RAPID SCREENING OF ANTIBACTERIAL AND ANTIOXIDANT METABOLITES FROM ENDOPHYTIC FUNGI ISOLATED FROM *Papuacedrus papuana* BY TLC-BIOAUTOGRAPHY

Praptiwi¹, Muhammad Ilyas², Kartika Diah Palupi¹, Ahmad Fathoni¹, Evana¹, Marlin Megalestin Raunsai¹ and Andria Agustina¹∗

¹) Research Center for Chemistry, Indonesian Institute of Sciences
Kawasan PUSPIPTEK, Tangerang Selatan, Banten 15314
²) Research Center for Biology, Indonesian Institute of Sciences
Jl. Raya Bogor Km. 46, Cibinong, Jawa Barat 16911

E-mail: andr002@lipi.go.id

Received: 28 April 2021; revised: 15 Juni 2021; accepted: 23 Juni 2021

ABSTRACT

RAPID SCREENING OF ANTIBACTERIAL AND ANTIOXIDANT METABOLITES FROM ENDOPHYTIC FUNGI ISOLATED FROM *Papuacedrus papuana*. *Papuacedrus papuana* is a plant species that grows in the highland of Papua. The aims of the study were to determine in vitro antibacterial activity and antioxidant activity of 17 endophytic fungal extracts isolated from *P. papuana* stem by the TLC-bioautography method. The antibacterial activity was assessed against *Staphylococcus aureus* InaCC B4 and *Escherichia coli* InaCC B5. The antioxidant activity was assessed by DPPH radical scavenging assay. All of 17 endophytic fungi were grouped into 7 taxa based on their morphological traits. The results showed that 11 fungal extracts were active against *S. aureus* InaCC B4, 15 fungal extracts were active against *E. coli* InaCC B5, and 6 extracts had antioxidant activity. Further analysis of active extracts by eluted TLC-bioautography showed several compounds responsible for antibacterial or antioxidant activity in one extract. The results showed a diversity of endophytic fungi inhabited *P. papuana* stem, and these endophytic fungi might be used as a good source of novel antibacterial or antioxidants.

Keywords: *Papuacedrus papuana*, endophytic fungi, antibacterial, antioxidant.

INTRODUCTION

*Papuacedrus papuana* (syn. *Liboceudrus papuana*) is one of the plant species that belongs to Cupressaceae and the only species in the genus of *Papuacedrus*. According to Johns (1995), *P. papuana* is native to New Guinea and Maluku. The timber of *P. papuana* has been used as a building material, while the stem bark is used for roof material. Some other
species from the conifer family (Cupressaceae) have been investigated for their bioactivity. According to Perry and Foster (1994), the extract of Libocedrus pulmosa, L. bidwillii, and Cupressus macrocarpa are active against leukemia cells P-388.

On the other hand, in the last two decades, many studies focus on the bioactivity of microbial endophytes. Endophytes usually colonized the healthy tissue plants (Aly et al. 2010) without causing any harm to the host plant (Idris, Al-tahir, and Idris 2013). Endophytes may have the ability to produce bioactive compounds that are the same or similar to bioactive compounds derived from the host plant so that endophytic fungi can serve as an alternative source of plant metabolites (Tikole, Tarate, and Shelar 2018). According to Sturz and Nowak (2000), there are several roles of endophytic fungi in the host plant such as stimulate plant growth, increase disease resistance, improve the ability of the plant to environmental stresses and recycle nutrients. A wide variety of natural products have been obtained from endophytes. Kusari, Lamshöft, and Spiteller (2009) stated that endophytes usually produce the same bioactive compounds as the host plant. Endophytic fungi can be used as a source of secondary metabolites that are useful for novel drug discovery (Yan, Sikora, and Zheng 2011; Guo et al. 2008). The endophytic fungi from several species of Cupressaceae have been investigated for their antimicrobial activity.

The search for novel antibacterial and natural antioxidants has become important. This is due to increasing resistance by pathogenic bacteria to commercial drugs (Costelloe et al. 2010). At the same time, the use of natural antioxidants was also increased lately. This is due to the use of synthetic antioxidants is suspected to be carcinogenic (Govindarajan et al. 2003).

To the best of our knowledge, there is still no report about the diversity of endophytic fungi from P. papuana, and also the study of their activities, especially for the antimicrobial and antioxidant activity. Therefore, this study aimed to determine the most potential endophytic fungi associated with P. papuana as a source of antibacterial and antioxidant metabolites.

**MATERIALS AND METHODS**

**Materials**

**Plant Source**

Young healthy stems of P. papuana were collected from Habema, Papua. The plant voucher was deposited and identified in the Botany Division, Research Center for Biology-Indonesian Institute of Sciences (LIPI).

**Chemicals**

Ethanol (70%), NaOCl, ethyl acetate (Merck), Thin Layer Chromatography (TLC) plates (silica gel GF254, Merck), Dichloromethane (Merck), MeOH (Merck), Ce(SO4)2 (Merck), Iodonitrotetrazolium p-violet (INT, Sigma), H2SO4 (Merck), chloramphenicol (Merck), Mueller-Hinton Broth (MHB, Merck), 2,2-diphenyl-1-picrylhydrazyl (DPPH, Sigma), and (+)-catechin (Sigma).

**Methods**

**Endophytic fungi isolation and cultivation**

The fresh young healthy stems of P. papuana were thoroughly washed under tap water. Stems were cut about 2 cm in length, then sterilized by dipping in 70% alcohol for 2 minutes, transferred into NaOCl 5.3% solution for 5 minutes, then transferred into 70% alcohol for 1 minute, and washed with distilled water. Sterilization is performed aseptically in laminar airflow. The samples that had been surface-sterilized were split with a sterile blade, and the inner part was placed on Corn Meal Malt Agar (CMMA) media that has been added with chloramphenicol 0.05 mg/mL in a petri dish. Petri dishes were incubated for 7 days at room temperature. The emerging fungi were isolated and subcultured on Potato Dextrose Agar (PDA) media several times to obtain single isolates (Agusta et al. 2005).

**Identification of endophytic fungal isolates**

Identification of endophytic fungi isolated from P. papuana was based on fungal morphological characters (Domsch, Gams, and Anderson 2008; Webster and Weber 2007; Ellis 1965). Morphological traits and characteristics macroscopically and microscopically were observed from fungal colonies grown on PDA at room temperature. Color and surface colonies (granular, such as flour, mounting, slippery), texture, zonation, growth area, the lines of radial and concentric, reverse color, and exudate drops were amongst of macroscopic characters that observed.

**Endophytic fungi cultivation and extraction**

A single isolate of endophytic fungi was inoculated into 200 ml Potato Dextrose Broth (PDB) and incubated for 3 weeks in a static condition at room temperature under dark conditions. After an incubation period, the biomass and culture broth was extracted with ethyl acetate. The organic phase was collected and concentrated with a rotary evaporator.

**Analysis of endophytic fungi metabolites**

The chemical compounds of ethyl acetate extract were analyzed by separation with TLC. The plate was developed using mobile phase...
dichloromethane: methanol (10:1). The chromatogram was viewed under UV light at wavelengths of 254 and 366 nm then sprayed with a staining reagent: 1% Ce(SO₄)₂/10% H₂SO₄ and 1% vanillin/H₂SO₄.

**TLC-Bioautography: Antibacterial Assay**

Endophytic fungal extracts were screened for their antibacterial activity against two bacteria (E. coli InaCC-B5 and S. aureus InaCC-B4). One hundred µg of endophytic fungal extract (10 mg/mL) were transferred on a TLC plate, then dipped into a bacteria suspension (10⁶ CFU/mL). The plate was placed on a sterile petri dish and incubated at 37°C for 18 hours. After an incubation period, the plate was sprayed with INT. A clear zone indicated the inhibition zone against a purple background on the TLC plate.

The active extracts were then observed for the active compounds responsible for antibacterial activity. One hundred µg of endophytic fungi extract (10 mg/mL) was transferred on a TLC plate, and the compounds were separated with the mobile phase of dichloromethane : methanol (10:1) and then dipped into bacteria suspension. The plate was placed on a sterile petri dish and incubated at 37°C for 18 hours. After an incubation period, the plate was sprayed with INT. The spots that are responsible for antibacterial activity were indicated by white spot formation.

**TLC-Bioautography: Antioxidant potential by DPPH radical scavenging assay**

Ten µl of endophytic fungi extract (10 mg/mL) were transferred to the TLC plate, with (+)-catechin as positive control and culture media as negative control were also transferred to the TLC plate. The plate was then allowed to air dry, followed by spraying with 1 mM DPPH in methanol solution. The antioxidant potential was indicated by the formation of a white-yellow spot against a purple background. The active extract (100 µg) was transferred on a TLC plate, then eluted with the mobile phase of dichloromethane-methanol (10:1). After air drying, the plate was sprayed with 1 mM DPPH in methanol solution.

**RESULTS AND DISCUSSION**

**Endophytic fungi isolation and identification**

The potential of the endophytic fungi associated with P. papuana has not been had much attention yet. Totally 17 filamentous fungi isolates were obtained from the young stem of P. papuana (Table 1). Based on their morphological characters, including macroscopic (Figure 1) and microscopic characters, these fungi were classified into 5 taxa, which are Phomopsis sp. (1 isolate), Dematiaceae (9 isolates), Coelomycetes (3 isolates), Hyphomycetes (2 isolates), and Sordariomycetes (2 isolates). The genus Phomopsis is a good source of bioactive compounds which have remarkable value in medical application (Xu et al. 2021).

**Table 1. List of endophytic fungi isolated from P. papuana stem.**

| No. | Fungal Isolates | Fungal taxa         | Extract Production (mg/200 ml medium) |
|-----|------------------|---------------------|---------------------------------------|
| 1   | PC-01            | Dematiaceae         | 227.4                                 |
| 2   | PC-02            | Coelomycetes        | 687.5                                 |
| 3   | PC-03            | Sordariomycetes     | 66.6                                  |
| 4   | PC-04            | Coelomycetes        | 314.5                                 |
| 5   | PC-05            | Phomopsis sp.       | 127.8                                 |
| 6   | PC-06            | Hyphomycetes        | 141.5                                 |
| 7   | PC-07            | Dematiaceae         | 212.2                                 |
| 8   | PC-08            | Dematiaceae         | 2090.0                                |
| 9   | PC-11            | Dematiaceae         | 68.0                                  |
| 10  | PC-13            | Coelomycetes        | 814.1                                 |
| 11  | PC-14            | Dematiaceae         | 368.2                                 |
| 12  | PC-15            | Dematiaceae         | 145.9                                 |
| 13  | PC-16            | Dematiaceae         | 122.6                                 |
| 14  | PC-17            | Sordariomycetes     | 236.4                                 |
| 15  | PC-18            | Hyphomycetes        | 95.9                                  |
| 16  | PC-19            | Dematiaceae         | 114.3                                 |
| 17  | PC-20            | Dematiaceae         | 83.8                                  |

Endophytic fungi, in general, has a wide range of host. They could be isolated from the different plants from different taxa and grow under different ecological and geographical conditions. However, some endophytic fungi have only one specific host genera. The result indicated that P. papuana stem harbored diverse taxa of fungal endophytes. Qadri et al. (2013) stated that conifers possessed a broad range of fungal endophytes. Carroll and Carroll (1978) observed some specificity concerning the location of fungal endophytes. Carroll and Carroll (1978) observed some specificity concerning the location of fungal endophytes. Carroll and Carroll (1978) observed some specificity concerning the location of fungal endophytes.
TLC-Bioautography: Antibacterial Activity

The antibacterial and antioxidant assay was done by TLC-bioautography because this method was a rapid approach (Rajauria and Abu-Ghannam 2013). The result from TLC-bioautography for antibacterial (Figure 2) showed that 11 extracts (64.71%) inhibit the growth of \textit{S. aureus}, 15 extracts (88.24%) inhibit the growth of \textit{E. coli} and 6 extracts (35.29%) have antioxidant activity (Table 2.). Further analysis by eluted TLC-bioautography was used to determine the active spots (metabolites) as clear zones surrounding the purple background as shown in Figure 3.

Table 2. The Antibacterial activity and antioxidant potential of endophytic fungi extract isolated from the young stem of \textit{P. papuana}.

| No | Isolate | \textbf{Antibacterial activity} | \textbf{Antioxidant potential} |
|----|---------|--------------------------------|--------------------------------|
|    |         | \textit{S. aureus} | \textit{E. coli} |            |
| 1  | PC-01   | -                 | -                 | -            |
| 2  | PC-02   | +                 | +++               | -            |
| 3  | PC-03   | -                 | +                 | -            |
| 4  | PC-04   | +                 | +                 | +++          |
| 5  | PC-05   | +                 | +                 | -            |
| 6  | PC-06   | -                 | -                 | -            |
| 7  | PC-07   | +                 | +                 | ++           |
| 8  | PC-08   | -                 | -                 | -            |
| 9  | PC-11   | +++               | ++                | +            |
| 10 | PC-13   | +                 | +                 | -            |
| 11 | PC-14   | -                 | +                 | -            |
| 12 | PC-15   | +                 | +                 | -            |
| 13 | PC-16   | +                 | +                 | +            |
| 14 | PC-17   | +                 | +                 | -            |
| 15 | PC-18   | +                 | +                 | -            |
| 16 | PC-19   | -                 | +                 | -            |
| 17 | PC-20   | ++                | ++                | -            |

\textbf{Note:} +++ : strong activity, ++ moderate activity, + weak activity, - : no activity

Figure 3. Bioautogram of active extracts developed with dichloromethane : methanol (10:1), (a) viewed under 254 nm, (b) viewed under 366 nm, (c) against \textit{E. coli}, and (d) \textit{S. aureus}. White bands indicated the active chemical compounds in the extracts. Picture information refers to Table 1.

Table 3. The MIC (antibacterial) and IC\textsubscript{50} value (antioxidant) of endophytic fungi extract from \textit{P. papuana}.

| No | Isolate | MIC (µg/mL) | IC\textsubscript{50} (ppm) |
|----|---------|-------------|--------------------------|
|    |         | \textit{S. aureus} | \textit{E. coli} |            |
| 1  | PC-02   | 256         | 256                     | >1000       |
| 2  | PC-04   | >256        | >256                    | 345          |
| 3  | PC-07   | 256         | 256                     | 710          |
| 4  | PC-11   | >256        | >256                    | >1000       |
| 5  | PC-18   | >256        | >256                    | >1000       |
| 6  | PC-20   | 256         | 256                     | >1000       |

Further analysis of active extracts to determine their MIC values. The MIC values of active extracts were in the range of 256 µg/mL or more (Table 3). It showed that the antibacterial activity of endophytic fungi extracts from \textit{P. papuana} were not strong antibacterial. Extracts are considered to have significant antimicrobial activity if the MIC values are lower than 100 µg/mL (Ríos and Recio 2005; Gibbons 2004).

Results of the present study showed that endophytic fungal extracts of \textit{P. papuana} inhibited the growth of bacteria. The growth inhibition is indicated by clear zone formation around the extract or the chemical compounds responsible for antibacterial activity. Clear zone
formation indicated the reduction of INT into a colored formazan that inhibits the growth of bacteria (Suleiman et al. 2010). In several previous studies, the crude extract of culture broth of endophytic fungi showed various bioactivity such as antibacterial, antifungal, anti-inflammatory, antiviral, and anti-tumor activity (Silva et al. 2006). The result from the study also showed that endophytic fungi associated with P. papuana stem are dominated by Dematiaceae such as PC-7, PC-11, PC-14, PC-15, and PC-16. The result showed that these fungi isolates have antibacterial activity and antioxidant activity. This result is in harmony with Tsuge et al. (2013), and Bräse et al. (2009) that Alternaria fungi belong to Dematiaceae produce metabolites with a variety of biological activities such as phytotoxic, cytotoxic, and antimicrobial properties. Tenuazonic acid produced by Alternaria alternata was found to be active against Mycobacterium tuberculosis H37Rv (Logrieco, Moretti, and Solfrizzo 2009). The result also showed that PC-05 (Phomopsis sp.) was active against S. aureus and E. coli. Previous studies showed that the genus Phomopsis is a rich source of bioactive compounds as antimalarial and antitubercular phomoxanthones (Isaka et al. 2001), antifungal phomoxanthone-A (Elsässer et al. 2005), and antibacterial chromones (Ahmed et al. 2011).

**TLC-Bioautography: Antioxidant potential by DPPH radical scavenging assay**

The antioxidant activity of the endophytic fungal extracts associated with P. papuana was assessed by TLC-bioautography with DPPH radical scavenging assay. The result showed 6 isolates have antioxidant activity (PC-04, PC-07, PC-11, PC-14, PC-15, and PC-16), which is indicated by white-yellowish area formation on the TLC plate (Figure 4).

The active extracts were further assay by separating their chemical compounds on a TLC plate and developed with mobile phase dichloromethane-methanol (10:1). This analysis could be used to determine the active spots (metabolites) as pale yellow spots surrounding the purple background as shown in Figure 5.

**CONCLUSION**

A total of 17 isolates of endophytic fungi were isolated from P. papuana and based on morphological characters they were classified into 5 taxa. Among 17 extracts of endophytic fungi, 11 extracts were active against S. aureus.
InaCC B4, 15 extracts were active against E. coli InaCC B5, and 6 extracts have antioxidant potential. Endophytic fungi from P. papuana might use as a novel source for antimicrobial and antioxidant agents which is under further investigation.

ACKNOWLEDGMENT

The authors thank Dr. Ary Prihardianto Keim, Research Center for Biology LIPI for collecting and taxonomical identification of plant materials.

REFERENCES

Agusta, A., S. Maehara, K. Ohashi, P. Simanjuntak, and H. Shibuya. 2005. “Stereo-selective Oxidation at C-4 of Flavans by the Endophytic Fungus Diaporthe sp. Isolated from a Tea Plant.” Chemical and Pharmaceutical Bulletin 53 (12): 1565–69. https://doi.org/10.1248/cpb.53.1565.

Ahmed, I., H. Hussain, B. Schulz, S. Draeger, D. Padula, G. Pescitelli, T. Van Ree, and K. Krohn. 2011. “Three New Antimicrobial Metabolites from the Endophytic Fungus Phomopsis sp.” European Journal of Organic Chemistry 9 (15): 2867–73. https://doi.org/10.1002/ejoc.201100158.

Aly, A. H., A. Debbab, J. Kjer, and P. Proksch. 2010. “Fungal Endophytes from Higher Plants: A Prolific Source of Phytochemicals and Other Bioactive Natural Products.” Fungal Diversity 41: 1–16. https://doi.org/10.1007/s13225-010-0034-4.

Blois, M. S. 1958. “Antioxidant Determinations by the Use of a Stable Free Radical.” Nature 181 (4617): 1199–1200. https://doi.org/10.1038/1811199a0.

Bräse, S., A. Encinas, J. Keck, and C. F. Nising. 2009. “Chemistry and Biology of Mycotoxins and Related Fungal Metabolites.” Chemical Reviews 109 (9): 3903–90. https://doi.org/10.1021/cr050001f.

Carroll, G. C., and F. E. Carroll. 1978. “Studies on the Incidence of Coniferous Needle Endophytes in the Pacific Northwest.” Canadian Journal of Botany 56: 3034–43.

Costelloe, C., C. Metcalfe, A. Lovering, D. Mant, and A. D. Hay. 2010. “Effect of Antibiotic Prescribing in Primary Care on Antimicrobial Resistance in Individual Patients: Systematic Review and Meta-Analysis.” BMJ 340: 1–11. https://doi.org/10.1136/bmj.c2096.

Domsch, K. H., W. Gams, and T Anderson. 2008. “Compendium of Soil Fungi.” European Journal of Soil Science 59: 1007–11. https://doi.org/10.1111/j.1365-2389.2008.01052.x.

Ellis, M B. 1965. Dematiaceous Hyphomycetes. VI. Mycological Papers.

Elsässer, B., K. Krohn, U. Flörke, N. Root, H. J. Aust, S. Draeger, B. Schulz, S. Antus, and T. Kurtán. 2005. “X-Ray Structure Determination, Absolute Configuration and Biological Activity of Phomoxanthone A.” European Journal of Organic Chemistry, no. 21: 4563–70. https://doi.org/10.1002/ ejoc.200500265.

Gibbons, S. 2004. “Anti-Staphylococcal Plant Natural Products.” Natural Product Reports 21 (2): 263–77. https://doi.org/10.1039/b212695h.

Govindarajan, R., S. Rastogi, M. Vijayakumar, A. Shiriwaikar, A. K. Singh Rawat, S. Mehrotra, and P. Pushpangadan. 2003. “Studies on the Antioxidant Activities of Desmodium gangeticum.” Biological and Pharmaceutical Bulletin 26 (10): 1424–27. https://doi.org/10.1248/bpb.26.1424.

Guo, B., Y. Wang, X. Sun, and K. Tang. 2008. “Bioactive Natural Products from Endophytes: A Review.” Applied Biochemistry and Microbiology 44 (2): 136–42. https://doi.org/10.1134/S0003683808020026.

Idris, Al-mahi, I. Al-tahir, and E. Idris. 2013. “Antibacterial Activity of Endophytic Fungi Extracts from the Medicinal Plant Kigelia africana.” Egyptian Academic Journal of Biological Sciences, G. Microbiology 5 (1): 1–9. https://doi.org/10.21608/eajbsg.2013.16639.

Isaka, M., A. Jaturapat, K. Rukseere, K. Danwisetkanjana, M. Tanticharoen, and Y. Thebtaranonth. 2001. “Phomoxanthones A and B, Novel Xanthone Dimers from the Endophytic Fungus Phomopsis Species.” Journal of Natural Products 64 (8): 1015–18. https://doi.org/10.1021/np010006h.

Johns, R. J. 1995. “Papuacedrus papuana var. Papuana, Cupressaceae.” Curtis’s Botanical Magazine 12 (2): 66–72.

Kumar, S., and A. K. Pandey. 2012. “Antioxidant, Lipo-Protection and Antibacterial Activities of Phytoconstituents Present in Solanum xanthocarpum Root.” International Review of Biophysical Chemistry 3 (3): 42–47.

Kusari, S., M. Lamshöft, and M. Spiteller. 2009. “Aspergillus fumigatus Fresenius, an Endophytic Fungus from Juniperus communis L. Horstmann as a Novel Source of the Anticancer pro-Drug Deoxypodophyllotoxin.” Journal of Applied Microbiology 107 (3): 1019–30. https://doi.org/10.1111/j.1365-2672.2009.04285.x.

Logrieco, A., A. Moretti, and M. Solfrizzo. 2009.
“Alternaria Toxins and Plant Diseases: An Overview of Origin, Occurrence and Risks.” World Mycotoxin Journal 2 (2): 129–40. https://doi.org/10.3920/WMJ2009.1145.

Mahlo, S. M., H. R. Chauke, L. McGaw, and J. Eloff. 2016. “Antioxidant and Antifungal Activity of Selected Medicinal Plant Extracts against Phytopathogenic Fungi.” African Journal of Traditional, Complementary and Alternative Medicines 13 (4): 216–22. https://doi.org/10.21010/ajtcam.v13i4.28.

Perry, N. B., and L. M. Foster. 1994. “Antitumour Lignans and Cytotoxic Resin Acids from a New Zealand Gymnosperm, Libocedrus plumosa.” Phytomedicine 1 (3): 233–37. https://doi.org/10.1016/S0944-7113(11)80070-X.

Qadri, M., S. Johri, B. A. Shah, A. Khajuria, T. Sidiq, S. K. Laloo, M. Z. Abdin, and S. Riyaz-Ul-Hassan. 2013. “Identification and Bioactive Potential of Endophytic Fungi Isolated from Selected Plants of the Western Himalayas.” SpringerPlus 2 (8): 1–14.

Rajauria, G., and N. Abu-Ghannam. 2013. “Isolation and Partial Characterization of Bioactive Fucoxanthin from Himanthalia elongata Brown Seaweed: A TLC-Based Approach.” International Journal of Analytical Chemistry, 1–6. https://doi.org/10.1155/2013/802573.

Ríos, J. L., and M. C. Recio. 2005. “Medicinal Plants and Antimicrobial Activity.” Journal of Ethnopharmacology 100 (1–2): 80–84. https://doi.org/10.1016/j.jep.2005.04.025.

Silva, Geraldo Humberto, Helder Lopes Teles, Lisinéia Maria Zanardi, Maria Claudia Marx Young, Marcos Nogueira Eberlin, Renato Hadad, Ludwig H. Pfenning, et al. 2006. “Cadinane Sesquiterpenoids of Phomopsis cassiae, an Endophytic Fungus Associated with Cassia spectabilis (Leguminosae).” Phytochemistry 67 (17): 1964–69. https://doi.org/10.1016/j.phytochem.2006.06.004.

Sturz, A. V., and J. Nowak. 2000. “Endophytic Communities of Rhizobacteria and the Strategies Required to Create Yield Enhancing Associations with Crops.” Applied Soil Ecology 15(2):183–90. https://doi.org/10.1016/S0929-1393(00)00094-9.

Suleiman, M. M., L. J. McGaw, V. Naidoo, and J. N. Eloff. 2010. “Detection of Antimicrobial Compounds by Bioautography of Different Extracts of Leaves of Selected South African Tree Species.” African Journal of Traditional, Complementary and Alternative Medicines 7 (1): 64–78. https://doi.org/10.4314/ajtcam.v7i1.57269.

Tikole, S. S., B. Tarate, and P. Shelar. 2018. “Endophytic Micro-Organisms as Emerging Trend of Secondary Metabolite.” International Journal of Pharma Sciences and Research 9 (12): 211–14.

Tsuge, T., Y. Harimoto, K. Akimitsu, K. Ohtani, M. Kodama, Y. Akagi, M. Egusa, M. Yamamoto, and H. Otani. 2013. “Review Article: Host-Selective Toxins Produced by the Plant Pathogenic Fungus Alternaria alternata.” FEMS Microbiology Reviews 37 (1): 44–66. https://doi.org/10.1111/femsm.12005.x.

Webster, J., and R. Weber. 2007. “Introduction to Fungi.” In Third Edit. Melbourne: Cambridge University Press, Third edit. Melbourne: Cambridge University Press.

Xu, T. C., Y. H. Lu, J. F. Wang, Z. Q. Song, Y. G. Hou, S. S. Liu, C. S. Liu, and S. H. Wu. 2021. “Bioactive Secondary Metabolites of the Genus Diaporthe and Anamorph Phomopsis from Terrestrial and Marine Habitats and Endophytes: 2010–2019.” Microorganisms 9(2):1–49. https://doi.org/10.3390/microorganisms9020217.

Yan, X. N., R. A. Sikora, and J. W. Zheng. 2011. “Potential Use of Cucumber (Cucumis sativus L.) Endophytic Fungi as Seed Treatment Agents against Root-Knot Nematode Meloidogyne Incognita.” Journal of Zhejiang University: Science B 12 (3): 219–25. https://doi.org/10.1631/jzus.B1000165.