. Structure of aureobasidin A. *J. Antibiot. 1991*, 44, 925–933. [CrossRef] [PubMed]

204. Ikai, K.; Shiomi, K.; Takesako, K.; Mizutani, S.; Yamamoto, J.; Ogawa, Y.; Ueno, M.; Kato, I. Structures of aureobasidins B to R. *J. Antibiot. 1991*, 44, 1187–1198. [CrossRef] [PubMed]

205. Yoshikawa, Y.; Ikai, K.; Umeda, Y.; Ogawa, A.; Takesako, K.; Kato, I. Isolation, structures, and antifungal activities of new aureobasidins. *J. Antibiot. 1993*, 45, 1347–1354. [CrossRef]

206. Aeed, P.A.; Young, C.L.; Nagiec, M.M.; Elhammer, A.P. Inhibition of inositol phosphorylceramide synthase by the cyclic peptide aureobasidin A. *Antimicrob. Agents Chemother. 2009*, 53, 496–504. [CrossRef] [PubMed]

207. Ueda, K.; Xiao, J.; Doke, N.; Nakatsuka, S. Structure of BZR-cotoxin I produced by *Bipolaris zeicola* race 3, the cause of leaf spot disease in corn. *Tetrahedron Lett. 1994*, 35, 7033–7036. [CrossRef]
Aoyagi, A.; Yano, T.; Kozuma, S.; Takatsu, T. Pleofungins, novel inositol phosphorylceramide synthase inhibitors, from Phoma sp. SANK 13899. II. Structure elucidation. *J. Antibiot.* 2007, 60, 143–152. [CrossRef] [PubMed]

Yano, T.; Aoyagi, A.; Kozuma, S.; Kawamura, Y.; Tanaka, I.; Suzuki, Y.; Takamatsu, Y.; Takatsu, T.; Inukai, M. Pleofungins, novel inositol phosphorylceramide synthase inhibitors, from *Phoma* sp. SANK 13899. I. Taxonomy, fermentation, isolation, and biological activities. *J. Antibiot.* 2007, 60, 136–142. [CrossRef] [PubMed]

Liu, X.; Wang, J.; Guo, P.; Mao, C.; Zhu, Z.; Li, H. In vitro inhibition of postharvest pathogens of fruit and control of grey mold of strawberry and green mold of citrus by aureobasidin A. *Int. J. Food Microbiol.* 2007, 119, 223–229. [CrossRef] [PubMed]

Tan, H.W.; Tay, S.T. The inhibitory effects of aureobasidin A on *Candida planktonic* and biofilm cells. *Mycoses* 2013, 56, 150–156. [CrossRef] [PubMed]

Takesako, K.; Ikai, K.; Haruna, F.; Endo, M.; Shimanaka, K.; Sono, E.; Nakamura, T.; Kato, I.; Yamaguchi, H. Aureobasidins, new antifungal antibiotics. Taxonomy, fermentation, isolation, and properties. *J. Antibiot.* 1991, 44, 919–924. [CrossRef] [PubMed]

Ueda, K.; Xiao, J.; Doke, N.; Nakatsuka, S. Structure of BZR-cotoxin II produced by *Bipolaris zeicola* race 3, the cause of leaf spot disease in corn. *Tetrahedron Lett.* 1992, 33, 5377–5380. [CrossRef]

Ueda, K.; Xiao, J.; Doke, N.; Nakatsuka, S. Structure of BZR-cotoxin III produced by *Bipolaris zeicola* race 3, the cause of leaf spot disease in *corn*. *Nat. Prod. Lett.* 1995, 6, 43–48. [CrossRef]

Herath, K.; Harris, G.; Jayasuriya, H.; Zink, D.; Smith, S.; Vicente, F.; Gillis, G.; Collado, J.; Gonzalez, A.; Jiang, B.; et al. Isolation, structure and biological activity of phomafungin, a cyclic lipodepsipeptide from a widespread tropical *Phoma* sp. *Bioorg. Med. Chem.* 2009, 17, 1361–1369. [CrossRef] [PubMed]

Suzuki, Y.; Ojika, M.; Sakagami, Y.; Kajda, K.; Fudou, R.; Kameyama, T. New cyclic depsipeptide antibiotics, clavipristin A and B, produced by an aquatic hyphomycetes, *Clavariopsis aquatica*. 2. Structure analysis. *J. Antibiot.* 2001, 54, 22–28. [CrossRef] [PubMed]

Kaida, K.; Fudou, R.; Kameyama, T.; Tubaki, K.; Suzuki, Y.; Ojika, M.; Sakagami, Y.;Ng; Takasu, Y. New cyclic depsipeptide antibiotics, clavipristins A and B, produced by an aquatic hyphomycetes, *Clavariopsis aquatica*. 1. Taxonomy, fermentation, isolation, and biological properties. *J. Antibiot.* 2001, 54, 17–21. [CrossRef] [PubMed]

Hedge, V.R.; Puar, M.S.; Dai, P.; Pu, H.; Patel, M.; Anthes, J.C.; Richard, C.; Terracciano, J.; Das, P.R.; Gullo, V. A family of depsipeptide fungal metabolites, as selective and competitive human tachykinin receptor (NK1) antagonists: Fermentation, isolation, physico-chemical properties, and biological activity. *J. Antibiot.* 2001, 54, 125–135. [PubMed]

El-Elmat, T.; Raja, H.A.; Day, C.S.; McFeeters, H.; McFeeters, R.L.; Oberlies, N.H. α-Pyrene derivatives, tetra/hexahydroxanthones, and cyclodepsipeptides from two freshwater fungi. *Bioorgan. Med. Chem.* 2017, 25, 795–804. [CrossRef] [PubMed]

Nakadate, S.; Nozawa, K.; Sato, H.; Horie, H.; Fujii, Y.; Nagai, M.; Hosoe, T.; Kawai, K.; Yaguchi, T. Antifungal cyclic depsipeptide, eujavanicin A, isolated from *Eupenicillium javanicum*. *J. Nat. Prod.* 2008, 71, 1640–1642. [CrossRef] [PubMed]

Isaka, M.; Palasarn, S.; Komwjit, S.; Somrithipol, S.; Sommai, S. Pleosporatin A, an antimalarial cyclodepsipeptide from an elephant dung fungus (BCC 7069). *Tetrahedron Lett.* 2014, 55, 469–471. [CrossRef]

Hedge, V.R.; Puar, M.S.; Chan, T.M.; Dai, P.; Das, P.R.; Patel, M. Sch 217048: A novel cyclodepsipeptide with neurokinin antagonist activity. *J. Org. Chem.* 1998, 63, 9584–9586. [CrossRef]

Fujie, A.; Iwamoto, T.; Muramatsu, H.; Okudaira, T.; Nitta, K.; Tomoko, N.; Sakamoto, K.; Hori, Y.; Hino, M.; Hashimoto, S.; et al. FR901469, a novel antifungal antibiotic from an unidentified fungus No. 11243. 1. Taxonomy, fermentation, isolation, physico-chemical properties and biological properties. *J. Antibiot.* 2000, 53, 912–919. [CrossRef] [PubMed]

Lee, K.K.; Gloer, J.B. Petriellin A: A novel antifungal depsipeptide from the coprophilous fungus *Petriella sordida*. *J. Org. Chem.* 1995, 60, 5384–5385. [CrossRef]

Abdalla, M.A.; Matasyoh, J.C. Endophytes as producers of peptides: An overview about the recently discovered peptides from endophytic microbes. *Nat. Prod. Bioprospect.* 2014, 4, 257–270. [CrossRef] [PubMed]

Zhao, J.; Shan, T.; Mou, Y.; Zhou, L. Plant-derived bioactive compounds produced by endophytic fungi. *Mini-Rev. Med. Chem.* 2011, 11, 159–168. [CrossRef] [PubMed]
228. El-Hossary, E.M.; Cheng, C.; Hamed, M.M.; Hamed, A.N.E.; Ohlsen, K.; Hentschel, U.; Abdelmohsen, U.R. Antifungal potential of marine natural products. *Eur. J. Med. Chem.* 2017, 126, 631–651. [CrossRef] [PubMed]

229. Faulkner, D.J. Highlights of marine natural products chemistry (1972–1999). *Nat. Prod. Rep.* 2000, 17, 1–6. [CrossRef] [PubMed]

230. Renaud, J.B.; Kelman, M.J.; McMullin, D.R.; Yeung, K.K.-C.; Sumarah, M.W. Application of C8 liquid chromatography-tandem mass spectrometry for the analysis of enniatins and bassianolides. *J. Chromatogr. A.* 2017, 1508, 65–72. [CrossRef] [PubMed]

231. Sussmuth, R.; Muller, J.; von Dohen, H.; Monar, I. Fungal cyclooligomer depsipeptides: From classical biochemistry to combinatorial biosynthesis. *Nat. Prod. Rep.* 2011, 28, 99–124. [CrossRef] [PubMed]

232. Zobel, S.; Boecker, S.; Kulke, D.; Heibach, D.; Meyer, V.; Suessmuth, R.D. Reprogramming the biosynthesis of cyclodepsipeptide synthetases to obtain new enniatins and beauvericins. *ChemBioChem* 2016, 17, 283–287. [CrossRef] [PubMed]

233. Cavelier, F.; Verducci, J.; Andre, F.; Haraux, F.; Sigalat, C.; Traris, M.; Vey, A. Natural cyclopeptides as leads for novel pesticides: Tentoxin and destruxin. *Pestic. Sci.* 1998, 52, 81–89. [CrossRef]

234. Kitagaki, J.; Shi, G.; Miyauchi, S.; Murakami, S.; Yang, Y. Cyclic depsipeptides as potential cancer therapeutics. *Anti-Cancer Drug* 2015, 26, 259–271. [CrossRef] [PubMed]

235. Hershenhorn, J.; Casella, F.; Vurro, M. Weed biocontrol with fungi: Past, present and future. *Biocontrol Sci. Technol.* 2016, 26, 1313–1328. [CrossRef]

236. Hu, D.X.; Bielitza, M.; Koos, P.; Ley, V.S. A total synthesis of the ammonium ionophore, (−)-enniatin B. *Tetrahedron Lett.* 2012, 53, 4077–4079. [CrossRef]

237. Wang, Y.; Zhang, F.; Zhang, Y.; Liu, J.O.; Ma, D. Synthesis and antitumor activity of cyclodepsipeptide zygosporamide and its analogues. *Bioorg. Med. Chem. Lett.* 2008, 18, 4385–4387. [CrossRef] [PubMed]

238. Xu, Y.; Orozco, R.; Wijeratne, E.M.K.; Gunatilaka, A.A.L.; Stock, S.P.; Molnar, I. Biosynthesis of the cyclooligomer depsipeptide beauvericin, a virulence factor of the entomopathogenic fungus *Beauveria bassiana*. *Chem. Biol.* 2008, 15, 898–907. [CrossRef] [PubMed]

239. Hornbogen, T.; Glinski, M.; Zocher, R. Biosynthesis of depsipeptide mycotoxins in *Fusarium*. *Eur. J. Plant Pathol.* 2002, 108, 713–718. [CrossRef]

240. Soerensen, J.L.; Sondergaard, T.E.; Covarelli, L.; Fuertes, P.R.; Hansen, F.T.; Frandsen, R.J.N.; Saei, W.; Nielsen, K.F.; et al. Identification of the biosynthetic gene clusters for the lipopeptides fusaristatin A and W493 B in *Fusarium graminearum* and *F. pseudograminearum*. *J. Nat. Prod.* 2014, 77, 2619–2625. [CrossRef] [PubMed]

241. Ishidoh, K.; Kinoshita, H.; Nihira, T. Identification of a gene cluster responsible for the biosynthesis of cyclic lipopeptide verlamelin. *Appl. Microbiol. Biotechnol.* 2014, 98, 7501–7510. [CrossRef] [PubMed]

242. Harder, A.; Holden-Dye, L.; Walker, R.; Wunderlich, F. Mechanisms of action of emodepside. *Parasitol. Res.* 2005, 97, S1–S10. [CrossRef] [PubMed]

243. Kolf-Clauw, M.; Sassahara, M.; Lucioli, J.; Rubira-Gerez, J.; Alassan-Kpembi, I.; Lyazhri, F.; Borin, C.; Oswald, I.P. The emerging mycotoxin, enniatin B1, down-modulates the gastrointestinal toxicity of T-2 toxin in vitro on intestinal epithelial cells and ex vivo on intestinal explants. *Arch. Toxicol.* 2013, 87, 2233–2241. [CrossRef] [PubMed]

244. Devreeese, M.; Broekaert, N.; De Mil, T.; Fraeyman, S.; De Backer, P.; Croubels, S. Pilot toxicokinetic study and absolute oral bioavailability of the *Fusarium* mycotoxin enniatin B1 in pigs. *Food Chem. Toxicol.* 2014, 63, 161–165. [CrossRef] [PubMed]

245. Taevernier, L.; Detroyer, S.; Veryser, L.; De Spiegeleer, B. Enniatin-containing solutions for oromucosal use: Quality-by-design ex-vivo transmucosal risk assessment of composition variability. *Int. J. Pharm.* 2015, 491, 144–151. [CrossRef] [PubMed]

246. Baltz, R.H. Combinatorial biosynthesis of cyclic lipopeptide antibiotics: A mode for synthetic biology to accelerate the evolution of secondary metabolite biosynthetic pathways. *ACS Synth. Biol.* 2014, 3, 748–758. [CrossRef] [PubMed]