Untapped Potential of Marine-Associated *Cladosporium* Species: An Overview on Secondary Metabolites, Biotechnological Relevance, and Biological Activities

Gamal A. Mohamed 1,∗ and Sabrin R. M. Ibrahim 2,3

1 Department of Natural Products and Alternative Medicine, Faculty of Pharmacy, King Abdulaziz University, Jeddah 21589, Saudi Arabia
2 Preparatory Year Program, Batterjee Medical College, Jeddah 21442, Saudi Arabia; sabrin.ibrahim@bmc.edu.sa
3 Department of Pharmacognosy, Faculty of Pharmacy, Assiut University, Assiut 71526, Egypt

∗ Correspondence: gahussein@kau.edu.sa; Tel.: +966-597-636-182

Abstract: The marine environment is an underexplored treasure that hosts huge biodiversity of microorganisms. Marine-derived fungi are a rich source of novel metabolites with unique structural features, bioactivities, and biotechnological applications. Marine-associated *Cladosporium* species have attracted considerable interest because of their ability to produce a wide array of metabolites, including alkaloids, macrolides, diketopiperazines, pyrones, tetralones, sterols, phenolics, terpenes, lactones, and tetracyclic acid derivatives that possess versatile bioactivities. Moreover, they produce diverse enzymes with biotechnological and industrial relevance. This review gives an overview on the *Cladosporium* species derived from marine habitats, including their metabolites and bioactivities, as well as the industrial and biotechnological potential of these species. In the current review, 286 compounds have been listed based on the reported data from 1998 until July 2021. Moreover, more than 175 references have been cited.

Keywords: bioactivity; biotechnology; *Cladosporium*; Cladosporiaceae; marine fungi; metabolite

1. Introduction

The marine environment covers approximately 70% of the Earth’s surface and represents an enormous pool of biodiversity resources [1–3]. Marine microorganisms possess the potential for several biotechnological and industrial applications and play an important ecological role [4,5]. The last decades have witnessed numerous studies in the natural metabolites derived from marine creatures or their associated microorganisms [6–8]. Marine-derived fungi consist of a wide range of parasites, saprotrophs, symbionts, epiphytes, and endophytes [9,10]. They can be obtained from various marine samples such as algae, seagrasses, corals, sponges, ascidians, crustaceans, bivalves, fishes, and inorganic matter [11,12]. Jones et al. reported 530 marine taxa in 321 genera, which included 12 Basidiomycota (nine genera), 94 asexual morphs (61 genera), and 424 Ascomycota (251 genera) [13]. In 2011, the number of marine fungi was estimated to be 10,000 to 12,500 species based on substrates and geographical locations [14]. Currently, 1901 species have been listed on the marine fungi website, in 769 genera, 88 orders, 226 families, 22 classes, and seven phyla [15]. They are acknowledged as a rich source of novel metabolites with unique structural features, bioactivities, and biotechnological applications that attracted the attention of many biologists and chemists [16]. *Cladosporium* (Cladosporiaceae) is one of the largest genera of dematiaceous hyphomycetes [17]. *Cladosporium* species are frequent airborne molds, which can be isolated from almost every environment and geographic location, because their small conidia are easily dispersed [18–21]. *C. herbarum*, *C. cladosporioides*, and *C. sphaerospermum* are its three major species [22]. It comprises many important plant pathogens causing stem rots and leaf spots such as *C. fulvum* is the causal agent of tomato leaf mold [23,24]. Some
species are also known as common contaminants in clinical laboratories and cause allergic lung diseases [25–28]. Some species have been reported as endophytes and possessed a positive influence, for example, *C. sphaerospermum* isolated from *Glycine max* roots which can promote its growth [29]. Several species were linked to allergic rhinitis and respiratory arrest in asthmatic patients, and some are described as a cause of opportunistic phaeohyphomycosis, including subcutaneous and deep infections in humans and animals [30,31]. Some species are fungicolous that possess a potential for biological control in agriculture and forestry [32,33]. Moreover, many *Cladosporium* species have the potential to be used in various industrial processes [34,35]. Marine-associated *Cladosporium* species have attracted considerable interest because of their ability to produce a wide array of metabolites, including macrolides, pyrones, phenolics, diketopiperazines, terpenes, sterols, quinones, lactones, and tetramic acid derivatives. These metabolites possess versatile bioactivities such as anticancer, antimicrobial, antiviral, insecticidal, antifouling, anti-malarial, anti-hyperlipidemic, and α-glucosidase and protein tyrosine phosphatase inhibition [36–42]. It has been shown that these species have significant impacts on biotechnology, ecosystems, and food production. They are a wealthy source of enzymes such as pectinases, agarases, carrageenases, xylanases, laccases, peroxidases, tannases, invertases, cellulases, and reductases that have wide biotechnological influences in developing eco-friendly technologies in the pulp and paper industry, food feed industries, biomasses and contaminants bioremediation and biodegradation, and generation chemicals and liquid fuels [11,12,43–50]. The main goal of this review is the focus on the reported research in *Cladosporium* species derived from a marine habitat, including the structures and bioactivities of the reported metabolites, as well as the industrial and biotechnological potential of these species (Tables 1 and 2). This work covers the studies that have appeared in literature from 1998 until July 2021. The structures and bioactivities of reported metabolites from *Cladosporium* species have been highlighted. Furthermore, the biotechnological and industrial potential of *Cladosporium* species has been summarized. We hope that this work can provide knowledge that can help for the dereplication and bioactivities evaluation of these marine-associated *Cladosporium* species. The present data were collected through the search on the various databases, including Web of Knowledge, ScienceDirect, SCOPUS, Taylor & Francis, Wiley Online Library, PubMed, JACS, Springer, and Google Scholar.

2. Importance of Marine Associated *Cladosporium* Species

Recently, cold-active microbial enzymes have attracted a great attention, and they are preferred to the thermophilic and mesophilic enzymes due to the reduction in the energy expenditure and costs of processing accompanied by industrial heating steps [51]. Many marine-associated *Cladosporium* species display noticeable enzyme production capacity. Many of these enzymes are exclusively produced at low temperature and high salt concentrations. Therefore, they play a substantial ecological role in lignin-cellulosic materials decomposition in the marine environment. Besides, these enzymes can be utilized in various biotechnological applications and allow the performance of industrial processes even in harsh conditions. In this review, the biotechnological and industrial relevance of *Cladosporium* species has been highlighted.

The polycyclic aromatic hydrocarbons (PAHs) are volatile pollutants that can cause various environmental pollutions such as oceanic and freshwater contamination, which can take place during storage, use, or transportation of crude oil and its products. PAHs inhalation or ingestion through contaminated food and airborn contaminants leads to serious health disorders such as endocrine disruption, cancer, and reproductive and birth problems [52]. Therefore, introducing marine-adapted microorganisms to increase the PAH-biodegradation rate is an important approach to reduce PAHs concentration in the contaminated regions. Investigation of the PAH biodegradation potential of various marine-derived fungi revealed that *Cladosporium* sp. CBMAI 1237 had a great potential for bioremediation and biodegradation of PAHs (e.g., anthracene, anthrone, anthraquinone,acenaphthene, phenanthrene, fluorene, pyrene fluoranthene, and nitropyrene) even in a non-marine environment [44].
Table 1. Secondary metabolites reported from marine associated Cladosporium species.

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| 1. Tetramic acid derivatives |
| Cladosin A (1) | 282 | C₁₄H₂₂N₂O₄ | Cladosporium sphaerospermum 2005-01-E3 | Deep-sea sludge, Pacific Ocean | Qingdao, China | [42] |
| Cladosin B (2) | 268 | C₁₃H₂₀N₂O₄ | Cladosporium sphaerospermum 2005-01-E3 | Deep-sea sludge, Pacific Ocean | Qingdao, China | [42] |
| Cladosin C (3) | 250 | C₁₃H₁₈N₂O₄ | Cladosporium sphaerospermum SW67 | Hydractinia echinata | South Korea | [53] |
| Cladosin D (4) | 250 | C₁₃H₁₈N₂O₄ | Cladosporium sphaerospermum 2005-01-E3 | Deep-sea sludge, Pacific Ocean | Qingdao, China | [42] |
| Cladosin F (5) | 268 | C₁₃H₂₀N₂O₄ | Cladosporium sphaerospermum 2005-01-E3 | Deep-sea sludge, Pacific Ocean | Qingdao, China | [54] |
| Cladosin G (6) | 282 | C₁₄H₂₂N₂O₄ | Cladosporium sphaerospermum 2005-01-E3 | Deep-sea sludge, Pacific Ocean | Qingdao, China | [54] |
| Cladosin H (7) | 358 | C₂₀H₂₆N₂O₄ | Cladosporium sphaerospermum L3P3 | Marine sediment | Mariana Trench, South Pacific Ocean, China | [55] |
| Cladosin I (8) | 358 | C₂₀H₂₆N₂O₄ | Cladosporium sphaerospermum L3P3 | Marine sediment | Mariana Trench, South Pacific Ocean, China | [55] |
| Cladosin J (9) | 419 | C₂₅H₂₆N₂O₃ | Cladosporium sphaerospermum L3P3 | Marine sediment | Mariana Trench, South Pacific Ocean, China | [55] |
| Cladosin K (10) | 419 | C₂₅H₂₆N₂O₃ | Cladosporium sphaerospermum L3P3 | Marine sediment | Mariana Trench, South Pacific Ocean, China | [55] |
| Cladosin L (11) | 270 | C₁₃H₂₀N₂O₄ | Cladosporium sphaerospermum SW67 | Hydractinia echinata | South Korea | [53] |
| Cladosporinic A (12) | 401 | C₂₁H₂₇N₂O₅ | Cladosporium sphaerospermum SW67 | Hydractinia echinata | South Korea | [53] |
| Cladodionen (13) | 233 | C₁₉H₁₇N₂O₅ | Cladosporium sp. OUCMDZ-1635 | Unidentified sponge | Xisha Islands, China | [56] |
| Cladosporinum A (14) | 349 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum B (15) | 349 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum C (16) | 349 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum D (17) | 253 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum E (18) | 253 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum F (19) | 269 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum G (20) | 269 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum H (21) | 253 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum I (22) | 253 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum J (23) | 251 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum K (24) | 251 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum L (25) | 887 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum M (26) | 233 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum N (27) | 233 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum O (28) | 233 | C₂₁H₂₇N₂O₅ | Cladosporium sp. SCISO z0025 | Deep sea sediment | Okinawa, Japan | [58] |
| Cladosporinum P (29) | 349 | C₂₀H₂₇N₂O₅ | Cladosporium sphaerospermum SW67 | Hydractinia echinata | South Korea | [38] |
| Cladosporinum J (30) | 349 | C₂₀H₂₇N₂O₅ | Cladosporium sphaerospermum SW67 | Hydractinia echinata | South Korea | [38] |
| 2. Diketopiperazines |
| Cyclo-(Pro, Trp) (31) | 283 | C₁₉H₁₇N₂O₂ | Cladosporium sp. EF424419 | Porphyra yezoensis (Red alga, Bangiaceae) | Liyangang, Jiangsu, China | [59] |
### 3. Alkaloids

#### 3.1. Indole alkaloids

##### 3.1.1 Simple indole alkaloids

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| Cyclo-(Val-Pro) (32) | 196 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>2</sub> | Cladosporium sp. EF424419 | *Porphyra yezoensis* (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China | [59] |
| Cyclo-(Phe-Pro) (33) | 244 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>2</sub> | Cladosporium sp. F14 | Seawater from mangrove stand | Kei Ling Ha Lo Wu, Sai Kung, China | [60] |
| Cyclo-(Phe-Val) (34) | 246 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>2</sub> | Cladosporium sp. F14 | Seawater from mangrove stand | Kei Ling Ha Lo Wu, Sai Kung, China | [60] |
| Cyclo-(Gly-Leu) (35) | 170 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>2</sub> | Cladosporium sp. SCSIO41007 | (Sponge, Callyspongiidae) | Xuzhou, Guangdong, China | [61] |
| Cladosporin A (36) | 460 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>5</sub>S<sub>2</sub> | Cladosporium sp. | Marine sediment | Yangshashan Bay, Ningbo, Zhejiang, China | [62] |
| Cladosporin B (37) | 442 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>5</sub>S<sub>2</sub> | Cladosporium sp. | Marine sediment | Yangshashan Bay, Ningbo, Zhejiang, China | [62] |
| Haematocin (38) | 502 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>5</sub>S<sub>2</sub> | Cladosporium sp. | Marine sediment | Yangshashan Bay, Ningbo, Zhejiang, China | [62] |

#### 3.2. Quinazoline alkaloids

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| N-Acetyltryptamine (39) | 202 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O | Cladosporium sp. EF424419 | *Porphyra yezoensis* (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China | [59] |
| N-methyl-1H-indole-2-carboxamide (40) | 174 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>2</sub> | C. cladosporioides | Cliona sp. (Sponge, Clionaidae) | Los Molles, Chile | [63] |
| Indole-3-carboxylic acid (41) | 161 | C<sub>4</sub>H<sub>7</sub>NO<sub>2</sub> | Cladosporium sp. SCSIO41007 | (Sponge, Callyspongiidae) | Xuzhou, Guangdong, China | [61] |

#### 3.3. Quinolone alkaloids

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| Norquinolactin A (49) | 471 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>4</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Quinolactin A (50) | 485 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>5</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Deoxytryptophan (51) | 516 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Deoxytryptophan (52) | 530 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Tryptophan (53) | 546 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| CS-C (54) | 546 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Quinidolactone B (55) | 439 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. PX-41 | Soil around a mangrove | Guangzhou, China | [64] |
| Circumdatin A (56) | 391 | C<sub>2</sub>H<sub>1</sub>N<sub>2</sub>O<sub>6</sub> | Cladosporium sp. MFC353-b | (Red alga, Rhodomelaceae) | Yokki Island, Kyeongnam, Korea | [65] |

#### 3.4. Quinolone alkaloids

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| Quinolactin A1 (57) | 270 | C<sub>1</sub>H<sub>15</sub>N<sub>2</sub>O<sub>2</sub> | *C. oxysporum* BRS2A-AR2F | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Compound Name    | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family)                                                                 | Place                                      | Ref. |
|------------------|----------|--------------|---------------|--------------------------------------------------------------------------------------|--------------------------------------------|------|
| Quinolactacin A2 | 270      | C_{16}H_{18}N_{2}O_{2} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin B1 | 256      | C_{16}H_{16}N_{2}O_{2} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin B2 | 256      | C_{16}H_{16}N_{2}O_{2} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin C1 | 286      | C_{16}H_{18}N_{2}O_{3} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin C2 | 286      | C_{16}H_{18}N_{2}O_{3} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin D1 | 286      | C_{16}H_{18}N_{2}O_{3} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinolactacin D2 | 286      | C_{16}H_{18}N_{2}O_{3} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinocitrinine A | 272      | C_{16}H_{19}N_{2}O_{2} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Quinocitrinine B | 272      | C_{16}H_{19}N_{2}O_{2} | C. oxysporum BRS2A-AR2F | Conocarpus erectus (Mangrove plant, Combretaceae) Laguncularia racemosa (Mangrove plant, Combretaceae) Rhizophora racemosa (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
### Table 1. Cont.

| Compound Name       | Mol. Wt. | Mol. Formula   | Fungal Source                                                                 | Host (Sample, Family)                                                                 | Place                                      | Ref. |
|---------------------|----------|----------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------|------|
| Quinolactacide (67) | 236      | C_{14}H_{19}N_{2}O_{2} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Citrinadin derivatives |         |                |                                                                               |                                                                                       |                                            |      |
| Citrinadin A (68)   | 624      | C_{36}H_{52}N_{4}O_{6} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Citrinadin B (69)   | 481      | C_{26}H_{39}N_{3}O_{4} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| Butrecitrinadin (70) | 682      | C_{38}H_{57}N_{4}O_{7} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| PF1270 A (71)       | 566      | C_{32}H_{41}N_{3}O_{6} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| PF1270 B (72)       | 552      | C_{31}H_{41}N_{3}O_{6} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| PF1270 C (73)       | 558      | C_{32}H_{39}N_{3}O_{6} | *C. oxysporum* BRS2A-AR2F                                                      | *Conocarpus erectus* (Mangrove plant, Combretaceae) *Laguncularia racemosa* (Mangrove plant, Combretaceae) *Rhizophora racemosa* (Mangrove plant, Rhizophoraceae) | Banks of the River Butre, Western Region of Ghana | [66] |
| 3.5. Pyrrolidine derivatives |         |                |                                                                               |                                                                                       |                                            |      |
| Cladosporatin A (74) | 505      | C_{32}H_{43}NO_{4} | *Cladosporium* sp. HNWSW-1                                                      | *Cladosporium* tagal (Mangrove plant, Rhizophoraceae)                               | Dong Zhai Gang, Hainan, China             | [67] |
| Cladosporatin B (75) | 505      | C_{32}H_{43}NO_{4} | *Cladosporium* sp. HNWSW-1                                                      | *Cladosporium* tagal (Mangrove plant, Rhizophoraceae)                               | Dong Zhai Gang, Hainan, China             | [67] |
| Talaroconvolutin A (76) | 487      | C_{32}H_{41}NO_{3} | *Cladosporium* sp. HNWSW-1                                                      | *Cladosporium* tagal (Mangrove plant, Rhizophoraceae)                               | Dong Zhai Gang, Hainan, China             | [67] |
| Cladosporamide A (77) | 273      | C_{14}H_{11}NO_{6} | *Cladosporium* sp. TPU1507                                                      | *Unidentified marine sponge*                                                        | Manado, Indonesia                          | [68] |
Table 1. Cont.

| Compound Name                  | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family)                        | Place                                      | Ref. |
|--------------------------------|----------|--------------|---------------|---------------------------------------------|--------------------------------------------|------|
| 3.6. Other class of alkaloids  |          |              |               |                                             |                                            |      |
| Cladosporilactam A (78)        | 181      | C_{10}H_{12}NO_{2} | Cladosporium sp. RA07-1 | Anthogorgia ochracea (Gorgonian, Acanthogorgiidae) | Weizhou coral reef, South China Sea | [69] |
| Cladospamide A (79)            | 268      | C_{9}H_{20}N_{2}O_{4} | Cladosporium sp. SCNU-F0001 | Cladosporium sp. SCNU-F0001 | Mangrove plant | Zhumai Mangrove Nature, Guangdong, China | [70] |
| Cladosporin A (80)             | 233      | C_{12}H_{12}NO_{3} | Cladosporioides SCSIO 2015 | Cladosporioides SCSIO 2015 | Deep sea sediment | Okinawa, Japan | [36] |
| Cladosporin B (81)             | 233      | C_{13}H_{15}NO_{3} | Cladosporioides SCSIO 2015 | Cladosporioides sp. | Deep sea sediment | Okinawa, Japan | [36] |
| 2′-Deoxythymidine (82)         | 241      | C_{12}H_{12}NO_{5} | Cladosporium sp. SCSIO41007 | Calypsoonia sp. | Wangmu, Guangdong, China | [61] |
| Nicotinic acid (83)            | 123      | C_{6}H_{12}NO_{2} | Cladosporium sp. EF42419 | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China | [59] |
| 2′-Methacetalate-3,5,6-trimethylpyrazine (84) | 194 | C_{10}H_{11}N_{2}O_{2} | Cladosporium sp. JS1-2 | Cereops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaihai, Hainan, China | [71] |
| Cytochalasin D (85)            | 507      | C_{12}H_{17}NO_{6} | Cladosporium sp. JS1-2 | Cereops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaihai, Hainan, China | [71] |
| Cladosin E (86)                | 251      | C_{13}H_{17}NO_{4} | C. sphaerospermum 2005-01-E3 | Cladosporium sp. RA07-1 | Deep-sea sludge, Pacific Ocean | Xuhu, Guangdong, China | [61] |
| N-Acetyltyramine (87)          | 179      | C_{13}H_{17}NO_{4} | Cladosporium sp. EF42419 | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China | [59] |
| 4. Macrolides                  |          |              |               |                                             |                                            |      |
| Cladospolide A (88)            | 228      | C_{12}H_{20}O_{4} | Cladosporium sp. FT-0012 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Cladospolide B (89)            | 228      | C_{12}H_{20}O_{4} | Cladosporium sp. FT-0012 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Cladospolide C (90)            | 228      | C_{12}H_{20}O_{4} | C. cladosporioides MCCC 3A0182 | C. cladosporioides (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Cladospolide D (91)            | 228      | C_{12}H_{20}O_{4} | Cladosporium sp. FT-0012 | Seawater nearby mangrove stand | Kei Ling Ha Lo Wa, Sai Kung, Hong Kong, China | [76] |
| Cladospolide E (92)            | 188      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Niophates novi (Sponge, Niphatidae) | Gulf of Aqaba, Israel | [77] |
| Pandagolide 1 (93)             | 244      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Seawater from mangrove stand | Kei Ling Ha Lo Wa, Sai Kung, China | [76] |
| Pandagolide 1a (94)            | 244      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 2 (95)             | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 2a (96)            | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 3 (97)             | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 3a (98)            | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 4 (99)             | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Pandagolide 4a (100)           | 318      | C_{12}H_{20}O_{5} | Cladosporium sp. F14 | Rhizophora stylosa (Mangrove plant, Rhizophoraceae) | Pohnpe island, Federated State of Micronesia | [72] |
| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| Pandangolide 3 (96) | 362 | C_{12}H_{26}O_{5}S | C. herbarum (Pers.) | Callipogon aereus (Sponge, Callipogoniidae) | Bali Bata National Park, Indonesia, [74] |
| Pandangolide 4 (97) | 486 | C_{12}H_{26}O_{5}S | C. herbarum (Pers.) | Callipogon aereus (Sponge, Callipogoniidae) | Hainan, China | [76] |
| 5R-Hydroxyrecifeiolide (98) | 212 | C_{12}H_{26}O_{5} | C. cladosporioides | Cladosporium sp. MA-299 (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide A (101) | 346 | C_{12}H_{26}O_{5}S | C. cladosporioides MA-299 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide B (102) | 360 | C_{12}H_{26}O_{5}S | C. cladosporioides MA-299 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide C (103) | 330 | C_{12}H_{26}O_{5}S | C. cladosporioides MA-299 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide D (104) | 364 | C_{12}H_{26}O_{5}S | C. cladosporioides MA-299 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide E (105) | 306 | C_{12}H_{26}O_{5}S | Cladosporium sp. SCNU-F0001 | Mangrove plant | Hainan Island, China | [39] |
| Thiocladosolide F (106) | 332 | C_{12}H_{26}O_{5}S | C. cladosporioides MA-299 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide G (107) | 386 | C_{12}H_{26}O_{5}S | C. oxysporum HDN13-314 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide H (110) | 332 | C_{12}H_{26}O_{5}S | C. oxysporum HDN13-314 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide I (111) | 560 | C_{12}H_{26}O_{5}S | C. oxysporum HDN13-314 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Thiocladosolide J (112) | 558 | C_{12}H_{26}O_{5}S | C. oxysporum HDN13-314 | Brugueria gymnorrhiza (Mangrove plant, Rhizophoraceae) | Hainan Island, China | [39] |
| Sporiolide A (113) | 348 | C_{12}H_{26}O_{5} | Cladosporium sp. L037 | Actinomucor fragilis (Red alga, Galaxauraceae) | Seragaki Beach, Okinawa Island, Japan | [80] |
| Sporiolide B (114) | 258 | C_{12}H_{26}O_{5} | Cladosporium sp. L037 | Actinomucor fragilis (Red alga, Galaxauraceae) | Seragaki Beach, Okinawa Island, Japan | [80] |
| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|----------------------|-------|------|
| (3R,6S)-6-Hydroxy-12-methyl-2,5-dioxooacyclododecan-3-yl-(E)-4,11-dihydroxydodec-2-enoate (116) | 456 | C_24H_40O_8Cladosporium sp. IFB3lp-2 | Rhizophora stylosa | Mangrove forest, Hainan, China | [73] |
| Dendrodolide A (117) | 256 | C_13H_20O_5Cladosporium sp. RA07-1 | Anthogorgia ochracea | Weizhou coral reef, South China Sea | [69] |
| Dendrodolide C (118) | 242 | C_13H_18O_3Cladosporium sp. RA07-1 | Anthogorgia ochracea | Weizhou coral reef, South China Sea | [69] |
| Dendrodolide L (119) | 228 | C_12H_20O_4Cladosporium sp. RA07-1 | Anthogorgia ochracea | Weizhou coral reef, South China Sea | [69] |
| Dendrodolide M (120) | 256 | C_13H_20O_5Cladosporium sp. RA07-1 | Anthogorgia ochracea | Weizhou coral reef, South China Sea | [69] |
| Cladocladosin A (121) | 224 | C_12H_16O_4C. cladosporioides MA-299 | Bruguiera gymnorrhiza | Hainan Island, China | [79] |
| 5. Butenolides and butanolides | | | | | |
| Cladospolide F (122) | 230 | C_12H_22O_4Cladosporium sp. TZP29 | Unidentified soft coral | Guangzhou, China | [41] |
| Ent-cladospolide F (123) | 230 | C_14H_24O_5C. cladosporioides MA-299 | Bruguiera gymnorrhiza | Hainan Island, China | [40] |
| Cladospolide G (124) | 272 | C_13H_24O_5C. cladosporioides MA-299 | Bruguiera gymnorrhiza | Hainan Island, China | [40] |
| 11-Hydroxy-γ-dodecalactone (125) | 214 | C_13H_22O_3Cladosporium sp. TZP29 | Unidentified soft coral | Guangzhou, China | [41] |
| iso-Cladospolide B (126) | 228 | C_13H_20O_4C. herbarum (Pers.) | Calliptyon aerizusa | Bali Bata National Park, Indonesia, | [74] |
| | | Cladosporium sp. | Niphates rotus (Sponge, Niphatidae) | Gulf of Aqaba, Israel | [77] |
| | | Cladosporium sp. F14 | Seawater from the mangrove stand | Kei Ling Ha Lo Wai, Sai Kung, China | [60] |
| Cladospolide H (127) | 210 | C_13H_18O_3C. cladosporioides MA-299 | Rhizophora stylosa | Guangzhou, China | [73] |
| 6. Seco-acids | | | | | |
| Cladospolide A II (128) | 228 | C_13H_20O_4Cladosporium sp. IFB3lp-2 | Rhizophora stylosa | Mangrove forest, Hainan, China | [73] |
| Cladospolide E (129) | 228 | C_13H_20O_4Cladosporium sp. TZP29 | Unidentified soft coral | Guangzhou, China | [41] |
| Seco-Patulolide A (130) | 228 | C_13H_20O_4Cladosporium sp. TZP29 | Unidentified soft coral | Guangzhou, China | [41] |
| Seco-Patulolide C (131) | 230 | C_13H_22O_4Cladosporium sp. F14 | Seawater from the mangrove stand | Kei Ling Ha Lo Wai, Sai Kung, China | [60] |
| | | Cladosporium sp. | Unidentified soft coral | Guangzhou, China | [41] |
| | | Cladosporium sp. MA-299 | Bruguiera gymnorrhiza | Hainan Island, China | [40] |
| Seco-Secopatulolide C (132) | 230 | C_13H_22O_4C. oxysporum HDN13-314 | Avicennia marina | Hainan Island, China | [78] |
| Cladosporester A (133) | 244 | C_13H_24O_4C. cladosporioides OUCMDZ-187 | Rhizophora stylosa | Shankou, Guangxi, China | [81] |
| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|---------|-------------|---------------|-----------------------|-------|------|
| Cladosporester B (134) | 244 | C_{20}H_{16}O_{6} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol/Cladosporol A (142) | 352 | C_{20}H_{16}O_{6} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol C (143) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol D (144) | 354 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol E (145) | 370 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol F (146) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol G (147) | 388 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol H (149) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol I = Cladosporanol A (150) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol J (151) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporone A (152) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |

7. Tetralones (napthalenones)

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|---------|-------------|---------------|-----------------------|-------|------|
| Cladosporol/Cladosporol A (142) | 352 | C_{20}H_{16}O_{6} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol C (143) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol D (144) | 354 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol E (145) | 370 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol F (146) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol G (147) | 388 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol H (149) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol I = Cladosporanol A (150) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporol J (151) | 338 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Cladosporone A (152) | 352 | C_{20}H_{16}O_{5} | Cladosporium sp. KcFl6′ | \textit{Kandelia candel} | Daya Bay, Shenzhen city, Guangdong, China | 82 |
| Compound Name             | Mol. Wt. | Mol. Formula | Fungal Source                  | Host (Sample, Family)               | Place                      | Ref. |
|---------------------------|----------|--------------|---------------------------------|-------------------------------------|---------------------------|------|
| Altertoxin XII (153)      | 322      | C_{20}H_{15}O_{4} | Cladosporium sp. KFD33          | Blood cockle (Bivalve mollusk, Cardiidae) | Haikou Bay, China         | [85] |
| Clindanone A (154)        | 394      | C_{22}H_{16}O_{7} | C. cladosporioides HDN14-342    | Marine sediment                     | Indian Ocean, Qingdao, China | [83] |
| Clindanone B (155)        | 394      | C_{22}H_{16}O_{7} | C. cladosporioides HDN14-342    | Marine sediment                     | Indian Ocean, Qingdao, China | [83] |
| Isosclerone = (-)-(4R)-Regiolone (156) | 178 | C_{10}H_{10}O_{3} | C. perangustm FS62             | Marine sediment                     | South China Sea, China     | [87] |
| (-)-trans-(3R,4R)-3,4,8-Trihydroxy-6,7-dimethyl-3,4-dihydronaphthalen-1(2H)-one (157) | 222 | C_{12}H_{14}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Hainan, China | [88] |
| (3S,3,8-Dihydroxy-6,7-dimethyl-α-tetralone (158) | 206 | C_{12}H_{14}O_{3} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Hainan, China | [88] |
| (3R,4R,3,4,8-trihydroxy-1(2H)-naphthalenone (159) | 194 | C_{10}H_{10}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Hainan, China | [88] |
| Cladonaphchrom A (169)    | 350      | C_{22}H_{22}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |
| Cladonaphchrom B (170)    | 350      | C_{22}H_{22}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |

8. Perylenequinones

| Compound Name             | Mol. Wt. | Mol. Formula | Fungal Source                  | Host (Sample, Family)               | Place                      | Ref. |
|---------------------------|----------|--------------|---------------------------------|-------------------------------------|---------------------------|------|
| Altertoxin VIII (161)     | 304      | C_{20}H_{16}O_{3} | Cladosporium sp. KFD33          | Blood cockle (Bivalve mollusk, Cardiidae) | Haikou Bay, Hainan, China | [85] |
| Altertoxin IX (162)       | 290      | C_{20}H_{18}O_{2} | Cladosporium sp. KFD33          | Blood cockle (Bivalve mollusk, Cardiidae) | Haikou Bay, China         | [85] |
| Altertoxin X (163)        | 290      | C_{20}H_{18}O_{2} | Cladosporium sp. KFD33          | Blood cockle (Bivalve mollusk, Cardiidae) | Haikou Bay, China         | [85] |
| Altertoxin XI (164)       | 304      | C_{21}H_{20}O_{2} | Cladosporium sp. KFD33          | Blood cockle (Bivalve mollusk, Cardiidae) | Haikou Bay, China         | [85] |

9. Naphthalene derivatives

| Compound Name             | Mol. Wt. | Mol. Formula | Fungal Source                  | Host (Sample, Family)               | Place                      | Ref. |
|---------------------------|----------|--------------|---------------------------------|-------------------------------------|---------------------------|------|
| 8-Methoxynaphthalene-1-ol (165) | 174 | C_{13}H_{10}O_{2} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |
| 1,8-Dimethoxynaphthalene (166) | 188 | C_{13}H_{12}O_{2} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |
| 4-Methoxynaphthalene-1,5-diol (167) | 190 | C_{13}H_{10}O_{3} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [91] |
| 8-Methoxynaphthalene-1,7-diol (168) | 190 | C_{13}H_{10}O_{3} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [91] |
| Cladonaphchrom A (169)    | 350      | C_{22}H_{22}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |
| Cladonaphchrom B (170)    | 350      | C_{22}H_{22}O_{4} | Cladosporium sp. JMM22         | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China     | [90] |
| Compound Name                              | Mol. Wt. | Mol. Formula | Fungal Source                     | Host (Sample, Family)                  | Place                                              | Ref. |
|--------------------------------------------|----------|--------------|-----------------------------------|----------------------------------------|---------------------------------------------------|------|
| 10. Xanthones                              |          |              |                                   |                                        |                                                   |      |
| 8-Hydroxy-6-methylxanthone-1-carboxylic    | 270      | C₁₅H₁₀O₅     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| acid (171)                                 |          |              |                                   |                                        |                                                   |      |
| Methyl 8-hydroxy-6-methyl-9-oxo-9H-xanthene-1-carboxylate (172) | 284      | C₁₆H₁₂O₃     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| Methyl 8-hydroxy-6-(hydroxymethyl)-9-oxo-9H-xanthene-1-carboxylate (173) | 300      | C₁₆H₁₂O₆     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| Vertixanthone (174)                        | 270      | C₁₅H₁₀O₅     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| 8-(Methoxycarbonyl)-1-hydroxy-9-oxo-9H-xanthene-1-Carboxylate (175) | 316      | C₁₆H₁₂O₇     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| Conioxanthone A (177)                      | 316      | C₁₆H₁₂O₇     | C. halotolerans GXIMD 02502       | Porites lutea (Stony coral, Poritidae)  | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China [92] |      |
| 11. Tropolones                             |          |              |                                   |                                        |                                                   |      |
| Malettinin A (178)                         | 288      | C₁₆H₁₂O₅     | Cladosporium sp. KF501            | Water sample                           | German Wadden Sea                                  | [93] |
| Malettinin B (179)                         | 292      | C₁₆H₂₀O₅     | Cladosporium sp. KF501            | Water sample                           | German Wadden Sea                                  | [93] |
| Malettinin C (180)                         | 292      | C₁₆H₂₀O₅     | Cladosporium sp. KF501            | Water sample                           | German Wadden Sea                                  | [93] |
| Malettinin E (181)                         | 292      | C₁₆H₂₀O₅     | Cladosporium sp. KF501            | Water samples                          | German Wadden Sea                                  | [93] |
| 12. Binaphthopyrones                       |          |              |                                   |                                        |                                                   |      |
| Cladosporinine (182)                       | 650      | C₃₅H₃₅O₁₄    | C. cladosporioides                | Sediment of a hypersaline lake El Hamra | Wadi el Natrun, Egypt                              | [94] |
| Viriditoxin (183)                          | 662      | C₃₅H₃₅O₁₄    | C. cladosporioides                | Sediment of a hypersaline lake El Hamra | Wadi el Natrun, Egypt                              | [94] |
| Viriditoxin derivative 1 (184)             | 646      | C₃₅H₃₅O₁₃    | C. cladosporioides                | Sediment of a hypersaline lake El Hamra | Wadi el Natrun, Egypt                              | [94] |
| Viriditoxin derivative 2 (185)             | 646      | C₃₅H₃₅O₁₃    | C. cladosporioides                | Sediment of a hypersaline lake El Hamra | Wadi el Natrun, Egypt                              | [94] |
| 13. Benzopyranes, benzopyrones, and pyrones|          |              |                                   |                                        |                                                   |      |
| (2S)-5-Hydroxy-2-methyl-chroman-4-one (186) | 178      | C₁₀H₁₀O₃     | Cladosporium sp. JJM22            | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Dongzhaiang, Hainan, China [88] |      |
| (R)-5-Hydroxy-2-methylchroman-4-one (187)  | 178      | C₁₀H₁₀O₃     | Cladosporium sp. JJM22            | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China [90]                       |      |
| (2R)-7-O-a-D-Ribofuranosyl-5-hydroxy-2-methyl chroman-4-one (188) | 326      | C₁₃H₁₆O₄     | Cladosporium sp. OUCMDZ-302       | Ceriops tagal (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China [95]                      |      |
|                                             |          |              |                                   | Ceriops tagal (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China [95]                      |      |
|                                             |          |              |                                   | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China [91]                       |      |
| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|-----|
| (2S)-7-O-D-Ribofuranosyl-5-hydroxy-2-methylchroman-4-one | 326 | C_{13}H_{10}O_{8} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| (189) | 194 | C_{10}H_{19}O_{4} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| 5-Hydroxy-2-methyl-4H-chromen-4-one | 176 | C_{10}H_{16}O_{3} | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China | [90] |
| Clapone | 216 | C_{13}H_{12}O_{3} | Cladosporium sp. HNWSW-1 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Dong Zhai Gang Mangrove, Hainan, China | [67] |
| 7-O-α-D-Ribosyl-5-hydroxy-2-propylchromone | 352 | C_{17}H_{23}O_{8} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| Coniochaetone A | 230 | C_{13}H_{10}O_{4} | C. halotolerans GXIMD 02502 | Porites lutea (Stony coral, Poritidae) | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China | [92] |
| Coniochaetone B | 232 | C_{13}H_{12}O_{4} | C. halotolerans GXIMD 02502 | Porites lutea (Stony coral, Poritidae) | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China | [92] |
| Coniochaetone K | 262 | C_{13}H_{10}O_{6} | C. halotolerans GXIMD 02502 | Porites lutea (Stony coral, Poritidae) | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China | [92] |
| α-Diversonolonic ester | 320 | C_{14}H_{16}O_{7} | C. halotolerans GXIMD 02502 | Porites lutea (Stony coral, Poritidae) | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China | [92] |
| β-Diversonolonic ester | 320 | C_{14}H_{16}O_{7} | C. halotolerans GXIMD 02502 | Porites lutea (Stony coral, Poritidae) | Weizhou Islands coral reef, Guangxi Zhuang autonomous region, China | [92] |
| Secalonic acid D | 638 | C_{29}H_{33}O_{14} | Cladosporium sp. JSI-2 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaigang, Hainan, China | [71] |
| (2S,3S,4R)-2-Methylchroman-3,4,5-triol | 196 | C_{10}H_{12}O_{4} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| (2S,4S)-4-Methoxy-2-methylchroman-5-ol | 194 | C_{11}H_{14}O_{3} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| (2R,4R)-3,4-Dihydro-4-methoxy-2-methyl-2H-1-benzopyran-5-ol | 194 | C_{11}H_{14}O_{3} | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China | [91] |
| (2S,4S)-2-methylchroman-4,5-diol | 180 | C_{10}H_{12}O_{3} | Cladosporium sp. OUCMDZ-302 | Exococaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |
| (2R,4S)-2,3-Dihydro-2-methyl-benzopyran-4,5-diol | 180 | C_{10}H_{12}O_{3} | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China | [91] |
| (2R,4R)-3,4-Dihydro-5-methoxy-2-methyl-1(2H)-benzopyran-4-ol | 164 | C_{10}H_{12}O_{2} | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Dongzhaigang, Hainan, China | [88] |
| Citrinin H1 | 428 | C_{26}H_{28}O_{7} | Cladosporium sp. JSI-2 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaigang, Hainan, China | [71] |
| Cladosporin C | 248 | C_{17}H_{14}O_{4} | C. cladosporoides SCSIO z015 | Deep sea sediment | Okinawa, Japan | [36] |
| (5)-5-Hydroxy-4-methylchroman-2-one | 178 | C_{10}H_{10}O_{3} | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China | [91] |
Table 1. Cont.

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| (3R)-3-(2-Hydroxypropyl)-6,8-dihydroxy-3,4-dihydroxy-coumarin (209) | 238 | C_{13}H_{14}O_{5} | Cladosporium sp. CSIO41007 | Callyspongia sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| Phomasatin (208) | 208 | C_{10}H_{10}O_{5} | C. cladosporioides MCCC 3A00182 | Marine sediment | Southwest Pacific Ocean | [75] |

14. Pyrones derivatives

| Herbarin A (211) | 256 | C_{12}H_{12}O_{5} | C. herbarum (Pers.) | Aplysina aerophoba (Sponge, Aplysiniidae) | Bali Bata National Park, Indonesia | [96] |
| Herbarin B (212) | 210 | C_{10}H_{10}O_{5} | C. herbarum (Pers.) | Aplysina aerophoba (Sponge, Aplysiniidae) | Bali Bata National Park, Indonesia | [96] |
| Citroevidrin A (213) | 402 | C_{12}H_{12}O_{5} | C. herbarum (Pers.) | Aplysina aerophoba (Sponge, Aplysiniidae) | Bali Bata National Park, Indonesia | [96] |
| Vermatin (214) | 328 | C_{18}H_{16}O_{6} | Cladosporium sp. JS1-2 | Callyspongia aerizusa (Sponge, Callyspongiidae) | Bali Bata National Park, Indonesia | [96] |

15. Lactones, cyclohexene, and azaphilone derivatives

| Herbarin A (211) | 130 | C_{12}H_{10}O_{3} | Cladosporium sp. EF424419 | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China | [59] |
| Cladosporactone A (216) | 196 | C_{12}H_{12}O_{4} | C. cladosporioides MCCC 3A00182 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Southwest Pacific Ocean | [75] |
| Cladoscyclitol A (218) | 244 | C_{12}H_{20}O_{5} | Cladosporium sp. JMM22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, China | [91] |
| Cladoscyclitol B (219) | 290 | C_{12}H_{22}O_{7} | Cladosporium sp. JMM22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaihong of Hainan Province, China | [97] |
| Cladoscyclitol C (220) | 250 | C_{12}H_{22}O_{5} | Cladosporium sp. JMM22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaihong of Hainan Province, China | [97] |
| Cladoscyclitol D (221) | 246 | C_{12}H_{22}O_{5} | Cladosporium sp. JMM22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | Dongzhaihong of Hainan Province, China | [97] |
| 2-Butyryl-3,5-dihydroxycyclohex-2-enone (222) | 198 | C_{13}H_{14}O_{4} | Cladosporium sp. OUCMDZ-302 | Exocoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China | [95] |

16. Phenolics and other aromatic compounds

| 3-Phenyl-propionic acid (226) | 210 | C_{13}H_{14}O_{4} | Cladosporium sp. JMM22 | Ceriops tagal (Rhizophoraceae) | South China Sea, China | [91] |
| P-Toluic acid (227) | 136 | C_{9}H_{8}O_{2} | Cladosporium sp. | Ceriops tagal (Mangrove plant, Euphorbiaceae) | Argentina | [98] |
| L-β-Phenylactic acid (228) | 166 | C_{7}H_{6}O_{3} | Cladosporium sp. EF424419 | Ceriops tagal (Mangrove plant, Euphorbiaceae) | Lianyungang, Jiangsu, China | [59] |
| α-Resorcylic acid (229) | 154 | C_{7}H_{6}O_{4} | Cladosporium sp. EF424419 | Ceriops tagal (Mangrove plant, Euphorbiaceae) | Lianyungang, Jiangsu, China | [59] |
Table 1. Cont.

| Compound Name                                      | Mol. Wt. | Mol. Formula | Fungal Source          | Host (Sample, Family)                     | Place                        | Ref.          |
|-----------------------------------------------------|----------|--------------|------------------------|-------------------------------------------|------------------------------|---------------|
| Phenylacetic acid (230)                             | 156      | C₆H₆O₂       | Cladosporium sp.       | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China  | [59]          |
| P-Hydroxyphenylacetic acid (231)                    | 152      | C₆H₅O₂       | Cladosporium sp.       | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China  | [59]          |
| Cinnamic acid (3-Phenyl-2-propanoic acid) (232)      | 148      | C₆H₅O₂       | Cladosporium sp. F14   | Seawater from the mangrove stand          | Kei Ling Ha Lo Wai, Sai Kung, China | [60]         |
| 3-(2,3-Dihydroxy phenoxy) butanoic acid (233)        | 212      | C₁₀H₁₂O₃     | Cladosporium sp. OUCMDZ-302 | Exoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China     | [95]          |
| P-Hydroxy benzoic acid methyl ester (234)            | 152      | C₆H₄O₂       | Cladosporium sp.       | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China  | [59]          |
| Methyl (35)-3-(2,3-dihydroxy phenoxy)butanoate (235)| 226      | C₁₁H₁₄O₅     | Cladosporium sp. OUCMDZ-302 | Exoecaria agallocha (Mangrove plant, Euphorbiaceae) | Lianyungang, Jiangsu Province, China | [59]         |
| P-Hydroxyphenylethyl alcohol (236)                  | 138      | C₆H₅O₂       | Cladosporium sp.       | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu Province, China | [59]         |
| 2-Phenylenol (237)                                   | 142      | C₆H₅O₂       | Cladosporium sp.       | Porphyra yezoensis (Red alga, Bangiaceae) | Lianyungang, Jiangsu, China  | [59]          |
| 2-Phenylethanol (238)                                | 122      | C₆H₅O        | Cladosporium sp. F14   | Seawater from the mangrove stand          | Kei Ling Ha Lo Wai, Sai Kung, China | [60]         |
| 4-O-α-D-Ribofuranose-3-hydroxymethyl-2-pentyl-1-phenol (239) | 342 | C₁₇H₂₆O₇     | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Dongzhaigang, Hainan, China | [88]         |
| 4-O-α-D-Ribofuranose-2-pentyl-3-phenethylol (240)    | 326      | C₁₇H₂₆O₈     | Cladosporium sp. JMJ22 | Ceriops tagal (Mangrove plant, Rhizophoraceae) | South China Sea, Dongzhaigang, Hainan, China | [88]         |
| Clavatol (241)                                       | 180      | C₁₀H₁₂O₃     | Cladosporium sp. MFC353-b | Chondria crassicalis (Red alga, Rhododolomelaceae) | Yokji Island, Kyeongnam, Korea | [65]          |
| 1-(3,5-Dihydroxy-4-methylphenyl)propan-2-one (242)   | 180      | C₁₀H₁₂O₃     | C. perangustm FS62     | Marine sediment                           | Marine acicent, China        | [87]          |
| 5-Acetlyorcinol (243)                                | 166      | C₆H₅O₃       | C. perangustm FS62     | Marine sediment                           | South China Sea, China       | [87]          |
| 1-(2,6-Dihydroxyphenyl) ethanone (244)               | 152      | C₆H₅O       | Cladosporium sp. OUCMDZ-302 | Exoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China     | [95]          |
| 1-(2,6-Dihydroxyphenyl)-1-butanone (245)             | 180      | C₁₀H₁₂O₃     | Cladosporium sp. OUCMDZ-302 | Exoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China     | [95]          |
| 1-(2,6-Dihydroxyphenyl)-1-butanone (246)             | 210      | C₁₁H₁₄O₄     | Cladosporium sp. JMJ22 | Ceriops tagal (Rhizophoraceae)             | South China Sea, China       | [91]          |
| Cladosporin D (247)                                  | 224      | C₁₁H₁₆O₄     | C. cladospoiroids SCSIO z015 | Deep sea sediment                         | Manado, Indonesia           | [68]          |
| (2S,7,9,14,17,20,22,26)-dihydroxy-5-methoxy-8-(γ,γ- dimethylallyl)-flavanone (248) | 284 | C₂₃H₂₂O₅    | Cladosporium sp. TPU1507 | Unidentified marine sponge                 | Manado, Indonesia           | [68]          |
| Bis(2-Ethylhexyl)phthalate (249)                    | 390      | C₁₃H₂₆O₄     | Cladosporium sp. F14   | Seawater from the mangrove stand          | Kei Ling Ha Lo Wai, Sai Kung, China | [60]         |
| Herbaric acid (250)                                 | 196      | C₆H₄O₃       | C. herbarum (Pers.)    | Calypogon cagriga (Sponge, Callyspongidae) | Bali Bata National Park, Indonesia | [96]         |
| Cladosacid (251)                                    | 250      | C₁₁H₁₂O₃     | Cladosporium sp. OUCMDZ-1635 | Unidentified sponge                        | Xisha Islands, China        | [56]          |
| L1′-Dioxine-2,2′-dipropionic acid (252)              | 228      | C₁₀H₁₂O₆     | Cladosporium sp. JSI-1 | Ceriops tagal (Mangrove, plant, Rhizophoraceae) Calypogon cagriga (Sponge, Callyspongidae) | Dongzhaigang, Hainan, China | [71]          |
| Sumiki’s acid (253)                                 | 142      | C₆H₄O₄       | C. herbarum (Pers.)    | Calypogon cagriga (Sponge, Callyspongidae) | Bali Bata National Park, Indonesia | [73]          |
### Table 1. Cont.

| Compound Name | Mol. Wt. | Mol. Formula | Fungal Source | Host (Sample, Family) | Place | Ref. |
|---------------|----------|--------------|---------------|-----------------------|-------|------|
| Acetyl Sumiki’s acid (254) | 184 | C₅₇H₇₃O₃ | C. herbarum (Pers.) | Callyspongia aerizusa (Sponge, Callyspongiidae) | Bali Bata National Park, Indonesia | [74] |
| 5α,8α-Epidoxy-24(R)-methyl-cholesta-6,22-diene-3β-ol (255) | 428 | C₃₀H₄₄O₅ | C. sphaerospermum Penz | Ceramium condi (Red alga, Ceramiaceae) | Usuririysk Bay, Japan | [99] |
| 5α,8α-Epidoxy-ergosta-6,22E-dien-3β-ol (256) | 428 | C₃₀H₄₄O₅ | C. cladosporioides MCCC 3A00182 | Dichothelia gemmaea (Gorgonian, Ellisellidae) | Weizhou Island coral reef, South China Sea | [75] |
| 5α,8α-Epidoxy-ergosta-6,9,22E-triene-3β-ol (257) | 426 | C₂₈H₄₂O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Weizhou Island coral reef, South China Sea | [100] |
| 5α,8α-Epidoxy-ergosta-6,9,22E-triene-3β-ol (258) | 426 | C₂₈H₄₂O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Weizhou Island coral reef, South China Sea | [75] |
| 3β,5α,6β-Trithydroxyergosta-7,22-diene = Cerevisterol (259) | 430 | C₂₈H₄₈O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Weizhou Island coral reef, South China Sea | [100] |
| Ergosta-7,22E-diene-3β,5α,6β-triol (260) | 430 | C₂₈H₄₈O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Weizhou Island coral reef, South China Sea | [75] |
| 3β,5α,6α-Trithydroxy-(22E,24R)-ergosta-7,22-diene-6-one (261) | 430 | C₂₈H₄₈O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Weizhou Island coral reef, South China Sea | [100] |
| Ergosterol (263) | 396 | C₂₈H₄₄O₅ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| Cladosporisteroid A (264) | 460 | C₂₈H₄₄O₅ | Cladosporium sp. SCSIO41007 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| 3β,5α,9α-Trithydroxy-(22E,24R)-ergosta-7,22-diene-6-one (265) | 444 | C₂₈H₄₄O₄ | Cladosporium sp. SCSIO41007 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| 3β,5α-Dihydroxy-(22E,24R)-ergosta-7,22-diene-6-one (266) | 428 | C₂₈H₄₄O₃ | Cladosporium sp. SCSIO41007 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| Stigma-5-en-3-O-β-glucopyranoside (267) | 576 | C₃₃H₄₆O₆ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
| 3α-Hydroxy-pregn-7-one-6,20-dione = Cladosporisteroid B (268) | 330 | C₂₁H₃₂O₃ | Cladosporium sp. WZ-2008-0042 | Cladosporium sp. (Sponge, Callyspongiidae) | Xuwen, Guangdong, China | [61] |
### Table 1. Cont.

| Compound Name                      | Mol. Wt. | Mol. Formula    | Fungal Source                  | Host (Sample, Family)                          | Place                                    | Ref.  |
|------------------------------------|----------|----------------|-------------------------------|------------------------------------------------|------------------------------------------|-------|
| Cladosporisteroid C (269)          | 374      | C₂₃H₃₄O₄       | Cladosporium sp.              | Calyptoporia sp. (Sponge, Callyspongiidae)     | Xuwen, Guangdong, China                  | [61]  |
| Pregn-7-dien-3,6,20-trione (270)   | 328      | C₂₁H₂₈O₃       | Cladosporium sp.              | Calyptoporia sp. (Sponge, Callyspongiidae)     | Xuwen, Guangdong, China                  | [61]  |
| 18. Alcohols and aldehydes         |          |                |                               |                                                 |                                          |       |
| Compound (271)                     | 434      | C₃₀H₅₈O        | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (272)                     | 458      | C₳₂₃H₅₈O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (273)                     | 458      | C₳₂₃H₅₈O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (274)                     | 458      | C₳₂₃H₅₈O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (275)                     | 460      | C₳₂₃H₆₀O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (276)                     | 460      | C₳₂₃H₆₀O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (277)                     | 462      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (278)                     | 462      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (279)                     | 482      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (280)                     | 484      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (281)                     | 484      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (282)                     | 484      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (283)                     | 484      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| Compound (284)                     | 486      | C₳₂₃H₆₂O       | Cladosporium sp.              | Marine sediment                                | San Antonio Oeste, Río Negro, Argentina  | [102] |
| (2S,3S,4E)-Hepta-4,6-diene-2,3-diol (285) | 128     | C₇H₁₂O₂         | Cladosporium sp. OUCMDZ-302   | Excoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China                  | [95]  |
| (3E,8E,6S)-Undeca-3,8,10-trien-1,6-diol (286) | 182     | C₁₁H₁₈O₂        | Cladosporium sp. OUCMDZ-302   | Excoecaria agallocha (Mangrove plant, Euphorbiaceae) | Wenchang, Hainan, China                  | [95]  |

### Table 2. Biological activity of secondary metabolites isolated from Cladosporium species.

| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref.  |
|---------------|---------------------|-------------------------------|--------------------|------------------|-------|
| Cladosin C (3) | Antiviral           | Neuraminidase inhibition assay/Influenza A H1N1 virus | 276.0 µM (IC₅₀)   | Ribavirin 131.0 µM (IC₅₀) | [42]  |
| Cladosin I (8) | Cytotoxicity        | MTT/K562                      | 4.1 µM (IC₅₀)      | Doxorubicin 0.3 µM (IC₅₀) | [55]  |
|                | Cytotoxicity        | MTT/HL-60                     | 2.8 µM (IC₅₀)      | Doxorubicin 0.2 µM (IC₅₀) | [55]  |
|                | Cytotoxicity        | SEB/HCT-116                   | 11.0 µM (IC₅₀)     | Doxorubicin 0.2 µM (IC₅₀) | [55]  |
|                | Cytotoxicity        | SRB/PC-3                      | 13.0 µM (IC₅₀)     | Doxorubicin 1.0 µM (IC₅₀) | [55]  |
|                | Cytotoxicity        | SRB/SY-5Y                     | 12.0 µM (IC₅₀)     | Doxorubicin 0.1 µM (IC₅₀) | [55]  |
|                | Cytotoxicity        | SRB/MGC-803                   | 19.0 µM (IC₅₀)     | Doxorubicin 0.2 µM (IC₅₀) | [55]  |
| Compound Name          | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|-----------------------|---------------------|--------------------------------|--------------------|------------------|------|
| Cladosin K (10)       | Cytotoxicity        | MTT/K562                       | 5.9 µM (IC₅₀)      | Doxorubicin 0.3 µM (IC₅₀) | [55] |
| Cladosporicin A (12)  | Cytotoxicity        | SRB/Bt549                      | 70.88 µM (IC₅₀)    | Etoposide 1.82 µM (IC₅₀) | [38] |
| Cladodionen (13)      | Cytotoxicity        | MTT/K562                       | 4.5 µM (IC₅₀)      | Doxorubicin 0.3 µM (IC₅₀) | [55] |
| Cladosporitum I (29)  | Cytotoxicity        | SRB/Bt549                      | 7.86 µM (IC₅₀)     | Etoposide 1.82 µM (IC₅₀) | [38] |
| Cyclo-(Val-Pro) (32)  | Insecticidal        | Inhibition 50% / B. amphitrite | 37.82 µg/mL (IC₅₀) | FSW with DMSO     | [60] |

**Table 2. Cont.**
| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|----------------|---------------------|-------------------------------|--------------------|------------------|------|
| Cyclo-(Val-Pro) (32) | Antimicrobial | Serial dilution / L. longkongensis | 80 µg/mL (MIC) | Streptomycin 250 µg/mL (MIC) | [60] |
| Cyclo-(Phe-Pro) (33) | Insecticidal | Inhibition 50% / B. amphitrite | 68.57 µg/mL (EC₅₀) | FSW with DMSO | [60] |
| | | Lethality 50% / B. amphitrite | 115.04 µg/mL (LC₅₀) | FSW with DMSO | [60] |
| | | Inhibition 50% / B. neritina | 70.43 µg/mL (EC₅₀) | FSW with DMSO | [60] |
| | | Lethality 50% / B. neritina | >200 µg/mL (LC₅₀) | FSW with DMSO | [60] |
| Cyclo-(Phe-Pro) (33) | Antimicrobial | Serial dilution / L. longkongensis | 200 µg/mL (MIC) | Streptomycin 250 µg/mL (MIC) | [60] |
| | | | | Penicillin 0.25 µg/mL (MIC) | [60] |
| | | | | Penicillin 0.5 µg/mL (MIC) | [60] |
| | | | | Penicillin 1.0 µg/mL (MIC) | [60] |
| | | | | Penicillin 2.0 µg/mL (MIC) | [60] |
| Glynantrypine (42) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 150 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| 3-Hydroxyglyantrypine (43) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 110 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| 14R-Oxoglyantrypine (44) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 130 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| 14S-Oxoglyantrypine (45) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 85 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Cladoquinazoline (47) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 150 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Epit-Cladoquinazoline (48) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 140 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Norquinadoline A (49) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 82 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Quinadoline A (50) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 130 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Deoxynortryptoquivaline (51) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 87 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Deoxytryptoquivaline (52) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 85 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Tryptoquivaline (53) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 89 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| CS-C (54) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 140 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Quinadoline B (55) | Antiviral | CPE inhibition assay / Influenza A H1N1 virus | 82 µM (IC₅₀) | Ribavirin 87.0 µM (IC₅₀) | [62] |
| Quinolactacin A2 (56) | Cytotoxicity | MTT / HepG-2 | 96.54 µM (IC₅₀) | Curcumin 61.36 µM (IC₅₀) | [66] |
| | | MTT / HL-60 | 54.47 µM (IC₅₀) | Curcumin 13.78 µM (IC₅₀) | [66] |
| | | MTT / MCF-7 | 94.49 µM (IC₅₀) | Curcumin 20.68 µM (IC₅₀) | [66] |
| | | MTT / LNCap | 45.71 µM (IC₅₀) | Curcumin 6.15 µM (IC₅₀) | [66] |
| | | | | FSW with DMSO | [60] |
| Anti-malarial | Flow cytometry / SYBR Green I fluorescence / P. falciparum chloroquine sensitive (3D7) | MTT / HepG-2 | 24.8 µM (EC₅₀) | Artesunate 0.074 µM (EC₅₀) | [66] |
| Citrinadin A (60) | Cytotoxicity | MTT / HepG-2 | 82.15 µM (IC₅₀) | Curcumin 61.36 µM (IC₅₀) | [66] |
| | | MTT / HL-60 | 57.23 µM (IC₅₀) | Curcumin 13.78 µM (IC₅₀) | [66] |
| | | MTT / MCF-7 | 66.07 µM (IC₅₀) | Curcumin 20.68 µM (IC₅₀) | [66] |
| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control Ref. |
|---------------|---------------------|------------------------------|--------------------|-----------------------|
|               | Anti-malarial       | MTT/LNCap                    | 41.42 µM (IC₅₀)    | Curcumin 6.15 µM (IC₅₀) [66] |
| Butrectrinadin (70) | Cytotoxicity | [Flow cytometry/SYBR Green I fluorescence/P. falciparum chloroquine sensitive (3D7)] | >25.0 µM (EC₅₀) | Artesunate 0.074 µM (EC₅₀) [66] |
|               | Cytotoxicity        | MTT/Hept G-2                 | 78.57 µM (IC₅₀)    | Curcumin 61.38 µM (IC₅₀) [66] |
|               | Cytotoxicity        | MTT/HL-60                    | 60.31 µM (IC₅₀)    | Curcumin 13.78 µM (IC₅₀) [66] |
|               | Cytotoxicity        | MTT/MCF-7                    | 51.32 µM (IC₅₀)    | Curcumin 20.68 µM (IC₅₀) [66] |
|               | Anti-malarial       | MTT/LNCap                    | 32.94 µM (IC₅₀)    | Curcumin 6.15 µM (IC₅₀) [66] |
| Cladosporitin B (74) | Cytotoxicity | [Flow cytometry/SYBR Green I fluorescence/P. falciparum chloroquine sensitive (3D7)] | >25.0 µM (EC₅₀) | Artesunate 0.074 µM (EC₅₀) [66] |
| Cladosporilactam A (78) | Cytotoxicity | MTT/BEL-7042                 | 29.4 µM (IC₅₀)    | Adriamycin 11.9 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/K562                     | 25.6 µM (IC₅₀)     | Adriamycin 14.2 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/SGC-7901                 | 41.7 µM (IC₅₀)     | Adriamycin 6.66 µM (IC₅₀) [67] |
| Talaroconvolutin A (76) | Cytotoxicity | MTT/HeLa                     | 14.9 µM (IC₅₀)    | Adriamycin 11.5 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/BEL-7042                 | 26.7 µM (IC₅₀)     | Adriamycin 11.9 µM (IC₅₀) [67] |
| Talaroconvolutin A (76) | α-Glucosidase inhibitory | Glucose oxidase method | 78.2 µM (IC₅₀)    | Acarbose 275.7 µM (IC₅₀) [67] |
| Cladosporamide A (77) | Protein tyrosine phosphatase 1B inhibitory | PTP1B/Spectrophotometry | 48.0 µM (IC₅₀)    | Oleanolic acid 0.9 µM (IC₅₀) [68] |
|               | Cytotoxicity        | MTT/Bel-7042                 | 29.4 µM (IC₅₀)    | Adriamycin 11.9 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/K562                     | 25.6 µM (IC₅₀)     | Adriamycin 14.2 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/SGC-7901                 | 41.7 µM (IC₅₀)     | Adriamycin 6.66 µM (IC₅₀) [67] |
| Talaroconvolutin A (76) | Cytotoxicity | MTT/HeLa                     | 14.9 µM (IC₅₀)    | Adriamycin 11.5 µM (IC₅₀) [67] |
|               | Cytotoxicity        | MTT/BEL-7042                 | 26.7 µM (IC₅₀)     | Adriamycin 11.9 µM (IC₅₀) [67] |
| Cladosporilactam A (78) | Cytotoxicity | MTT/HeLa                     | 0.76 µM (IC₅₀)    | Adriamycin [69] |
|               | Cytotoxicity        | MTT/HT-29                    | 2.48 µM (IC₅₀)     | Adriamycin [69] |
| SRB/P388      | 1.35 µM (IC₅₀)      | Adriamycin [69]              |
| SRB/AS49      | 3.11 µM (IC₅₀)      | Adriamycin [69]              |
| 2-Methylacetate-3,5,6-trimethylpyrazine (84) | Insecticidal | CM/Helicoverpa armigera Hubner larvae | 100.0 µg/mL (IC₅₀) | Azadirachtin 25.0 µg/mL (IC₅₀) [71] |
|               | Antimicrobial       | Microplate assay/S. aureus   | 12.5 µg/mL (MIC)   | Ciprofloxacin 0.39 µg/mL (MIC) [71] |
|               | Antimicrobial       | Microplate assay/S. aureus   | 25.0 µg/mL (MIC)   | Ciprofloxacin 0.39 µg/mL (MIC) [71] |
| Pandangolide 3 (96) | Antimicrobial | Microplate assay/C. gleosporioides | 2.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) [39] |
|               | Antimicrobial       | Microplate assay/B. sorokiniana | 8.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) [39] |
| Thiocladosolide A (101) | Antimicrobial | Microplate assay/E. tarda | 8.0 µg/mL (MIC) | Chlormphenicol 0.5 µg/mL (MIC) [39] |
|               | Antimicrobial       | Microplate assay/E. tarda | 8.0 µg/mL (MIC) | Chlormphenicol 0.5 µg/mL (MIC) [39] |
|               | Antimicrobial       | Microplate assay/C. gleosporioides | 2.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) [39] |
| Compound Name            | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control                      | Ref. |
|--------------------------|---------------------|-------------------------------|--------------------|---------------------------------------|------|
| Thiocladospolide B (102) | Antimicrobial       | Microplate assay/C. glecosporioides | 2.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/P. piricola   | Nose 32.0 µg/mL (MIC) | Amphotericin B 2.0 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/F. oxysporum f. sp. cucumerinum | 32.0 µg/mL (MIC) | Amphotericin B 2.0 µg/mL (MIC) | [39] |
| Thiocladospolide C (103) | Antimicrobial       | Microplate assay/C. glecosporioides | 1.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/P. piricola   | Nose 32.0 µg/mL (MIC) | Amphotericin B 2.0 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/F. oxysporum f. sp. cucumerinum | 32.0 µg/mL (MIC) | Amphotericin B 0.5 µg/mL (MIC) | [39] |
| Thiocladospolide D (104) | Antimicrobial       | Microplate assay/E. ictarda    | 1.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/C. glecosporioides | 32.0 µg/mL (MIC) | Amphotericin B 2.0 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/P. piricola   | Nose 32.0 µg/mL (MIC) | Amphotericin B 2.0 µg/mL (MIC) | [39] |
|                          |                     | Microplate assay/F. oxysporum f. sp. cucumerinum | 1.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [39] |
| Thiocladospolide F (106) | Antimicrobial       | Microplate assay/E. tarda      | 2.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [79] |
|                          |                     | Microplate assay/H. magueis    | 2.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [79] |
| Thiocladospolide G (108) | Antimicrobial       | Microplate assay/E. tarda      | 4.0 µg/mL (MIC) | Chloramphenicol 1.0 µg/mL (MIC) | [78] |
| Thiocladospolide G (109) | Antimicrobial       | Microplate assay/E. tarda      | 4.0 µg/mL (MIC) | Chloramphenicol 1.0 µg/mL (MIC) | [78] |
| Thiocladospolide H (110) | Antimicrobial       | Microplate assay/E. ictarda    | 4.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [78] |
| Sporiolide A (113)       | Cytotoxicity        | MTT/L1210                      | 0.13 µM (IC50) | -                                     | [80] |
| Sporiolide B (114)       | Cytotoxicity        | MTT/L1210                      | 0.81 µM (IC50) | -                                     | [80] |
| Dendrodolide A (117)     | Antimicrobial       | Broth dilution assay/B. cereus  | 12.5 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/T. halophilus | 3.13 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/S. epidermidis | 6.25 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/S. aureus  | 6.25 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/E. coli    | 12.5 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/P. putida  | 12.5 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/N. brasiliensis | 6.25 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/V. paraaemolyticus | 12.5 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
| Dendrodolide C (118)     | Antimicrobial       | Broth dilution assay/B. cereus  | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/T. halophilus | 3.13 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/S. epidermidis | 25.0 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/S. aureus  | 25.0 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/E. coli    | 12.5 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/P. putida  | 25.0 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                          |                     | Broth dilution assay/N. brasiliensis | 12.5 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
### Table 2. Cont.

| Compound Name   | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref.  |
|-----------------|---------------------|-------------------------------|--------------------|------------------|-------|
| Dendrodolide M (120) | Antimicrobial | Broth dilution assay / *V. parahaemolyticus* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *B. cereus* | 6.25 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *T. halophilus* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *S. epidermidis* | 25.0 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *S. aureus* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *E. coli* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *P. putida* | 6.25 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *N. brasiliensis* | 25.0 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
| Cladocladosin A (121) | Antimicrobial | Microplate assay / *E. tarda* | 1.0 µg/mL (MIC) | Chloramphenicol 0.5 µg/mL (MIC) | [79] |
|                 |                     | Microplate assay / *P. aeruginosa* | 4.0 µg/mL (MIC) | Chloramphenicol 2.0 µg/mL (MIC) | [79] |
| Ent-cladospolide F (123) | AchE inhibitory | Modified Ellman’s enzyme/Immunosorbent assay | 40.26 µM (IC₅₀) | Tacrine 0.5 µM (IC₅₀) | [40] |
| Iso-cladospolide B (126) | Antimicrobial | Broth dilution assay / *B. cereus* | 6.25 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *T. halophilus* | 6.25 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *S. epidermidis* | 25.0 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *S. aureus* | 25.0 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *E. coli* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *P. putida* | 6.25 µM (MIC) | Ciprofloxacin 0.39 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *N. brasiliensis* | 12.5 µM (MIC) | Ciprofloxacin 0.78 µM (MIC) | [69] |
|                 |                     | Broth dilution assay / *V. parahaemolyticus* | 25.0 µM (MIC) | Ciprofloxacin 1.56 µM (MIC) | [69] |
|                 |                     | Microplate assay / *C. mandshurica* Miura | 8.0 µg/mL (MIC) | Nystatin 1.0 µg/mL (MIC) | [78] |
| Cladosporol C (143) | Cytotoxicity | Trypan blue-cell viability assay / K562 | >30.0 µM (IC₅₀) | Trichostatin A 0.24 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / A549 | 33.9 µM (IC₅₀) | Trichostatin A 0.05 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / Huh-7 | >30.0 µM (IC₅₀) | Trichostatin A 0.08 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / H1975 | 45.6 µM (IC₅₀) | Trichostatin A 0.09 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / MCF-7 | >30.0 µM (IC₅₀) | Trichostatin A 0.78 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / U937 | >30.0 µM (IC₅₀) | Trichostatin A 0.06 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / BGC823 | >30.0 µM (IC₅₀) | Trichostatin A 0.09 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / HL-60 | 72.5 µM (IC₅₀) | Trichostatin A 0.09 µM (IC₅₀) | [82] |
|                 |                     | Trypan blue-cell viability assay / A549 | >30.0 µM (IC₅₀) | Trichostatin A 0.11 µM (IC₅₀) | [82] |
| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|---------------|---------------------|-------------------------------|--------------------|------------------|------|
| Trypan blue-cell viability assay/MOLT-4 | 14.4 μM (IC₅₀) | Trichostatin A 0.03 μM (IC₅₀) | Trichostatin A 0.03 μM (IC₅₀) | [82] |
| MTT/A549 | 14.0 μM (IC₅₀) | Cisplatin 1.3 μM (IC₅₀) | Cisplatin 1.0 μM (IC₅₀) | [84] |
| MTT/HeLa | 4.0 μM (IC₅₀) | Paclitaxel 4.9 μM (IC₅₀) | Paclitaxel 4.9 μM (IC₅₀) | [84] |
| **Antimicrobial** | | | | |
| Microplate assay/E. coli | 8.0 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | [84] |
| Microplate assay/M. luteus | 32.0 μg/mL (MIC) | Chloramphenicol 0.5 μg/mL (MIC) | Chloramphenicol 0.5 μg/mL (MIC) | [84] |
| Microplate assay/V. harveyi | 16.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | [84] |
| Microplate assay/S. aureus | 6.25 μg/mL (MIC) | Ciprofloxacin 0.39 μg/mL (MIC) | Ciprofloxacin 0.39 μg/mL (MIC) | [71] |
| Microplate assay/M. luteus | 12.5 μg/mL (MIC) | Ciprofloxacin 0.39 μg/mL (MIC) | Ciprofloxacin 0.39 μg/mL (MIC) | [71] |
| **Cladosporol D (144)** | Anti-inflammatory | Spectrophotometry/Anti-COX-2/PGF₂α inhibition | 60.2 μM (IC₅₀) | Indomethacin 18.3 μM (IC₅₀) | [82] |
| **Cladosporol E (145)** | Insecticidal | Measuring the corrected mortality (CM) | 150.0 μg/mL (IC₅₀) | Azadirachtin 25.0 μg/mL (IC₅₀) | [71] |
| **Cladosporol F (146)** | Cytotoxicity | MTT/K562 | 12.5 μg/mL (MIC) | Doxorubicin 0.6 μM (IC₅₀) | [83] |
| **Antimicrobial** | | | | | |
| Microplate assay/E. coli | 32.0 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | [84] |
| Microplate assay/M. luteus | 64.0 μg/mL (MIC) | Chloramphenicol 0.5 μg/mL (MIC) | Chloramphenicol 0.5 μg/mL (MIC) | [84] |
| Microplate assay/V. harveyi | 32.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | [84] |
| **Cladosporol G (147)** | Cytotoxicity | MTT/K562 | 13.0 μg/mL (IC₅₀) | Doxorubicin 0.6 μM (IC₅₀) | [83] |
| **Antimicrobial** | | | | | |
| Microplate assay/E. coli | 32.0 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | Chloramphenicol 0.025 μg/mL (MIC) | [84] |
| Microplate assay/M. luteus | 16.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | Chloramphenicol 2.0 μg/mL (MIC) | [84] |
| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|---------------|---------------------|-------------------------------|-------------------|-----------------|-----|
| Cladosporol H (149) | Cytotoxicity | Microplate assay/V. harveyi | 64.0 µg/mL (MIC) Chloramphenicol 2.0 µg/mL (MIC) | [84] |
| | | MTT/A549 | 5.0 µM (IC₅₀) Cisplatin 1.5 µM (IC₅₀) | [84] |
| | | MTT/H446 | 10.0 µM (IC₅₀) Adriamycin 4.0 µM (IC₅₀) | [84] |
| | | MTT/Huh7 | 1.0 µM (IC₅₀) Fluorouracil 6.2 µM (IC₅₀) | [84] |
| | | MTT/LM3 | 4.1 µM (IC₅₀) Cisplatin 9.1 µM (IC₅₀) | [84] |
| | | MTT/MCF-7 | 10.0 µM (IC₅₀) Paclitaxel 1.8 µM (IC₅₀) | [84] |
| | | MTT/SW1990 | 15.0 µM (IC₅₀) Gemcitabine 2.2 µM (IC₅₀) | [84] |
| Cladosporol I (150) | Cytotoxicity | Microplate assay/E. coli | 32.0 µg/mL (MIC) Chloramphenicol 0.025 µg/mL (MIC) | [84] |
| | | Microplate assay/M. luteus | 64.0 µg/mL (MIC) Chloramphenicol 0.5 µg/mL (MIC) | [84] |
| | | Microplate assay/V. harveyi | 10.8 µM (IC₅₀) Paclitaxel 4.9 µM (IC₅₀) | [84] |
| Cladosporol J (151) | Cytotoxicity | Microplate assay/E. coli | 16.0 µg/mL (MIC) Chloramphenicol 0.25 µg/mL (MIC) | [84] |
| | | Microplate assay/M. luteus | 64.0 µg/mL (MIC) Chloramphenicol 0.5 µg/mL (MIC) | [84] |
| | | Microplate assay/V. harveyi | 4.0 µg/mL (MIC) Chloramphenicol 2.0 µg/mL (MIC) | [84] |
| | Antimicrobial | Microplate assay/K562 | 14.3 µM (IC₅₀) Trichostatin A 0.24 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/A549 | 15.7 µM (IC₅₀) Trichostatin A 0.05 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/Huh7 | 29.9 µM (IC₅₀) Trichostatin A 0.08 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/H1975 | 40.6 µM (IC₅₀) Trichostatin A 0.09 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/MCF-7 | 21.3 µM (IC₅₀) Trichostatin A 0.78 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/U937 | 10.5 µM (IC₅₀) Trichostatin A 0.06 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/BGC823 | 17.0 µM (IC₅₀) Trichostatin A 0.09 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/HL-60 | 10.1 µM (IC₅₀) Trichostatin A 0.09 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/A549 | 53.7 µM (IC₅₀) Trichostatin A 0.11 µM (IC₅₀) | [82] |
| | | Trypan blue-cell viability assay/MOLT-4 | 14.6 µM (IC₅₀) Trichostatin A 0.03 µM (IC₅₀) | [82] |
| Compound Name          | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control          | Ref. |
|------------------------|---------------------|-------------------------------|--------------------|----------------------------|------|
| **Mar. Drugs 2021, 19, 645** |                     |                               |                    |                            |      |
| **Table 2. Cont.**     |                     |                               |                    |                            |      |
| **Table 2. Cont.**     |                     |                               |                    |                            |      |
| Anti-inflammatory      |                     |                               |                    |                            |      |
| Spectrophotometry/Anti-COX-2/PGF2α inhibition | 49.1 μM (IC₅₀) | Indomethacin 18.3 μM (IC₅₀) NS-398 1.0 μM (IC₅₀) | [82] |
| **Aladothalen (160)**  | Antimicrobial       | Agar dilution method/B. cereus | 50.0 μM (MIC)       | Ciprofloxacin < 0.4 μM (MIC) | [89] |
| **Cladonaphchrom A (169)** | Antimicrobial       | Microplate assay/S. albus     | 1.25 μg/mL (MIC)    | Ciprofloxacin 0.6 μg/mL (MIC) | [90] |
| **Malettinin A (178)** | Antimicrobial       | Microplate assay/T. rubrum    | 33.1 μM (IC₅₀)      | Clotrimazole 0.2 μM (IC₅₀)  | [93] |
| **Malettinin B (179)** | Antimicrobial       | Microplate assay/X. campestris| 28.3 μM (IC₅₀)      | Chloramphenicol 2.1 μM (IC₅₀) | [93] |
| **Malettinin C (180)** | Antimicrobial       | Microplate assay/T. rubrum    | 60.0 μM (IC₅₀)      | Clotrimazole 0.2 μM (IC₅₀)  | [93] |
| **Malettinin E (181)** | Antimicrobial       | Microplate assay/T. rubrum    | 28.7 μM (IC₅₀)      | Clotrimazole 0.2 μM (IC₅₀)  | [93] |
Table 2. Cont.

| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|---------------|----------------------|-------------------------------|--------------------|------------------|------|
| Cladosporinone (182) | Microplate assay/X. campestris | 30.7 µM (IC<sub>50</sub>) | Chloramphenicol 2.1 µM ((IC<sub>50</sub>) | [93] |
| Viriditoxin (183) | Broth dilution assay/S. aureus | 64.0 µg/mL (MIC) | - | [94] |
| Viriditoxin derivative 1 (184) | Broth dilution assay/S. aureus | 0.015 µg/mL (MIC) 0.023 µM (MIC) | - | [94] |
| Viriditoxin derivative 2 (185) | Broth dilution assay/S. aureus | 2.0 µg/mL (MIC) | - | [94] |
| (2S,4S)-4-Methoxy-2-methylchroman-5-ol (201) | Antioxidant | DPPH assay | 5.66 µM (IC<sub>50</sub>) | Ascorbic acid 3.29 µM (IC<sub>50</sub>) | [95] |
| (2S,4S)-2-Methylchroman-4,5-diol (203) | Antioxidant | DPPH assay | 6.67 µM (IC<sub>50</sub>) | Ascorbic acid 3.29 µM (IC<sub>50</sub>) | [95] |
| Citrinin H1 (206) | Insecticidal | Measuring the corrected mortality (CM) | 100.0 µg/mL (IC<sub>50</sub>) | Azadirachtin 25.0 µg/mL (IC<sub>50</sub>) | [71] |
| Vermistatin (214) | Insecticidal | CM/Helicoverpa armigera Hubner larvae | 150.0 µg/mL (IC<sub>50</sub>) | Azadirachtin 25.0 µg/mL (IC<sub>50</sub>) | [71] |
| Cladoscyclitol B (219) | α-Glucosidase inhibitory | Colorimetric assay | 2.95 µM (IC<sub>50</sub>) | Acarbose 2.35 µM (IC<sub>50</sub>) | [97] |
| 3-Phenyl-2-propenoic acid (232) | Insecticidal | Inhibition 50%/B. amphitrite | 84.28 µg/mL (EC<sub>50</sub>) | FSW with DMSO | [60] |
| Cladosporinone (182) | Broth dilution assay/S. aureus | 64.0 µg/mL (MIC) | - | [94] |
| 3-(2,3-Dihydroxy phenoxy) butanoic acid (233) | Antioxidant | DPPH assay | 0.24 µM (IC<sub>50</sub>) | Ascorbic acid 3.29 µM (IC<sub>50</sub>) | [95] |
| Methyl (3S)-3-(2,3-dihydroxy phenyloxy)butanoate (235) | Antioxidant | DPPH assay | 2.65 µM (IC<sub>50</sub>) | Ascorbic acid 3.29 µM (IC<sub>50</sub>) | [95] |
| 2-Phenylethanol (238) | Insecticidal | Inhibition 50%/B. amphitrite | 53.65 µg/mL (EC<sub>50</sub>) | FSW with DMSO | [60] |
Table 2. Cont.

| Compound Name | Biological Activity | Assay, Organism, or Cell Line | Biological Results | Positive Control | Ref. |
|---------------|---------------------|-------------------------------|--------------------|-----------------|-----|
| 4-α-D-Ribofuranose-2-pentyl-3-phemethyl (240) | α-Glucosidase inhibitory | Colorimetric assay | 2.05 µM (IC₅₀) | Acarbose 2.35 µM (IC₅₀) | [97] |
| Cladosporin D (247) | Antioxidant | DPPH assay | 16.4 µM (IC₅₀) | Ascorbic acid 4.9 µM (IC₅₀) | [36] |
| (25)-7,4'-dihydroxy-5-methoxy-8-(γ,γ-dimethylallyl)-flavanone (248) | Protein tyrosine phosphatase 1B inhibitory | PTP1B/Spectrophotometry | 11.0 µM (IC₅₀) | Oleanolic acid 0.9 µM (IC₅₀) | [68] |
| Bis(2-ethylhexyl)phthalate (249) | Insecticidal | Measuring the corrected mortality (CM)/Helicoverpa armigera Hubner larvae | 150.0 µg/mL (IC₅₀) | Azadirachtin 25.0 µg/mL (IC₅₀) | [70,71] |
| Antimicrobial | Microplate assay/S. aureus | 25.0 µg/mL (MIC) | Ciprofloxacin 0.39 µg/mL (MIC) | [71] |
| | Microplate assay/E. coli | 25.0 µg/mL (MIC) | Ciprofloxacin 0.19 µg/mL (MIC) | [71] |
| | Microplate assay/B. cereus | 12.5 µg/mL (MIC) | Ciprofloxacin 0.39 µg/mL (MIC) | [71] |
| 5α,8α-Epideoxy-ergosta-6,22E-dien-3β-ol (256) | Antiviral | Neuraminidase inhibition assay/RSV | 0.11 µM (IC₅₀) | Ribavirin 0.08 µM (IC₅₀) | [100] |
| 3β,5α-Dihydroxy-6β-methoxyergosta-7,22-diene (262) | Antiviral | Neuraminidase inhibition assay/RSV | 0.11 µM (IC₅₀) | Ribavirin 0.08 µM (IC₅₀) | [100] |
| 5α,8α-Epideoxy-ergosta-6,9,22E-triene-3β-ol (258) | Antiviral | Neuraminidase inhibition assay/RSV | 0.17 µM (IC₅₀) | Ribavirin 0.08 µM (IC₅₀) | [100] |
| 3α-Hydroxy-pregna-7-ene-6,20-dione = Cladosporisteroid B (268) | Antiviral | Neuraminidase inhibition assay/RSV | 0.12 µM (IC₅₀) | Ribavirin 0.08 µM (IC₅₀) | [100] |
| (3E,8E,6S)-Undeca-3,8,10-trien-1,6-diol (286) | Cytotoxicity | SRB/H1975 | 10.0 µM (IC₅₀) | Adriamycin 0.38 µM (IC₅₀) | [95] |
Pectinases are hydrolytic enzymes that are accountable for the hydrolysis of pectins. They are commonly found in fungi, bacteria, and plants. They have remarkable importance in the food industry such as vegetables and fruits processing, wine production, and olive oil extraction, as well as coffee, cocoa, and tea fermentation. They are utilized in the beverage industry to produce high yields due to improving clarification and pressing of concentrated fruit juices [103]. Bastos et al. purified pectinase enzymes PG and PME from \textit{C. cladosporioides} using the Buescher and Furmanski procedure after 10-day incubation and precipitation with (NH$_4$)$_2$SO$_4$ and benzoate buffer at pH 4.0 [49].

Agarases and carrageenases can decompose algal biomass, producing carrageenans and agars that are the major components of the red algae cell wall. Furthermore, agarases hydrolyze agar, resulting in oligosaccharides that are employed as food additives with beneficial influences on human health [104,105]. Additionally, carrageenases are used to obtain carrageenans that have varied industrial applications as emulsifying, thickening, and gelling agents in the preparation of food, as well as bioactivities such as anti-tumor, antiviral, anti-thrombotic, immunomodulatory, anticoagulant, and antioxidant [106]. \textit{Cladosporium} sp. isolated from the Antarctic macroalgae \textit{Ascoseira mirabilis} and \textit{Georgiella confuens} produced agarase that may have industrial importance in the extraction of agar or its byproducts such as bioactive galactose and oligosaccharides exist in the algal biomass to be utilized as substrates of 3rd generation bioethanol [11].

Xylan, the main component of hemicelluloses in the plant cell walls, represents about one-third of all renewable organic carbon on earth. Xylanases hydrolyze xylan to oligosaccharides that are further degraded to xylose. The latter is utilized for xylitol and bioethanol production. Xylanases have remarkable biotechnological influence in developing eco-friendly technologies in the pulp and paper industry and in food and feed industries, and for generating chemicals and liquid fuels from lignocellulose [107–109]. The cold-active xylanases have notable applications in bioremediation and food and textile and industries [110]. \textit{Cladosporium} sp. isolated from Antarctic marine sponge had high xylanase potential when grown on wheat bran and pure xylans at lower temperatures that is a feature of cold-active enzymes [48]. Therefore, cold-active xylanases preparations from \textit{Cladosporium} sp. could be convenient for many biotechnological processes, utilizing moderate- to low-temperature processes, especially those in food industries [48]. Gil-Durán et al. purified and characterized XynA, a cold-active endo-xylanase from \textit{Cladosporium} sp. derived from Antarctic sponge. XynA is highly active on xylans with high arabinose content. Moreover, it is the most thermolabile endo-xylanase reported from filamentous fungus. Therefore, it could be a good alternative in some biotechnological operations to avoid heating, thereby reducing the costs [45].

The three main lignin-hydrolyzing enzymes that have great potential for industrial applications are LiP (lignin peroxidase), MnP (manganese-dependent peroxidase), and Lac (laccase) [111]. LiP is a high oxidant heme protein that oxidizes non-phenolic and phenolic substrates. MnP is a H$_2$O$_2$-dependent glycoprotein that needs Mn$^{2+}$ for oxidizing aromatic dyes and mono-aromatic phenols [112]. Laccase is multi-copper oxidase, which oxidizes aromatic amines and catalyzes the O$_2$ reduction to H$_2$O [111]. \textit{C. cladosporioides} CBMAI 857 isolated from the Brazilian cnidarian \textit{Palythoa variabilis} produced ligninolytic enzymes (LiP, MnP, and Lac) with particular response to the various conditions of salinity and carbon sources. It possessed high values of MnP and laccase activities under salinity (12.5% and 23% \textit{w/v}, respectively), indicating the potential use of this fungus for industrial applications and bioremediation of high-salt contaminated sites [50].

RBBR (Remazol Brilliant Blue R) and polymeric dyes decolorization has been assigned as an effective screening method for the fungi ability to degrade recalcitrant pollutants, including aromatic compounds such as PAHs. It was demonstrated that marine-derived fungi are often more effective than terrestrial fungi in treating various colored effluents because they are better adapted to perform under extreme conditions such as high salinity [113]. \textit{C. cladosporioides} CBMAI-857 associated with the coral \textit{Palythoa caribaeorum} was
tested for its RBBR decolorizing potential. It had efficient dye decolorization potential (93%) after 12 days in both liquid and solid media [114]. Further, *Cladosporium* sp. associated with the seagrass *Posidonia oceanica* produced tannases and ligninolytic enzymes at high salt concentrations. Its laccase and peroxidase activity was evident by the degradation of RBBR and Amaranth Red dyes [12,115].

Invertase is a β-fructo-furanosidase that catalyzes sucrose conversion into fructose and glucose, giving invert syrup. This invert syrup is utilized in the beverage and food industries as a humectant in non-crystallizing creams, candies, artificial honey, and jam preparation [116]. Molasses is a sugar solution that is obtained as a co-product of sugar production. Due to its high sucrose content and low cost, it is utilized as an invertase production substrate to produce industrially valuable substances [117]. However, it contains melanoids, which are dark brown pigments. Its discharge in the soil prohibits seed germination and decreases manganese availability and soil alkalinity. Furthermore, it blocks photosynthesis and sunlight penetration in the aquatic system [118]. Therefore, its removal from molasses-based wastewater is potentially important for environmental safety. Taskin et al. reported that *C. herbarum* ER-25 possessed a high invertase potential and removed melanoids from molasses through bio-adsorption and biodegradation mechanisms by Lac and MnP in the non-sterilized medium than in sterilized one at 5.5 pH and 20 °C. Therefore, this cold-adapted fungus can be used for molasses de-colorization [46].

Cellulose is a main component of the plant material that is abundantly utilized for the production of alternative liquid fuels such as bioethanol. *C. sphaerospermum* obtained from deteriorated seaweed *Ulva* through SSF (solid-state fermentation) produced cellulase that had saccharification potential of seaweed biomass using green seaweed *Ulva fasciata*. Therefore, this cellulase can be utilized for saccharification of cellulosic feedstock for bioethanol production from marine macro-algal feedstock [47].

Biocatalysis is an eco-friendly process for renewable raw materials and clean energy production and for the remediation of environmental contaminants [119]. Recently, the synthesis of industrial and chemically interesting complex molecules using biocatalysts, including enzymes and whole-cell systems is a grown-research field. Reductases have been utilized for various substrates reduction such as aldehydes, carboxylic acid derivatives, ketones, nitro compounds, and nitriles [119,120]. Furthermore, it has been reported that microorganisms’ whole cells are a potential source for new enzymes used in carbonylated compounds reduction [121]. Knoevenagel condensation is a very useful synthetic tool for functionalization, as well as for increasing the carbon chains that is applied for the synthesis of intermediates polymers and various bioactive organic compounds [122]. Birolli et al. reported that the bio-reduction of Knoevenagel adducts between cyanacetamide and aromatic aldehydes was achieved in considerable yields with whole-cells of *Cladosporium* sp. CBMAI 1237 isolated from *Dragmacidon reticulatum*, revealing the existence of ene-reductases [43]. Additionally, *C. cladosporioides* CBMAI-857 isolated from the Brazilian cnidarian *Palythoa cardibaeorum* catalyzed the asymmetric bio-reduction of 1-(4-methoxyphenyl)ethanol to 1-(4-methoxyphenyl)ethanol [123]. Moreover, the sponge-associated *C. cladosporioides* CBMAI-857 catalyzed the enantio-selective bio-reduction of different aromatic ketones at pH 7.0 and 32 °C [124].

3. Secondary Metabolites and Bioactivities of Marine-Associated *Cladosporium* Species

Marine-associated *Cladosporium* species are rich with diverse types of metabolites with varied structural features such as macrolides, fatty acids, pyrones, phenolics, alkaloids, diketopiperazines, terpenes, sterols, quinones, lactones, and tetramic acid derivatives. Their classification was carried out here according to the chemical nature. During our search, it was found that some of the reported metabolites had the same structures and molecular formulae with different nomenclature. On the other hand, some metabolites had the same names with different structures. Moreover, some metabolites did not have names, thus they are named here using the AUPAC system for nomenclature. Herein, the reported
secondary metabolites from *Cladosporium* species, as well as their bioactivities have been discussed (Tables 1 and 2).

3.1. Tetramic Acid Derivatives

Tetramic acids are five-membered heterocycles with a pyrrolidine-2,4-dione core that are formed by the fusion of polyketide units and amino acid [125]. The tetramic acid moiety is commonly present as 3-acyl or 4-O-alkyl ether derivatives [126]. These structures can be characterized as simple heterocycles or more complex systems possibly containing long chains or fused polycyclic skeletons [127]. They are found in varied natural metabolites and isolated from various terrestrial and marine species, such as bacteria, sponges, and fungi [127,128]. They exhibited a wide range of bioactivities: cytotoxic, antimicrobial, antiulcer, and antiviral [125]. Note that 30 tetramic acid derivatives have been reported from marine-derived *Cladosporium* species, 28 (93.3%) of them are from *C. sphaerospermum*.

The tetramic acid derivatives, cladosins A, B, D, and E (1, 2, 4, and 5) biosynthesized by *C. sphaerospermum* 2005-01-E3 obtained from deep-sea sludge had no activity towards influenza A H1N1 virus (Figure 1). While 3 exhibited anti-H1N1 activity (IC$_{50}$ 276.0 µM) in comparison to ribavirin (IC$_{50}$ 131.0 µM) [42]. Moreover, they showed no NF-κB inhibitory and no cytotoxic effect towards BGC-823, HL-60, HCT-8, A2780, A549, and Bel-7402 cell lines, as well as no activity towards *Mycobacterium tuberculosis* in the disk diffusion method [42]. Moreover, cladosins B (2), C (3), F (5), and L (11) separated from *C. sphaerospermum* SW67 associated with *Hydractinia echinata* hydroid polyp were assessed for protection towards cisplatin-caused cell damage in LLC-PK1 cells [53]. The co-treatment with compounds 2 and 5 alleviated the LLC-PK1 cells damage induced by cisplatin (Conc. 25 µM). Compound 2 (Conc. 100 µM) recovered cell viability with 90.68% that was more than NAC (N-acetylcysteine, 88.23%, Conc. 500 µM), whereas 5 (Conc. 50 and 100 µM) increased cell viability by 77.65 and 85.60%, respectively. Thus, 2 may be a candidate for treating cisplatin-produced unwanted effects and/or to prohibited nephrotoxicity induced by anticancer drugs. It was proposed that the existence of the C-8 hydroxy group may be essential for the reno-protective effect towards cisplatin-produced toxicity in LLC-PK1 cells [53].

In 2015, by OSMAC (one strain many compounds) technique, Yu et al. separated compounds 5 and 6 from *C. sphaerospermum* 2005-01-E3 that did not have anti-influenza A H1N1, anticancer, and anti-tubercular, as well as no NF-κB inhibitory activities [54]. Note that a tetramic acid derivative named cladosin L with a different structure was separated in 2020 by Pan et al. from the plant-associated *C. sphaerospermum* WBS017 isolated from *Fritillaria unibracteata* var. *wabuensis* [14]. Cladosins H-K (7–10) and cladodionen (13) were isolated from sediment-derived *C. sphaerospermum* L3P3 and evaluated for cytotoxic capacity towards PC-3, MGC-803, SH-SYSY, and HCT-116 cell lines using SRB method and against K562 and HL-60 using MTT method (Figure 2). Compounds 8–10 and 13 had a cytotoxic effect against HL-60 and K562 cell lines with IC$_{50}$ ranging from 2.8 to 7.8 µM, while 7 (IC$_{50}$ > 10 µM) was inactive. The results revealed that the C-8 absolute configuration and aniline moiety were essential for activity [55] (Table 2).

*C. sphaerospermum* SW67 associated with marine invertebrate *Hydractinia echinata* yielded three new spirocyclic tetramic acid-related metabolites 12, 29, and 30 (Figure 3). Compound 12 has a tetramic acid moiety conjugated with an unprecedented 2,7-diazaspiro[4.5]decane-1,4-dione core one, while 29 and 30 are tetramic acid stereoisomers with a C-3 quaternary center, bearing a six-membered lactone ring and a trans-hexylenic alcohol side chain. These metabolites had weak inhibitory effects versus HCC70, Bt549, MDA-MB-468, and MDA-MB-231 in the SRB bioassay (IC$_{50}$ ranged from 70 to 85 µM), compared to etoposide (IC$_{50}$ ranged from 1.76 to 2.27 µM) [38].
Figure 1. Tetramic acid derivatives 1–5.
Figure 2. Tetramic acid derivatives 6–9.
Figure 3. Tetramic acid derivatives 10–15.
C. spherospermum EIODSF 008 isolated from the deep-sea sediment collected from the East Indian Ocean yielded tetramic acid derivatives 13 and 22–28 (Figures 4 and 5). They were assessed for cytotoxicity towards HL-60, HepG2, and MCF-7. Only 13 had cytotoxicity (IC\textsubscript{50} 28.6 µM) towards the HL-60 cell line [57]. Additionally, they showed no antibacterial capacity towards ADR (adriamycin) (IC\textsubscript{50} ranged from 0.02 to 0.67 µM). However, it did not have antibacterial activities (conc. 100 µg/mL) against B. subtilis, P. aeruginosa, C. perfringens, S. aureus, E. coli, and C. albicans [56]. Compounds 14–21, new tetramic acid derivatives, were purified from the sea-sediment derived Cladosporium sp. acetone extract by Huang et al. in 2018. Compounds 14–16 are unusual 3-acyltetramic acids, having at C-3 of the pyrrolidine-2,4-dione core, a six-membered lactone ring, and hexyl-enic alcohol chain. They showed no obvious AchEI activity in the modified Ellman’s enzyme assay [58]. Moreover, they displayed no anti-biofilm effect against C. albicans and S. aureus in the broth micro-dilution method and no cytotoxic effect towards HL60, HepG-2, and MCF-7 cell lines in the CCK8 assay [58].

3.2. Diketopiperazines

Diketopiperazines (DKPs) are cyclic dipeptides, consisting of two amino acids with or without extra structural modifications in the DKPs nucleus [108]. Their main skeleton comprises a six-membered piperazine nucleus produced from the double condensations among two amino acids [129,130]. The formation of peptide bonds in DKPs are catalyzed mainly by cyclodipeptide synthases (CDPSs) and non-ribosomal peptide synthetases (NRPSs) [131]. They possessed interesting bioactivities such as anti-Alzheimer, antimicrobial, antiviral, microtubule polymerization inhibitory, antitumor, anti-quorum-sensing, and haemosuppressor [129,130,132].

Cyclo-(Val-Pro) (32) and cyclo-(Phe-Pro) (33) were separated from the EtOAc extract of Cladosporium sp. F14 isolated from seawater and investigated for their anti-larval activity at conc. 50 µg/mL towards Bugula neritina and Balanus amphitrite larvae in the settlement inhibition assays [60] (Figure 6). They inhibited B. neritina settlement (EC\textsubscript{50} 70.43 and >200 µg/mL, respectively) and B. amphitrite settlement (EC\textsubscript{50} 68.57 and 37.82 µg/mL, respectively). Furthermore, 32 and 33 obviously prohibited L. hongkongensis growth (IZDs 8 mm and MICs 200 and 200 µg/mL, respectively), compared to streptomycin (MIC 250 µg/mL). The MICs of 33 towards Ruegeria sp. and M. luteus were 200 and 100 µg/mL, respectively, compared to streptomycin (MIC 500 and 250 µg/mL, respectively) [60]. On the other hand, thio-diketopiperazine derivatives, cladosporins A (36) and B (37), and haematocin (38) purified from the sediment-derived Cladosporium sp. were moderately cytotoxic towards HepG2 cell line (IC\textsubscript{50} 48, 21, and 42 µg/mL, respectively) [62].

3.3. Alkaloids

Fungal alkaloids are nitrogen-containing metabolites that are derived from amino acid metabolism and the mevalonate pathway [133]. Many studies reported the detection of various classeses of alkaloids from marine-derived fungi such as pyrrolidine, indole, pyrrolizidine, quinazoline, quinoline, and purine classes [134–136]. These metabolites have shown broad biological activities: cytotoxic, anti-inflammatory, antioxidant, antibacterial, antifungal, antiviral, protease inhibitory. Therefore, they could have a potential for the development of innovative therapies [134–136]. In the current work, 49 alkaloids, belonging to different classes have been reported. Among them, 27 alkaloids were reported from unidentified Cladosporium species.
Figure 4. Tetramic acid derivatives 16–24.
Figure 5. Tetramic acid derivatives 25–30.
The glyantrypine-type alkaloids, 42–55, were separated from Cladosporium sp. PJX-41 isolated from mangrove and assessed for anti-H1N1 activity using CPE (cytopathic effect) inhibition assay (Figures 7 and 8). Compounds 45, 49, 51–53, and 55 displayed remarkable anti-H1N1 activities (IC_{50} values ranged from 82 to 89 µM), compared to ribavirin (IC_{50} 87 µM), while 42–44, 46–48, 50, and 54 (IC_{50} 100–150 µM) had weak activity [64]. The mycelium extract of the marine-derived Cladosporium sp. associated with Chondria crispicualis red alga afforded 56 that exhibited antioxidant potential (ED_{50} 82.0 µM) more than oxybenzone (sunscreen agent, ED_{50} 350 µM) as evident by their UV-A protecting potential [65]. Furthermore, it had a moderate antibacterial effect towards multidrug-resistant and methicillin-resistant S. aureus and S. aureus with MICs 31.0, 62.5, and 62.5, µg/mL, respectively [65]. The quinolactacins and citrinadins alkaloids 58, 68, and 70 separated from C. oxysporum were assessed for anti-plasmodial potential towards chloroquine-sensitive Plasmodium falciparum 3D7 [66] (Figure 9). Only 58 (conc. 3.13 µg to 25.0 µg) had an anti-plasmodial effect (EC_{50} 24.8 µM), while 68 and 70 displayed no activity (EC_{50} > 25.0 µM), compared to artesunate (EC_{50} 0.074 µM) in the SYBR Green I assay. Further, 58 (conc. ranged from 6.25 µM to 50.0 µM for 24 h) was investigated for apoptotic effect on 3D7-plasmodia strain by measuring the parasite ΔΨm (mitochondrial membrane potential). It induced loss of ΔΨm, leading to the release of cytochrome C from mitochondria to the cytosol resulted in parasite apoptosis. Therefore, it may provide a scaffold to apoptotic death in the stages of P. falciparum development [66]. Moreover, 58, 68, and 70 had no anti-buruli ulcer activity against Mycobacterium ulcerans (IC_{50} > 10 µM), compared to rifampicin (IC_{50} < 1 µM) in the Resazurin microtiter assay [66].
Figure 7. Alkaloids 39–49.
Figure 8. Alkaloids 50–61.
They had significant activity towards HepG-2 and MCF-7 (IC$_{50}$ ranging from 78.57 to 96.54 µM and from 51.32 to 94.49 µM, respectively), compared to curcumin (IC$_{50}$ 61.38 and 20.68 µM, respectively). However, they showed moderate activity versus LNCap and LNCap (IC$_{50}$ ranging from 32.94 to 45.71 µM and from 54.47 to 60.31 µM, respectively), in comparison to curcumin (IC$_{50}$ 6.15 and 13.78 µM, respectively) in the MTT assay [66]. *Cladosporium* sp. HNWSW-1 associated with the mangrove plant *Ceriops tagal* biosynthesized compounds 74–76 that were assessed for their cytotoxic and α-glycosidase inhibitory effects (Figure 10). Compound 75 had cytotoxicity versus SGC-7901, K562, and BEL-7042
cell lines (IC\textsubscript{50} 41.7, 25.6, and 29.4 µM, respectively), whereas 76 revealed cytotoxic potential towards BEL-7042 and Hela cell lines (IC\textsubscript{50} 26.7 and 14.9 µM, respectively) in the MTT assay.

![Alkaloids](image)

**Figure 10.** Alkaloids 71–79.

Additionally, 76 exhibited α-glucosidase inhibitory activity (IC\textsubscript{50} 78.2 µM), compared to acarbose (IC\textsubscript{50} 275.7 µM) in the glucose oxidase method [67]. Cladosporamide A (77) separated from *Cladosporium* sp. TPU1507 derived from marine sponge was assessed for its inhibitory effect towards PTP1B (protein tyrosine phosphatase) and TCPTP (T-cell PTP), using an enzyme-based assay [68]. It had mostly equivalent inhibition towards TCPTP and PTP1B (IC\textsubscript{50} 48 and 54 µM, respectively), in comparison to oleanolic acid (IC\textsubscript{50} 0.9 µM) [68]. Cao et al. purified a new 7-oxabicyclic[6.3.0]lactam, 78, from a gorgonian-
derived \textit{Cladosporium} sp. collected from the South China Sea. It (IC$_{50}$ 0.76–3.11 µM) exhibited significant cytotoxicity towards HeLa, P388, HT-29, and A549 cell lines [69]. On the other hand, it had weak antibacterial activity (MIC > 25.0 µM) in broth dilution assay towards \textit{B. cereus}, \textit{T. halophilus}, \textit{S. epidermidis}, \textit{S. aureus}, \textit{E. coli}, \textit{P. putida}, \textit{N. brasiliensis}, and \textit{V. parahaemolyticus} [69]. \textit{Cladosporium} sp. SCNU-F0001 isolated from a mangrove plant yielded a novel lactam macrolide named cladospamide A (79) that was evaluated for cytotoxic effect (conc. 50 µM) versus MDA-MB-435, A549, HCT116, HepG2, and BT549 in the MTT method and for antimicrobial potential (conc. 100 µg/mL) towards \textit{S. aureus}, \textit{B. subtilis}, \textit{E. coli}, \textit{Salmonella} ATCC 14028, and \textit{P. aeruginosa}. Unfortunately, it exhibited no noticeable activity [70].

The new cyano-containing alkaloids, cladosporins A (80) and B (81) purified from \textit{Cladosporium} sp. SCSIO z015 broth did not have an obvious anti-biofilm activity towards \textit{S. aureus}, \textit{E. coli}, and \textit{B. subtilis} [36] (Figure 11).

In the DPPH assay, they also had no activity (IC$_{50}$ > 100 µM), compared to ascorbic acid (IC$_{50}$ 4.9 µM). Besides, they showed moderate toxicity towards brine shrimp nauplii (LC$_{50}$ 72.0 and 81.7 µM, respectively), compared with toosendanin (LC$_{50}$ 21.2 µM) in the brine shrimp lethality assay [36]. In 2019, Bai et al. purified 84 and 85 from \textit{Cladosporium} sp. JS1-2 isolated from the mangrove \textit{Ceriops tagal} collected in the South China Sea. Compound 84 moderately prohibited the growth of \textit{Helicoverpa armigera} Hubner newly hatched larvae (IC$_{50}$ 100 µg/mL), compared to azadirachtin (IC$_{50}$ 25 µg/mL). Further, they showed moderate antibacterial potential versus \textit{S. aureus} with MICs 12.5 and 25.0 µg/mL, respectively, compared with ciprofloxacin (MIC 0.39 µg/mL) [71].

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{alkaloids80-87.png}
\caption{Alkaloids 80–87.}
\end{figure}
3.4. Macrolides

The term “macrolides” was first used to describe the natural antibiotics that have 12–16-membered macrocyclic lactone ring, functionalized by double bonds, and carrying different aminosaccharide and saccharide components [137]. Among these macrolides are 14-membered lactones (erythromycin and clarithromycin), 15-membered macrolides (azithromycin and spiramycin), and the 16-membered (avermectin B1a) that are clinically used macrolide antibiotics [138]. Members of this group possess a wide range of bioactivities such as antibacterial, anti-inflammatory, antiviral, antimalarial, antimitotic, and anticancer activity. They have been reported from various marine organisms [138,139]. The new 12-membered macrolide, cladospolide D (91), together with 88 and 89 were separated from Cladosporium sp. FT-0012 was obtained from Pohnpei Island, Federated State of Micronesia, and assessed for antimicrobial activity using paper disks at conc. 10 μg/disk (Figure 12). Compound 91 exhibited activity versus M. racemosus KB223, B. subtilis KB27, and P. oryzae KB110 (IZDs 11.5, 16.0, and 14.0 mm, respectively), while 88 was active (IZD 14.0 mm and IC₉₀ 17.0 μg/mL) towards X. campestris pv. oryzae. Moreover, 91 prohibited P. oryzae and M. racemosus growth (IC₉₀ 29.0 and 0.15 μg/mL, respectively) [72].

Cladosporium sp. F14 isolated from seawater yielded a nine-membered macrolide, 92 that had weak antibacterial potential towards M. smegmatis, E. coli, B. thuringiensis, S. aureus, and B. subtilis and weak cytotoxic potential toward A435, HeLa, K562, and A549 in the MTT method [76]. C. herbarum isolated from Callyspongia aerizusa sponge yielded cladospolide B (89) and pandangolides 2–4 (95–97) that showed no antimicrobial potential versus S. aureus ATCC 25923, B. subtilis 168, E. coli ATCC 25922, and C. albicans in the agar plate diffusion assay [74]. Moreover, the EtOAc extract of Cladosporium sp. IFB3lp-2 isolated from the mangrove forest of Hainan province of China yielded 88, 89, 93–96, 100, and 116 that had no significant activity against HCT-116, Coxsachievirus A16, A549, MD-MBA-231, HepG2, human enterovirus 71, A375, and SW1116 cell lines (conc. 20 μM) in the MTT assay [73] (Figure 13).

Additionally, Cladosporium sp. SCNU-F0001 isolated from a mangrove plant biosynthesized a new macrolide thiocladospolide E (105), along with 89 that were evaluated for cytotoxic effect (conc. 50 μM) versus MDA-MB-435, A549, HCT116, HepG2, and BT549 in the MTT method and for antimicrobial potential (conc. 100 μg/mL) towards S. aureus, B. subtilis, E. coli, Salmonella ATCC 14028, and P. aeruginosa. Unfortunately, none of them exhibited noticeable activity [70]. Cao et al. purified 12-membered macrolides 89 and 117–120 from a gorgonian-derived Cladosporium sp. collected from the South China Sea. They showed no cytotoxicity towards HeLa, P388, HT-29, and A549 cell lines [69]. Furthermore, they were evaluated for antibacterial activity in broth dilution assay towards B. cereus, T. halophilus, S. epidermidis, S. aureus, E. coli, P. putida, N. brasiliensis, and V. parahaemolyticus. Compounds 117–119 exhibited antibacterial potential against all tested bacteria (MIC values ranging from 3.13 to 25.0 μM), however 89 and 120 had weak activity (MIC > 25.0 μM) [69]. The metabolites 93 and 115 separated from Cladosporium sp. F14 at conc. 50 μg/mL had no anti-larval activity towards both B. neritina and B. amphitrite larvae in the settlement inhibition assays [60]. In 2019, Zhang et al. separated the new polyketides 98 and 99 and a known analog 93 from the rice culture EtOAc extract of C. cladosporioides associated with Bruguiéra gymnorrhiza. Their configuration was established using ECD, modified Mosher’s, and X-ray diffraction methods, as well as optical rotations to be 5R, 11R for 98; 11R for 99; and 3R, 5S, 11S for 93. They had weak AChEI activity (IC₉₀ > 50 μM), in comparison to tacrine in the modified Ellman’s method [40]. C. cladosporioides MA-299 obtained from the mangrove plant B. gymnorrhiza yielded 12-membered thio-macrolides 96 and 101–104 that were assessed for antimicrobial potential against E. tarda QDIO-2 and E. ictarda QDIO-9 (aquatic pathogens) and C. glecosporioides QDAU-2, B. sorokiniana QDAU-5, P. piricola Nose QDAU-15, and F. oxysporum f. sp. cucumerinum QDAU-8 (plant pathogenic fungi) in the microtiter plates assay. All metabolites revealed activity against C. glecosporioides (MIC 1 or 2 μg/mL), compared to amphotericin B (MIC 0.5 μg/mL). Moreover, 101 and 104 showed noticeable activity (MIC 1.0 μg/mL) towards E. tarda and E. ictarda, respec-
tively, compared to chloramphenicol (MIC 0.5 µg/mL), while 102 and 104 exerted obvious effectiveness (MIC 1.0 µg/mL) versus *F. oxysporum* f. sp. *cucumerinum*, compared to amphotericin B (MIC 0.5 µg/mL). The data revealed that sulfur substituent may influence the macrolides’ bioactivities [39]. The newly reported 12-membered macrolides having thioethers 107–112 and the related formerly reported 93 and 101 isolated from mangrove-derived *C. oxysporum* HDN13-314 had no cytotoxic activity versus HCT-116, BEL-7402, HL-60, A549, L-02, HeLa, K562, MGC-803, MCF-7, PC-3, SH-SY5Y, and MDA-MB-231 (IC₅₀ > 50 µM) [78] (Figure 14).

Figure 12. Macrolides 88–101.
Figure 13. Macrolides 102–111.
Additionally, they exerted antibacterial activities versus the aquatic pathogens *E. ictarda* and *E. tarda* (MICs ranging from 4 to 32 µg/mL), whereas 108 had the best effect (MIC 4 µg/mL) versus *E. tarda* [78]. In 2020, new thiomacrolides thiocladospolides F (106) and G (108) and cladocladosin A (121), a macrolide with bicyclo 5/9-ring, were purified from *C. cladosporioides* MA-299 by Zhang et al. and assessed for antimicrobial effect versus various plant, human, and aquatic pathogenic microbes in the microtiter plates assay. All metabolites revealed activity (MIC ranging from 1.0 to 4.0 µg/mL) towards *V. anguillarum* and *E. tarda* (aquatic pathogenic bacteria) [79].
Moreover, 108 and 121 exerted activity (MICs 4.0 µg/mL) towards H. maydis (plant-pathogenic fungus) and P. aeruginosa (aquatic-pathogenic bacterium), respectively [79]. The new 12-membered macrolides, 113 and 114, purified from Cladosporium sp. L037 isolated from the Okinawan marine brown alga Actinotrichia fragilis exhibited cytotoxic influence (IC50 0.13 and 0.81 µg/mL, respectively) towards L1210 murine lymphoma cells in the MTT assay [80]. Moreover, 113 had antifungal potential against C. albicans, C. neoformans, A. niger, and N. crassa (MICs 8.4–16.7 µg/mL), whereas 114 exhibited antibacterial activity only towards M. luteus and inactive against the other microorganisms [80].

3.5. Butanolides and Butenolides

Butanolides and butenolides are five-membered γ-lactones which may also be regarded as furan derivatives. They are an important class of structural motifs often encountered in various natural metabolites and synthetic targets [140]. They have an impressive range of bioactivities including antibiotic, antitumor, and anticancer that are intimately connected to their relative and absolute configurations [141].

The newly separated C12-macrolide, cladospolide F (122), purified from a soft coral-associated fungus Cladosporium sp. TZP-29, together with the formerly isolated derivative 126 showed no cytotoxic effect towards A-549, SMMC-7721, and HeLa cells in the SRB method [41]. Wuringge et al. reported that the butenolide, 126 isolated from Cladosporium sp. IFB3lp-2 exhibited no significant activity against HCT-116, Coxsackievirus A16, A549, MD-MBA-231, HepG2, human enterovirus 71, A375, and SW1116 cell lines (Conc. 20 µM) in the MTT assay [73]. Moreover, it showed no cytotoxicity towards various cancer cell lines: HeLa, P388, HT-29, HCT-116, BEL-7402, HL-60, A549, L-02, HeLa, K562, MGC-803, MCF-7, PC-3, SH-SY5Y, MDA-MB-231, and A549 [69,78]. On the other hand, it had antibacterial activity in broth dilution assay towards B. cereus, T. halophilus, S. epidermidis, S. aureus, E. coli, P. putida, N. brasiliensis, and V. parahaemolyticus (MIC values ranging from 6.25 to 25.0 µM) [46]. Qi et al. stated that 126 displayed no anti-larval activity towards both B. neritina and B. amphitrite larvae in the settlement inhibition assays [60]. Additionally, it exerted antimicrobial activity versus E. ictarda and Cytospora mandshurica Miura (MIC 8 µg/mL) [78]. The new metabolites 123, 124, and 127 and the known analog 126 separated from C. cladosporioides were assessed for AChEI activity using modified Ellman’s method (Figure 15). Only 123 exhibited potent AChEI activity with the IC50 value of 40.26 µM, in comparison to tacrine, while other metabolites possessed weak activity (IC50 > 50 µM) [40].

![Figure 15. Butenolides and butanolides 122–127.](image-url)
3.6. Seco-Acids

The seco-acids 128, 130, and 141 isolated from Cladosporium sp. IFB3lp-2 EtOAc extract had no noticeable cytotoxicity versus HCT-116, Coxsachievirus A16, A549, MD-MBA-231, HepG2, human enterovirus 71, A375, and SW1116 cell lines (Conc. 20 \(\mu\)M) in the MTT assay [73]. Compound 131 did not show any anti-larval activity towards both B. neritina and B. amphitrite larvae [60]. Moreover, 132 did not have cytotoxic activity towards HCT-116, BEL-7402, HL-60, A549, L-02, HeLa, K562, MGC-803, MCF-7, PC-3, SH-SY5Y, and MDA-MB-231 (IC\(_{50}\) > 50 \(\mu\)M) [78], while it exhibited weak activity versus the aquatic pathogens E. ictarda, E. tarda, and Cytospora glecosporioides (MICs ranging from 16 to 32 \(\mu\)g/mL) [78]. Cladospolide E (129) separated from a soft coral-associated Cladosporium sp. TZP-29, together with the formerly isolated derivatives 130 and 131 had no cytotoxic effect towards A-549, SMMC-7721, and HeLa cells in the SRB method. Moreover, 129–131 with IC\(_{50}\) ranged from 7.1 to 13.1 \(\mu\)M remarkably reduced the accumulation of lipid elicited by oleic acid (OA) in the HepG2 liver cells, in comparison to lovastatin as determined by oil-red O staining and intracellular triglyceride (TG) and total cholesterol (TC) quantification (Figure 16).

Further, they exhibited potent lipid-lowering potential in HepG2 hepatocytes, revealing a promising anti-hyperlipidemic capacity [41]. The new fatty acid esters 133, 134, and 138 and new fatty acids 135–137, 139, and 140 isolated from C. cladosporioides OUCMDZ-187 obtained from the mangrove plant Rhizophora stylosa collected in Shankou, Guangxi Province of China showed no cytotoxic effects (IC\(_{50}\) > 50 \(\mu\)M) towards K562, A549, and HeLa cells in the SRB method [81]. Additionally, they revealed no antimicrobial activities (MIC > 150 \(\mu\)M) towards S. aureus CGMCC-1.2465, E. coli CGMCC-1.2389, E. aerogenes CGMCC-1.0876, P. aeruginosa CGMCC-1.1785, B. subtilis CGMCC-1.3376, and C. albicans CGMCC-2.2086 in the agar dilution method [81].

3.7. Tetralones (Napthalenones)

Tetralones comprise a bicyclic aromatic hydrocarbon and a ketone and are regarded as benzo-fused cyclohexanone derivatives. They played a substantial role as a starting material for the synthesis of a range of synthetic heterocyclic compounds and pharmaceuticals due to their potential reactivity and suitability [142]. Additionally, they are precursors of many natural metabolites and their derivatives. They have been used in the synthesis of therapeutically functional compounds such as antibiotics, acetylcholinesterase inhibitors, antidepressants, and antitumor alkaloids [142,143].

Cladosporone A (152), a new dimeric tetralone bridged via C-C linkage, was separated from Cladosporium sp. KcFL6 derived from the mangrove plant Kandelia candel, together with 142–144 (Figure 17). In anti-COX-2 assay, 144 and 152 displayed COX-2 inhibitory activities (IC\(_{50}\) 60.2 and 49.1 \(\mu\)M, respectively), in comparison to NS-398 and indomethacin [82]. Moreover, none of these metabolites had antimicrobial activities against A. baumannii ATCC-19606, S. aureus ATCC-29213, E. faecalis ATCC-29212, A. hydrophila ATCC-7966, E. coli ATCC-25922, K. pneumonia ATCC-13883, Fusarium sp., F. oxysporum f. sp. cucumeris, F. oxysporum f. sp. niveum, A. niger, and R. solani in the disc diffusion assay [82].
Figure 16. Seco-acids 128–141.
Compounds 143 and 152 had moderate cytotoxic activity towards Huh-7, K562, HL-60, MCF-7, H1975, U937, A549, BGC823, MOLT-4, and HeLa cell lines (IC\textsubscript{50} of 143 ranging from 11.4 to 72.5 µM and for 152 ranging from 10.1 to 53.7 µM), compared to trichostatin A in the trypan blue-cell viability assay [82]. Zurlo et al. reported that 142 had a remarkable anti-proliferative potential towards SW480, HT-29, and CaCo-2, in particular towards HT-29. It was revealed that HT-29 cells exposure to 142 produced G1/S phase cell cycle arrest, assisted by a vigorous p21\textsuperscript{waf1/cip1} expression, a significant down-regulation of CDK4, CDK2, cyclin E, and cyclin D1, and repression of CDK4 and CDK2 kinase activity [144]. It was demonstrated that its antiproliferative potential towards HT-29 cells was mediated via activation PPAR\textgamma, resulting in upregulation of p21\textsuperscript{waf1/cip1} expression and inducing
degradation of β-catenin, as well as impairing TCF/β-catenin pathway as evident by reduced cyclin D1 and c-Myc transcription. Finally, it induced the expression of E-cadherin, therefore antagonizing invasion and metastasis [145]. C. cladosporioides HDN14-342 isolated from marine sediments yielded tetralone derivatives 143, 145–147, 154, and 157 that were evaluated for cytotoxic activities towards HCT-116, HeLa, and A549 cell lines by SRB method and towards HL-60 and K562 cell lines by MTT method, in comparison to doxorubicin (IC50 0.2–0.8 µM). Compounds 146 and 147 were active towards K562, HeLa, and HCT-116 cell lines (IC50 ranging from 3.9 to 23.0 µM), while other metabolites had no activity (IC50 > 50.0 µM) [83]. In 2020, He et al. reported that 143 possessed no anti-allergic effect (IC50 > 200 µM) on RBL-2H3 cells, in comparison to loratadine (IC50 35.01 µM) using fluorometric assay [75]. In 2017, Li et al. separated six cladosporol derivatives, cladosporol C (143) and cladosporol F-J (146 and 148–151) from the marine algal-derived C. cladosporioides EN-399 and evaluated their cytotoxic activities towards H446, A549, HeLa, L02, Huh7, LM3, SW1990, and MCF-7 using MTT assay. Note that 143, 148, and 149 displayed cytotoxic activities towards most of the tested cell lines with IC50 ranging from 1.0 to 20.0 µM. Notably, 149 had cytotoxic effect towards LM3, A549, and Huh7 cell lines (IC50 4.1, 5.0, and 1.0 µM, respectively), compared to cisplatin (IC50 1.3 µM for A549 and 9.1 µM for LM3) and fluorouracil (IC50 6.2 µM for Huh7), whereas 143 exhibited cytotoxic activity (IC50 4.0 µM) towards H446 cell line, compared to adriamycin (IC50 4.0 µM). These results revealed that the existence of dihydro-1,4-naphthoquinone nucleus was important for the activity (149 vs. 146, 148, and 143, 150, and 151) and C-4 methoxyl strengthened the activity (148 vs. 151) [84].

Moreover, their antimicrobial potential was assessed versus E. coli, A. hydrophila, S. aureus, E. tarda, P. aeruginosa, M. luteus, V. alginolyticus, V. parahemolyticus, V. harveyi, A. brassicaceae, F. oxysporum, G. graminis, C. gloeosporioides, and P. piricloav using micro-plate assay. Compounds 143, 146, and 148–151 showed inhibitory potential towards M. luteus, E. coli, and V. harveyi (MICs 4–128 µg/mL). None of them had activity (MIC > 128 µg/mL) towards other tested microbes [84]. Bai et al. purified 143 and 145 from Cladosporium sp. JS1-2 isolated from the mangrove Ceriops tagal collected in the South China Sea [71]. Compound 145 prohibited the growth of Helicoverpa armigera Hubner newly hatched larvae (IC50 150 µg/mL), compared to azadirachtin (IC50 25 µg/mL) [71]. Further, they showed antibacterial potential versus S. aureus with MIC 6.25 and 1.56 µg/mL, respectively, compared with ciprofloxacin (MIC 0.39 µg/mL) [71]. Cladosporium sp. KFD33 isolated from blood cockle collected from Haikou Bay produced 150 and 153 that exhibited quorum sensing inhibitory potential towards Chromobacterium violaceum CV026 (MICs 30 and 20 µg/well, respectively) in the well diffusion assay [85]. Nevertheless, 156 had no observable cytotoxic activity towards SF-268, NCI-H460, MCF-7, and HepG-2 (conc. 100 µM) in the SRB assay [87]. The new naphthalenone derivative 157, in addition to 156, 158, and 159 isolated Cladosporium sp. JJM22 associated with the mangrove plant C. tagal had no cytotoxic effect (IC50 > 10 µM) versus HeLa cell line in the MTT assay, compared to epirubicin [88] (Figure 18). In the micro-plate assay, only 158 exhibited noticeable antibacterial potential towards S. aureus, B. cereus, E. coli, V. alginolyticus, V. parahemolyticus, and MR S. aureus (conc. 20 µM) [88]. One new tetralone derivative, aladothalen (160) and previously reported (35,45)-3,4,8-trihydroxy-1-tetralone (159) were isolated from a sediment-associated Cladosporium sp. HDN17-58 (Figure 17). Note that 160 possessed potent bacteriostatic potential versus Mycobacterium phlei, B. cereus, and MRCNS (methillin-resistant coagulase-negative Staphylococci) (MIC values of 25, 50, and 25 µM, respectively), compared to ciprofloxacin [89].
Figure 18. Tetralones (napthalenones) 154–160.

3.8. Perylenequinones

Perylenequinones comprise a class of natural products characterized by an oxidized pentacyclic core. They are dark-colored pigments isolated from diverse sources such as mold species, plants, and aphids [146]. They reported to have anthelmintic, photoactivity, antiviral and antitumor [146].

Four new perylenequinone derivatives, altertoxins VIII–XI (161–164), were isolated from Cladosporium sp. KFD33 (Figure 19). They exhibited quorum sensing inhibitory potential towards C. violaceum CV026 with MICs ranging from 20 to 30 µg/well in the well diffusion assay [85]. Structurally, these metabolites related to altertoxins I–III previously were reported from Alternaria alternata [147].

Figure 19. Perylenequinone 161–164.
3.9. Naphthalene Derivatives

Naphthalenes are a class of arenes containing two ortho-fused benzene rings that have been reported from plants, liverworts, fungi, and insects [148]. Their derivatives exhibited anti-inflammatory, antimicrobial, antioxidant, anti/protozoal, cytotoxic, and anti-platelet aggregation activities [148].

Cladosporium sp. associated with the mangrove C. tagal biosynthesized the naphthalene derivatives 166–168 that had anti-inflammatory potential via in-vitro inhibition of induced NO (nitric oxide) production by LPS (lipopolysaccharide) in RAW264.7 cells [91] (Figure 20). The mangrove-associated fungus Cladosporium sp. JJM22 yielded new naphthalene-chromane derivatives, cladonaphchroms A (169) and B (170), and related metabolites 165 and 168 that were assessed for antibacterial effectiveness versus S. albus ATCC-8799, E. coli ATCC-25922, B. subtilis ATCC-6633, Micrococcus tetragenus ATCC-13623, and M. luteus ATCC-9341, employing microplate assay. Compound 169 possessed significant potential against S. albus (MIC 1.25 µg/mL), compared to ciprofloxacin (MIC 0.6 µg/mL). Moreover, 169 and 170 demonstrated broad-spectrum antifungal activities (MICs 25.0–100.0 µg/mL) towards P. parasitica var. nicotianae, A. brassicicola, B. oryzae, C. capsici, C. paradoxa Moreau, and D. medusaea Nitschke, compared to pochloraz (MICs 12.5–50.0 µg/mL) [90]. Wu et al. stated that 166 had no cytotoxic effect (IC$_{50}$ > 10 µM) versus HeLa cell line in the MTT assay and no antibacterial activity towards S. aureus, B. cereus, E. coli, V. alginolyticus, V. parahemolyticus, and MR S. aureus (conc. 20 µM) in the microplate assay [88].

[Chemical structures of naphthalene derivatives 165–170]

Figure 20. Naphthalene derivatives 165–170.

3.10. Xanthones

Xanthones are secondary metabolites commonly reported from plants, fungi, and lichen [149]. They are heterocyclic metabolites with a xanthene-9-one framework, which is connected to different functional groups: methoxy, hydroxyl, prenyl, and dihydrofuran [150]. These metabolites showed diverse bioactivities: anti-HIV, anti-leishmanial, antitumor, anti-quorum sensing, antimicrobial, anti-inflammatory, antimalarial, advanced glycation end-products inhibitory, antioxidant, antihypertensive, and cytotoxic [150,151].

C. halotolerans GXMD 02502 associated with the coral Porites lutea yielded compounds 171–177 that were evaluated for their cytotoxicity versus 22RV1 and C4-2B (prostatic cancer cell lines), as well as RWPE-1 (normal prostate epithelial cell). Among them, 171–173, 175, and 176 revealed notable cytotoxicity versus C4-2B and 22RV1 cells (inhibitions ranged
from 55.8% to 82.1% at conc. 10 µM), whereas 176 was the potent one (inhibitions 77.7% and 82.1%, respectively). On the other hand, they exhibited nearly no cytotoxic effect versus RWPE-1 cell (inhibition < 27% at conc. 10 µM) [92] (Figure 21).

Figure 21. Xanthones 171–177.

3.11. Tropolones

Tropolones are natural metabolites with a cyclohepta-2,4,6-trienone moiety [152]. They are known to be produced by fungi, bacteria, and plants. It was reported to display diverse bioactivities, including antimicrobial, antiviral, anti-HIV, hepatitis, anti-inflammatory, and anticancer [152].

Silber et al. reported the isolation of malettinins A–C (178–180), along with the new metabolite, malettinin E (181) from Cladosporium sp. strain KF501 isolated from the German Wadden Sea (Figure 22). These metabolites have dihydropyran/tropolone structures connected to a furan ring. The configuration of 181 was determined by the single-crystal X-ray diffraction method. Interestingly, this was the first report for tropolones isolation from genus Cladosporium. They were evaluated for antimicrobial activity towards X. campestris, B. subtilis, S. epidermidis, C. albicans, and Trichophyton rubrum using the microplate assay. Note that 178–181 exhibited weak antifungal potential towards Trichophyton rubrum (IC\textsubscript{50} 30.7–83.2 µM), whereas 179–181 exhibited weak antibacterial effect towards Xanthomonas campestris (IC\textsubscript{50} 28.3–37.9 µM), compared to chloramphenicol (IC\textsubscript{50} 2.1 µM) [93].
3.12. Binaphthones 178–181

Binaphthones are dimers, belonging to naphthopyrones. They have C13 basic skeleton (C6-C4-C3) that consists of naphthalene and pyrone cores [153].

The new binaphthone, cladosporinone (182), and the formerly isolated viriditoxin (183) and viriditoxin derivatives (184 and 185) were separated from the sediment associated C. cladosporioides (Figure 23). Note that 183 was firstly reported from Aspergillus viridinutans [154]. They were assayed for their cytotoxic potential versus L5178Y cells in the MTT assay. Compound 183 was the most potent one (IC\textsubscript{50} 0.1 µM), however 182 and 184 had a cytotoxic effect (IC\textsubscript{50} 0.88 and 0.25 µM, respectively). However, 185 was ineffective [94]. Note that all metabolites had selective potential towards S. aureus ATCC-29213, with 183 being the most effective (MIC 0.023 µM) [94].

3.13. Benzopyranes, Benzopyrones, and Pyrones

Wang et al. reported the separation of compounds 188–190, 193, 200, 201, and 203 from Cladosporium sp. OUCMDZ-302 isolated from mangrove plant Excoecaria agallocha. They possessed no cytotoxic effect towards BEL-7402, A549, HeLa, K562, HL-60, and H1975 cell lines in the MTT and SRB methods. Whilst 201 and 203 showed radical scavenging activity against DPPH (IC\textsubscript{50} 5.66 and 6.67 µM, respectively). None of these metabolites exhibited antimicrobial activities against E. coli, E. aerogenes, P. aeruginosa, B. subtilis, and C. albicans [95]. The newly isolated benzopyrone, clapone (192), had no α-glycosidase inhibitory effect and no cytotoxic activity towards SGC-7901, K562, Hela, and BEL-7042 cell lines in the MTT assay [67]. Furthermore, 186 and 205 displayed no cytotoxic effect (IC\textsubscript{50} > 10 µM) versus HeLa cell line in the MTT assay, as well as no antibacterial potential towards S. aureus, B. cereus, E. coli, V. alginolyticus, V. parahemolyticus, and MR S. aureus (conc. 20 µM) in the microplate assay [88]. C. halotolerans GXIMD 02502 associated with the coral Porites lutea yielded a new benzopyranone derivative, coniochaetone K (196) with unusual C-8 carboxyl, along with 194, 195, 197, and 198 that were evaluated for their cytotoxicity versus 22RV1, C4-2B, and RWPE-1 cell lines (Figure 24).
Figure 23. Binaphthopyrones 182–185.
Among them, 194 and 196 revealed notable cytotoxicity versus 22RV1 cells (inhibition 67.4% and 64.6%, respectively, at conc. 10 µM). On the other hand, they exhibited nearly no cytotoxic effect versus RWPE-1 and C4-2B cells [92]. Bai et al. reported that 206 prohibited the growth of H. armigera Hubner newly hatched larvae (IC$_{50}$ 100 µg/mL), compared to azadirachtin (IC$_{50}$ 25 µg/mL) [71]. Further, it showed moderate antibacterial potential versus S. aureus (MIC 6.25 µg/mL), compared with ciprofloxacin (MIC 0.39 µg/mL) [71]. Cladosporin C (207) did not have obvious anti-biofilm activity towards S. aureus, E. coli, and B. subtilis [36]. On the other hand, it showed moderate toxicity towards brine shrimp naupalii (LC$_{50}$ 49.9 µM), compared to toosendanin (LC$_{50}$ 21.2 µM) in the brine shrimp lethality assay [36]. Furthermore, 210 possessed no anti-allergic effect (IC$_{50}$ > 200 µM) on RBL-2H3 cells, in comparison to loratadine (IC$_{50}$ 35.01 µM) using fluorometric assay [75]. α-Pyrone derivatives 211–213 were separated from C. herbarum isolated from the sponge
Aplysina aerophoba (Figure 25). Compounds 211 and 212 had activity towards Artemia salina (conc. 100 µg and 50 µg) with mortality rates 85 and 75% and 80 and 65%, respectively, while 213 did not have any activity. Besides, 213 showed growth inhibitory activity towards Spodoptera littoralis larvae (7 and 33% at conc. 250 and 100 ppm, respectively) [96]. However, 211–213 did not show any noticeable antimicrobial activity in the agar plate diffusion assay [96].

Figure 25. Benzopyrone 199–210 and pyrone (211–214) derivatives.

3.1.4. Lactones, Cyclohexene, and Azaphilone Derivatives

In 2020, He et al. purified 216 from C. cladosporioides that possessed no anti-allergic effect (IC_{50} > 200 µM) on RBL-2H3 cells, in comparison to loratadine (IC_{50} 35.01 µM) using fluorometric assay [75]. The mangrove plant C. tagal associated-fungus Cladosporium sp. JJM22 produced new cyclohexene derivatives, cladoscyclitols A–D (218–221) (Figure 26). Compound 219 (IC_{50} 2.95 µM) revealed potent α-glucosidase inhibitory activity, compared to acarbose (IC_{50} 2.35 µM) in the colorimetric assay [97]. On the other hand, it had no antimicrobial potential towards S. aureus ATCC-6538, E. coli ATCC-25922, B. cereu ATCC-6633, V. alginolyticus ATCC-3787, V. Parahemolyticus ATCC-17802, or MRSA CMCC-B-63303.
in the micro-plate assay [97]. Perangustols A (223) and B (224), representing new azaphilone epimers, together with bicyclic diol (225) were separated from sea sediment-associated C. perangustum FS62 fungus. They had no observable cytotoxic activity towards SF-268, NCI-H460, MCF-7, and HepG-2 (Conc. 100 µM) in the SRB assay [87].

Figure 26. Lactone (215–217), cyclohexene (218–222), and azaphilones (223–225) derivatives.

3.15. Phenolics and Other Aromatic Compounds

In the DPPH assay, 233 and 235 showed DPPH radical scavenging activity (IC₅₀s 0.24 and 2.65 µM, respectively), in comparison to ascorbic acid (IC₅₀ 3.29 µM). Further, none of these compounds had antimicrobial potential versus P. aeruginosa, E. aerogenes, B. subtilis, E. coli, and C. albicans [95]. The metabolites 232, 238, and 249 were separated from EtOAc extract of Cladosporium sp. F14 isolated from seawater and investigated for their anti-larval activity (conc. 50 µg/mL) towards B. neritina and B. amphitrite larvae in the settlement inhibition assays [60] (Figure 27). Compound 232 had weak larvae settlement inhibition towards B. neritina and B. Amphitrite, respectively, whereas 238 and 249 showed weak inhibitory effects towards B. amphitrite and B. neritina larvae, respectively. In another larval settlement bioassay, 232, 238, and 249 inhibited B. neritina larval settlement (EC₅₀ 11.51, 102.23, and 77.85 µg/mL, respectively) and B. amphitrite larval settlement (EC₅₀ 84.28, 53.65, and 9.18 µg/mL, respectively). The larval settlement EC₅₀ values of 249 towards B. amphitrite and 232 towards B. neritina were less than the US Navy program established standard requirement (EC₅₀ 25.0 µg/mL), revealing the potential of 232 and 249 as antifouling agents [60]. Furthermore, 232 obviously prohibited L. hongkongensis
growth (IZD 8 mm and MIC 80 µg/mL), compared to streptomycin (MIC 250 µg/mL) [60]. The ribofuranose phenol derivative, 239 isolated Cladosporium sp. JJM22 associated with the mangrove plant C. tagal had no cytotoxic effect (IC$_{50}$ > 10 µM) versus HeLa cell line in the MTT assay, compared to epirubicin [88].

Additionally, it exhibited no noticeable antibacterial potential towards *S. aureus*, *B. cereus*, *E. coli*, *V. alginolyticus*, *V. parahemolyticus*, and MR *S. aureus* (conc. 20 µM) in the microplate assay [88]. The new ribofuranose phenol derivative, 240 (IC$_{50}$ 2.05 µM)
revealed potent α-glucosidase inhibitory activity, compared to acarbose (IC\textsubscript{50} 2.35 µM) in the colorimetric assay [97]. On the other hand, it had no antimicrobial potential towards \textit{S. aureus ATCC-6538}, \textit{E. coli ATCC-25922}, \textit{B. cereus ATCC-6633}, \textit{V. alginolyticus ATCC-3787}, \textit{V. Parahemolyticus ATCC-17802}, and MRSA CMCC-B-63303 in the microplate assay [97]. Phytochemical investigation of the mycelium extract of the marine-derived fungus \textit{Cladosporium sp.} associated with \textit{Chondria crassicalis} red alga resulted in the separation of a phenol derivative, clavatol (241) that exhibited antioxidant capacity (ED\textsubscript{50} 227.0 µM) more than oxybenzone (sunscreen agent, ED\textsubscript{50} 350 µM) as evident by their UV-A protecting potential [65]. On the other hand, it was inactive towards MDRSA, MRSA, and \textit{S. aureus} [65]. Fan et al. stated that compounds 242 and 243 exhibited no observable cytotoxic activity towards SF-268, NCI-H460, MCF-7, and HepG-2 (Conc. 100 µM) in the SRB assay [87] (Figure 28). Cladosporin D (247) did not have obvious anti-biofilm activity towards \textit{S. aureus}, \textit{E. coli}, and \textit{B. subtilis} [36], while it exhibited significant antioxidant activity (IC\textsubscript{50} 16.4 µM), compared with ascorbic acid (IC\textsubscript{50} 4.9 µM). Besides, it showed moderate toxicity towards brine shrimp nauplii (LC\textsubscript{50} 81.4 µM), comparing with toosendanin (LC\textsubscript{50} 21.2 µM) in the brine shrimp lethality assay [13].

Compound 248 separated from \textit{Cladosporium sp. TPU1507} derived from marine sponge and assessed for inhibitory effect towards PTP1B and TCPTP using enzyme-based assay [68]. It showed an inhibitory effect on TCPTP (IC\textsubscript{50} 27 µM) that was 2-fold weaker than on PTP1B (IC\textsubscript{50} 11 µM) [68]. The new phthalide, herbaric acid (250), separated from \textit{C. herbarum} isolated from \textit{Callyspongia aerizusa} had no activity towards \textit{A. salina} and HL-60 human leukemia cell line [96]. In addition, the newly separated asbcsic acid analog 251 from \textit{Cladosporium sp. OUCMDZ-1635} possessed no cytotoxic effect towards MCF-7, HeLa, HCT-116, HeLa, HCT-116, K562, and HL-60. Furthermore, it did not show antibacterial activity (conc. 100 µg/mL) against \textit{B. subtilis, P. aeruginosa, C. perfringens, S. aureus, E. coli}, and \textit{C. albicans} [56]. The new pentenoic acid derivative, 1,1′-dioxine-2,2′-dipropionic acid (252) prohibited the growth of \textit{H. armigera} newly hatched larvae (IC\textsubscript{50} 150 µg/mL), compared to azadirachtin (IC\textsubscript{50} 25 µg/mL) [71]. Further, it showed moderate antibacterial potential versus \textit{S. aureus} (MIC 25.0 µg/mL), compared with ciprofloxacin (MIC 0.39 µg/mL) [71]. The furan carboxylic acid metabolites, Sumiki’s acid (253) and acetyl Sumiki’s acid (254) exerted activity towards \textit{S. aureus} and \textit{B. subtilis} (LD\textsubscript{50} 7 mm at conc. 5 µg/disk), whereas they had no activity towards \textit{C. albicans} and \textit{E. coli} [74].

3.16. Sterols and Terpenes

A study conducted by Yu et al. in 2018 led to the separation of a new pregnane; 3α-hydroxy-7-ene-6,20-dione (268) and six sterol derivatives: 256, 258, 260, 262, 263, and 267 from gorgonian-associated \textit{Cladosporium sp.} WZ-2008-0042 [100]. Note that 268 was reported in the same year by Pang et al. as new metabolites with the name cladosporisteroid B from \textit{Cladosporium sp.} SCSIO41007 associated with \textit{Callyspongia sp.} [61]. These metabolites (IC\textsubscript{50} values ranging from 0.11 to 0.17 µM) revealed antiviral activity against RSV (respiratory syncytial virus) with therapeutic ratio (TC\textsubscript{50}/IC\textsubscript{50}) values ranging from 5.18 to 9.92, in comparison to ribavirin in the neuraminidase inhibition assay. This could be due to their binding to RSV GREs (glucocorticoid response elements) [100]. Moreover, they (conc. 0.1 mg/mL) displayed weak to moderate AChEI potential, in comparison to huperzine A and galanthamine using the modified Ellman’s method [100]. Further, 268 had no noticeable antibacterial potential towards \textit{B. cereus, M. luteus, S. aureus, V. anguillarum E. coli, Slugella dysenteriae, B. subtilis}, and \textit{V. Parahemolyticus}, while 263 was moderately active (MIC 3.13 µM) towards \textit{S. dysenteriae} [100]. In 2020, He et al. reported that 256, 261, 265, 266, and 268 separated from \textit{C. cladosporioides} sea sediment-derived fungus possessed no anti-allergic effect on RBL-2H3 cells, in comparison to loratadine using fluorometric assay [75] (Figures 29 and 30). In 2018, Pang et al. separated new sterol cladosporisteroid A (264) and new pregnanes, cladosporisteroid B (268) and cladosporisteroid C (269), along with 259, 265, and 270 from \textit{Cladosporium sp. SCSIO41007} isolated from \textit{Callyspongia sp.}
and assessed their antiviral activity towards EV71 and H3N2 using CCK-8 and CPE assays, respectively. Only, 268 (IC$_{50}$ 16.2 µM) had weak activity towards H3N2 compared to oseltamivir (IC$_{50}$ 34.0 nM). Moreover, they revealed no cytotoxic effect towards K562, MCF-7, and SGC-7901 in the CCK-8 assay [61]. Additionally, 268 was purified from C. sphaerospermum EtOAc fraction by HPLC with the aid of LCMS and assessed for its influence on adipogenesis and lipid metabolism during maturation of adipocyte (Conc. 1.25, 2.5, 5, and 10 µM) using 3T3-L1 preadipocytes [101]. It substantially prohibited lipid accumulation and differentiation of 3T3-L1 preadipocytes into adipocytes, leading to reducing Adipsin (adipocyte marker gene) expression. Further, it significantly upregulated ATGL (lipolytic gene, Conc. 5 and 10 µM) and reduced FASN and SREBP1 (lipogenic genes, conc. 1.25, 2.5, 5, and 10 µM) expression. Collectively, 268 facilitated lipid metabolism and disrupted adipogenesis via promoting lipolysis and prohibiting lipogenesis [101].

Figure 28. Phenolics 242–248 and others 249–254.
Figure 29. Sterols 255–262.
3.17. Alcohols and Aldehydes

Gallo et al. reported for the first time from fungi the isolation of α,β-unsaturated aldehydes (271–284) from the culture of Cladosporium sp. isolated from intertidal marine sediment [102] (Figure 31). They exerted antimicrobial activity towards E. coli ATCC-25922,
B. subtilis ATCC-6633, and C. albicans ATCC-18804 in the agar diffusion method. It is noteworthy that this class of metabolites had been reported formerly from red algae (e.g., Corallina mediterranea and Laurencia papillosa, L. spectabilis, and L. undulata) [155,156]. The new aliphatic alcohols, (2S,3S,4E)-hepta-4,6-diene-2,3-diol (285) and (3E,8E,6S)-Undeca-3,8,10-trien-1,6-diol (286) were assessed for cytotoxic potential versus HeLa, BEL-7402, HL-60, A549, K562, and H1975 cell lines. Compound 286 had a cytotoxic effect versus H1975 cell line (IC$_{50}$ 10.0 µM), compared to ADR (IC$_{50}$ 0.38 µM). While both metabolites revealed no antioxidant and antimicrobial capacities [95].

Figure 31. Aldehydes (271–284) and alcohols (285 and 286).

3.18. Bioactivities of Cladosporium Species Extracts

Ding et al. stated that Cladosporium sp. isolate N5 associated with Porphyra yezoensis red alga did not produce any pathogenic symptoms in the reinfection assay. Further, its EtOAc extract displayed no lethality to A. salina and had a moderate antimicrobial activity which indicated that Cladosporium sp. had no toxicity to the aquatic ecosystem and could be applied as a biocontrol agent [59]. In the disc diffusion method, Cladosporium sp. EIODSF 008 EtOAc extract exhibited significant antibacterial potential towards E. coli, M. luteus, and B. subtilis (conc. 100 µg/disc) [57]. The EtOAc extract of Cladosporium sp. EN-S01 isolated from Sargassum cinereum brown algae showed anticancer activity towards MCF-7, HeLa, and DU-145 cell lines (IC$_{50}$ 8.46, 9.87, and 98.03 µg/mL, respectively). The extract had greater cytotoxic activity and anti-proliferative towards MCF-7 and HeLa cell lines than towards DU-145 [157]. Moreover, the EtOAc extract of C. cladosporioides KT384175 isolated from the seaweed Sargassum wightii possessed remarkable antioxidant potential.
that was comparable to ascorbic acid, as well as significant Fe$^{3+}$ reducing power that could be referred to its phenolic contents. Moreover, it revealed anti-angiogenic potential as evidenced by the decrease in the number and length of blood vessel branches on CAM (chick chorioallantoic membrane) in-vivo in the CAM assay. Further, *C. cladosporioides* extract (conc. 1.0 mg/mL) had lower wound healing potential than thalidomide (conc. 1.0 µg/mL) in the in vitro scratch assay using MCF-7 cells [158]. The sea water-derived fungus *Cladosporium* sp. F14 can produce antifouling and antibiotic metabolites in the existence of xylose or glucose. Significantly, it showed higher antibiotic activity towards *M. luteus*, *P. piscida*, *Rhodovulum* sp., *Ruegeria* sp., *V. fluvialis*, and *V. harveyi* in the existence of a sugar carbon source than in its absence in the disc diffusion assay, even though the fungal cells were well-grown under both conditions. Moreover, it possessed antifouling potential as it reduced the attachment of *B. neritina* (bryozoan larvae) in the larval settlement assay [159]. The gold nanoparticles synthesized from *C. cladosporioides* isolated from the seaweed *S. wightii* possessed noticeable antimicrobial potential towards *E. coli* MTCC-118, *B. subtilis* MTCC-441, *S. aureus* MTCC-7443, *P. aeruginosa* MTCC-424, and *A. niger* MTCC-281 with the highest growth inhibition towards *S. aureus* (IZD 12 mm) and least activity against *B. subtilis* (IZD 9.5 mm), compared to ampicillin (IZDs 15 and 12 mm, respectively) in the well diffusion method. Furthermore, they also had significant antioxidant potential comparable to ascorbic acid in the DPPH assay and moderate effectiveness in reducing power assay [160]. Ameen et al. reported that the AgNPs synthesized from *C. halotolerans* biomass isolated from the marine debris collected around Tarout Island showed a significant free radical scavenging effect (%inhibition 78% within 30 min incubation) in the DPPH assay. Moreover, it exhibited cytotoxic potential towards MCF-7 (IC$_{50}$ 34.27 µL/mL), compared to cisplatin (IC$_{50}$ 17.69 µL/mL) in the MTT assay, as well as an antifungal effect against *A. niger* (%inhibition 70 and 45% at conc. 1000 and 500 ppm, respectively) in the broth dilution method [161].

From the comprehensive review of the available literature, it was noticed that *C. phlei* (causal agent of Timothy leaf spot disease) and *C. cucumerinum* (causal agent of scab disease of many Cucurbitaceae plants) were isolated mainly from plant sources [162–165]. These species produced perylenequinone derivatives as major metabolites which are responsible for pigmentation and discolorations of the leaves [162,165]. Additionally, cotylenins, plant growth regulators were isolated from an unidentified *Cladosporium* species [166–170]. However, tetralones, seco-acids, macrolides, diketopiperazines, alkaloids, and tetramic acid derivatives were reported mainly from marine-associated *Cladosporium* species.

4. Conclusions

Numerous structurally diverse biometabolites are discovered from marine-derived fungi that represent a rich library for the development of drug lead. Marine-associated *Cladosporium* species are of biotechnological and industrial relevance and could be considered as substantial enzyme producers. Their enzymes are active in harsh conditions such as extremely low temperatures and high salinity. Therefore, they can be utilized in various industrial and biotechnological applications. Besides, these species were found to be a wealthy pool covering a wide array of metabolites with various bioactivities. Over the past 22 years, 286 metabolites have been separated from marine-associated *Cladosporium* species isolated from various marine samples, including mangrove, sediment, sponges, corals, gorgonians, algae, bivalves, hydroids, and others (Figure 32).

More than 75% of these metabolites have been reported from unidentified *Cladosporium* sp. (175 metabolites, 61%) and *C. cladosporioides* (53 metabolites, 18.5%) (Figure 33).

The results revealed that alkaloids, macrolides, tetramic acid and pyrone derivatives, and phenolics are the major metabolites reported from this marine-associated fungal species (Figure 34). They could be privileged and useful candidates for chemists and biologists to design structurally novel and pharmacologically important compounds for various diseases.
Figure 32. Number of compounds separated from Cladosporium species isolated from various marine samples.

Figure 33. Number of compounds separated from marine-derived Cladosporium species.

Although the structural diversity of these metabolites, they were insufficiently evaluated for their bioactivities. Most of them had been assessed for their antimicrobial, cytotoxicity, antiviral, and insecticidal activities (Figure 35).

Figure 36 illustrated the prominent activities of each class of secondary metabolites. However, there are limited studies that focus on the mechanism of action of these metabolites. Many of the tested metabolites possessed no noticeable efficacy in some of the tested activities. Therefore, estimation of other potential bioactivities and derivatization of these metabolites, as well as the mechanistic and in vivo studies of the active metabolites should clearly be the target of future research.
Figure 34. Number of metabolites from each class of natural products.

Figure 35. Number of bioactive compounds in each tested activity.
5. Strategies for Activating Silencing Gene Clusters

Growing evidence has revealed that the activation of silent gene clusters has the potential to significantly enhance the discovery of new natural metabolites of high-therapeutic leads. Different strategies to awake the silent biosynthetic gene clusters of *Cladosporium* species such as co-cultivation of organisms and elicitors epigenetic, as well as, modifiers can be applied [171–174]. The production of secondary metabolites (SMs) is affected by cultivation media, environment, and conditions [171,175]. Therefore, manipulating the culture conditions can improve the outputs from living organisms. Small changes in the growth media composition can induce not only variation in the amount of SMs, but also the production of a completely different pattern of molecules [171–173]. OSMAC (one strain many compounds) is a form of strain improvement that summarized the ability of single strains to produce different compounds when growing under different conditions e.g., aeration rate, media composition, type of culturing vessel, or a combination of these factors [174–176]. Challenging the fungi with external cues or chemicals has been shown to enhance the SMs production. Antibiotics have been widely reported as elicitors that can activate a broad spectrum of silent BGCs [171–174]. The co-cultivation of strains of the same or different species has been shown to represent a promising strategy for the activation of silent BGCs that enhances the production of SMs and discovery of new bioactive SMs [171,172,177]. Activation of silent biosynthetic gene clusters (BGCs) by quorum sensing class of signaling molecule is another strategy that has been shown to dramatically increase SMs production [171–173]. Engineering strains to circumvent the regulatory systems has the potential to free silent BGCs from their locked-in state and result in a significantly enhancement of SMs production. This can be done through various ways such as ribosome and polymerase engineering, an awakening of the genes encoding transcriptional regulatory proteins, and deletion or deactivation of the suppressor proteins. Another approach is the insertion of inducible artificial promoters to drive the expression of the silent genes [171,172,178]. Modulating epigenetic control also plays a role in the expression of silent gene clusters linked to natural product expression [173,179].

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Abbreviations

\[ ^3\text{H}\text{PDBu}: [^3\text{H}]\text{Phorbol-12,13-dibutyrate}; \text{22RV1}: \text{Human prostatic cancer cell line}; \text{A2780}: \text{Human ovarian cancer cell}; \text{A375}: \text{Melanoma cell line}; \text{A549}: \text{Lung adenocarcinoma epithelial cell line}; \text{Ab1}: \text{Proto-oncogene 1, non-receptor tyrosine kinase}; \text{ABPA}: \text{Allergic bronchopulmonary aspergillosis}; \text{ADR}: \text{Adriamycin}; \text{ATGL}: \text{Adipose triglyceride lipase}; \text{ATP}: \text{Adenosine triphosphate}; \text{Bax/Bel-2}: \text{Apoptosis regulator BAX}; \text{Beap-37}: \text{Human breast carcinoma cell line}; \text{Bel-7402}: \text{Human hepatocellular carcinoma cell line}; \text{BGC-823}: \text{Human gastric cancer cell line}; \text{BT549}: \text{Human breast cancer cells line}; \text{C4-2B}: \text{Human prostatic cancer cell line}; \text{C4-2B}: \text{Human prostatic cancer cell line}; \text{CAM}: \text{Chick chorioallantoic membrane assay}; \text{CCK8}: \text{Cell Counting kit-8}; \text{CD25}: \text{Cluster of differentiation 25}; \text{CD28}: \text{Cluster of differentiation 28}; \text{CDK}: \text{Cyclin-dependent kinase}; \text{CDKI}: \text{Cyclin-dependent kinase Inhibitor}; \text{CDPSs}: \text{Cyclodipeptide synthases}; \text{CM}: \text{Corrected mortality}; \text{COX-2}: \text{Cyclooxygenase-2}; \text{CPE}: \text{Cytopathic effect}; \text{DAPI}: \text{4,6-Diamidino-2-phenylindole}; \text{DELFIA}: \text{Dissociation-enhanced lanthanide fluorescence immunoassay}; \text{DKPs}: \text{Diketopiperazines}; \text{DMSO}: \text{Dimethylsulfoxide}; \text{DPPH}: \text{1,1-Diphenyl-2-picrylhydrazyl}; \text{DU-145}: \text{Human prostate cancer cell line}; \text{ED}_{50}: \text{Effective dose 50}; \text{EGFR}: \text{Epidermal growth factor receptor}; \text{ERK}: \text{Extracellular signal-regulated protein kinase}; \text{ETOA}: \text{Ethyl acetate}; \text{EthOH}: \text{Ethanol}; \text{EV71}: \text{Enterovirus 71}; \text{FASN}: \text{Fatty acid synthase}; \text{FRAP}: \text{Ferric reducing antioxidant power}; \text{FSW}: \text{Filtered seawater}; \text{Fyn}: \text{Proto-oncogene tyrosine-protein kinase}; \text{GREs}: \text{Glucocorticoid response elements}; \text{GW9662}: \text{Selective PPAR antagonist for PPARγ}; \text{H1974}: \text{Human colorectal cancer cell line}; \text{H3N2}: \text{Influenza A virus subtype H3N2}; \text{H446}: \text{Human small cell lung carcinoma}; \text{HCC70}: \text{Human breast cancer cells line}; \text{HCT-116}: \text{Human colorectal cancer cell line}; \text{HCT-15}: \text{Human colon cancer cell line}; \text{HCT-8}: \text{Human colorectal cancer cell line}; \text{HeLa}: \text{Human epithelial cervix carcinoma cell line}; \text{HeLa S3}: \text{Human cervix carcinoma cell line}; \text{HepG-2}: \text{Human liver cancer cell line}; \text{HL-60}: \text{Human promyelocytic leukemia cell}; \text{HT-29}: \text{Human colorectal adenocarcinoma cell line}; \text{HTRF}: \text{Homogeneous time-resolved fluorescence assay}; \text{Huh-7}: \text{Differentiated hepatocyte-derived cellular carcinoma cell line}; \text{IC}_{50}: \text{Half-maximal inhibitory concentration}; \text{IFNγ}: \text{Interferon γ}; \text{IL}-2: \text{Interleukin-2}; \text{IZD}: \text{Inhibition zone diameter}; \text{JNK}: \text{c-Jun NH2-terminal kinase}; \text{Jurkat}: \text{Human T lymphoblastic leukemia cell lines}; \text{K562}: \text{Human kidney cancer cell line}; \text{L02}: \text{Human hepatic cancer cell line}; \text{L1210}: \text{Mouse lymphocytic leukemia cell line}; \text{L5178Y}: \text{Murine lymphoma cell line}; \text{Lac}: \text{Laccase}; \text{LBD}: \text{Ligand binding domain}; \text{LC3-I, II}: \text{Microtubule-associated proteins 1A/1B light chain 3B}; \text{LC50}: \text{Lethal concentration 50}; \text{LCK}: \text{Lymphocyte-specific protein tyrosine kinase}; \text{LiP}: \text{Lignin peroxidase}; \text{LLC-PK1}: \text{Epithelial-like pig kidney cell line}; \text{LM3}: \text{Human hepatocellular carcinoma cell line}; \text{LNCap}: \text{Human prostate cancer cell line}; \text{LPS}: \text{Lipopolysaccharide}; \text{MCF-7}: \text{Breast cancer cell line}; \text{MDA-MB-231}: \text{Human breast cancer cell line}; \text{MDA-MB-435}: \text{Human breast cancer cell line}; \text{MDA-MB-468}: \text{Human breast cancer cell line}; \text{MDCK}: \text{Madin–Darby canine kidney}; \text{MD-MBA-231}: \text{Breast adenocarcinoma cell line}; \text{MeOH}: \text{Methanol}; \text{MGC-803}: \text{Human gastric carcinoma cell line}; \text{MIC}: \text{Minimum inhibitory concentration}; \text{MMP}: \text{Mitochondrial membrane potential}; \text{MnP}: \text{Manganese-dependent peroxidase}; \text{MOLT}-4: \text{T lymphoblast-acute lymphoblastic leukemia}; \text{MRCNS}: \text{Methicillin-resistant coagulase-negative Staphylococci}; \text{mRNA}: \text{Messenger ribonucleic acid}; \text{MRSA}: \text{Methicillin-resistant Staphylococcus aureus}; \text{MTT}: \text{3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide}; \text{NAC}: \text{N-acetylcysteine}; \text{NCI-H460}: \text{Human lung carcinoma cell line}; \text{NF-kB}: \text{Nuclear factor Kappa B}; \text{NO}: \text{Nitric oxide}; \text{NRPSs}: \text{Non-}
ribosomal peptide synthetases; NS-398: N-[2-(cyclohexyloxy)-4-nitrophenyl]methanesulphonamide; OA: Oleic acid; OGI-AML3: Acute myeloid leukemia cell line; OSMAC: One strain many compounds; OVCAR-3: Human ovarian Cancer cell line; P0: PAX6 promoter; P1: PAX6 promoter; P21: N-Myc-cyclin-dependent kinase inhibitor 1A; p21Waf1/cip1: Cyclin kinase inhibitor p21; P388: Mouse lymphocytic leukemia cell line; PANC-1: Human Pancreatic cancer cell line; PAX6: Paired box gene 6; PBMC: Peripheral blood mononuclear cell; PC-3: Human prostate carcinoma cell line; PG: Polygalacturonase; PGE2α: Prostaglandin F2α; PKA: cAMP-dependent protein kinase; PKC: Protein kinase C; PMA: Phorbol 12-myristate 13-acetate; PME: Pectin methylesterase; PPARγ: Peroxisome proliferator-activated receptor γ; PPRE: Peroxisome proliferator-activated receptor response element; PTP: Protein tyrosine phosphatase; PaC: PAX6 promoter; RHO: Rhodopsin; RSV: Respiratory syncytial virus; RWPE-1: Human normal prostate epithelial cell; SAR: Structure–activity relationship; SF-268: Human glioblastoma cell line; SGC-7901: Human gastric cancer cell line; SH-SY5Y: Human neuroblastoma cell line; SK-BR-3: Human Breast cancer cell line; SMMC-7721: Human hepatoma carcinoma cell line; SPR: Surface plasmon resonance; SRB: Sulforhodamine B; SREBP1: Sterol regulatory element binding transcription factor 1; SW1116: Human colon cancer cell line; SW1990: Human pancreatic adenocarcinoma cell line; T47D: Human breast cancer cell line; TC: Total cholesterol; TCG5: Half toxic concentration; TCF: T cell factor; TCPTP: T Cell protein tyrosine phosphatase; TG: Total triglyceride; TRF: Time-resolved fluorescence; U937: Human myeloid leukaemia cell line; WERI: Retinoblastoma cell line; WST-1: 4-[3-(4-Iodophenyl)-2-(4-nitrophenyl)-2H-5-tetrazolio]-1,3-benzene disulfonate; Y-79: Retinoblastoma cell line.

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