Article

Secondary Metabolite Production and Terpenoid Biosynthesis in Endophytic Fungi Cladosporium cladosporioides Isolated from Wild Cymbopogon martinii (Roxb.) Wats

Hemalatha Jayaram 1, Vinutha Marigowda 2* and Kunigal Jagadishchandra Thara Saraswathi 1,*

1 Department of Microbiology and Biotechnology, Inana Bharathi Campus, Bangalore University, Bengaluru 560056, Karnataka, India; hemalathaj24@gmail.com
2 Department of Biotechnology and Genetics, Ramaiyah College of Arts, Science and Commerce, Bengaluru 560054, Karnataka, India; vinutha Gowda@yahoo.co.in
* Correspondence: tharasaraswathi@bub.ernet.in; Tel.: +98-80-601-063

Abstract: Endophytic fungi Cladosporium cladosporioides (F1-MH810309) and Cladosporium tenuissimum (F2-MN715834) from the leaf of wild Cymbopogon martinii (MT90507) were isolated and selected based on the persistent occurrence during different seasons of the year. They were identified based on the morphological features and molecular characterization (ITS sequence), and later deposited at NCBI. Phytochemical studies on F1, F2 and host extracts showed the presence of alkaloids, flavonoids, phenols, terpenoids and tannins. The GC-MS of F1 extract (control) under the axenic condition revealed compounds like hexadecane, heptadecane, 2,4-Diter-butylpheno1, E-14 hexadecanol, geraniol, geranyl acetate and cubenol similar to the host. The GC-MS of F2 extract (control) revealed metabolites that were unique. Further, both F1 and F2 were cultured in the supplementation of different concentrations (5%, 10%, 15% and 20%) of the host plant extract (an-axenic condition). The GC-MS of F1 extracts (test) did not show any growth. These compounds such as hydroxymenthol, nor-borneol, cedralacetate, α-cyclogeraniol, campesterol, β-cyclogeraniol, linalool oxide, 2,3-boranol, citronellyltiglate and 2,3-pinanol were produced in a minor quantity and were known as biotransformed forms of the precursor compounds present in the host extract. In comparison, only F1 was able to produce terpenoids similar to the host species both in axenic and an-axenic conditions. Hence from the current study, the endophytic fungus F1 isolated from wild C. martinii for the first time can serve as a better resource for the bioprospection of an important terpenoid and its metabolites.

Keywords: Cymbopogon martinii; endophytic fungi; Cladosporium cladosporioides; Cladosporium tenuissimum; terpenoids; biotransformation

1. Introduction

Cymbopogon martinii (Roxb.) commonly called “Rosha” grass belongs to the Rusae series and serves as an important species of Cymbopogon, yielding essential oil rich in geraniol [1,2]. The species is found widely distributed in south India and exists in two distinct forms referred to as “motia and sofia” varieties producing quality essential oil [3,4]. The essential oil of C. martinii possesses significant traditional medicinal properties and finds extensive usage in the treatment of rheumatism, arthritis, lumbago and spasms past from ancient times [5]. Furthermore, because of its potential activity it is used in preventing chronic diseases like cancer, diabetes and coronary heart diseases as well as showing antimicrobial, antifungal, antiviral, anthelmintic, antioxidant and cytotoxicity [6,7]. These compounds are produced against biotic and abiotic stress and help in defense mechanisms, communication and attracting pollinators [8]. The essential oil compounds of C. martinii have been extensively used in aromatic industries in the prepa-
ration of perfumes, soaps, cosmetics, food and beverage industries. These essential oil compounds show high biodegradability, volatility and negligible toxicity and are replacing the synthetic metabolic compounds in aromatic industries [9]. Even the extracts of Cymbopogons have been known to possess biological activities such as antimicrobial, antioxidant, anti-hypercholesterolaemic potential, and anti-inflammatory and antimutagenic activities [10–12] and are commonly used in food preservation, pharmaceuticals and natural medicines [13].

Wild plants species growing in typical agro-geo climatic conditions offer unique niches and lodge a variety of fungi within them [14]. These large groups of endophytic fungi are ubiquitously found asymptotically associated with the plant tissues during their life cycle without negatively affecting the host [15–17] and are variable depending on components, plant genotype, growth stage, physiological status, tissue type and other environmental conditions [18]. They help the host plant adopt to various biotic and abiotic stresses and produce secondary metabolites including alkaloids, flavonoids, phenols, phenylpropanoids, quinines, indole derivatives, steroids, amines and terpenoids maintaining specific bioactivities [15,19,20]. The endophytic fungi associated with the host are identified using traditional taxonomic means and molecular tools like flanking internal transcribed spacers (ITS). They are also known to be a repository of secondary metabolites [17,21] possessing various biological activities, which are used in pharmaceutical applications [22,23].

The association of endophytic fungi with aromatic and medicinal plants is considered to be the prominent source for producing volatile organic or terpenoid compounds [24,25] and they show potential bioactivity and are hence used in pharmaceutical industries [26,27]. The biosynthetic potential of endophytes in producing terpenoid compounds similar to the host plant has gained a lot of commercial importance. Some of the known terpenoid compounds such as Taxol, HupA, 2-Carene, 5,8-diol, bisabolene and cadinene are produced from endophytic fungi along with other secondary metabolites [28,29]. A more intriguing and inexplicable issue with many endophytes that has to be critically evaluated is their ability to produce host metabolites, which can be harnessed on a large scale for potential use in diverse areas [19]. In the present study, the endophytic fungi isolated from wild Cymbopogon martinii were studied for the biogenesis of common terpenoid compounds between them and the biotransformation of plant metabolites into commercially useful terpenoids.

2. Materials and Methods

2.1. Collection and Authentication of Plant

The wild genotype of Cymbopogon martinii was collected from Devarayana Durga hills, Tumkur, Karnataka. The plant was identified and authenticated from Regional Ayurveda Research Institute for Metabolic Disorders (RARIMD), Ministry of AYUSH, Bengaluru, under the accession no. SMPU/RARIMD/BNG/2019-20/352/RRCBI-1052. The herbarium (AC-25/2021) and seeds were deposited at ICAR- National Bureau of Plant Genetic Resources (NBPRGR), Pusa, New Delhi and the DNA barcoding sequence of the plant was deposited in GenBank NCBI under accession no. MT90507.

2.2. Plant Extraction Method

The powdered leaf sample (50 g) of the plant was mixed with 150 mL ethyl acetate solvent and kept in a shaker at 120 rpm for 48 h. The extract was filtered through Whatman filter paper grade no. 1. The filtrate obtained was dried at 40 °C using a rotary vacuum evaporator. The residue was dissolved in 1 mL of ethyl acetate and the extract was used for the GC-MS analysis. Furthermore, the powdered leaf (50 g) of the plant was used as the host plant extract for supplementing in the broth culture of endophytic fungi by subjecting it to 48 h of shaking in distilled water and filtering it through Whatman filter paper grade no. 1.
2.3. Isolation and Characterization of Endophytic Fungi

The leaf samples of wild *C. martinii* were collected and rinsed in distilled water, blot dried and cut into small pieces (10–15 mm length). The leaves were surface sterilized by immersing in Tween-20 for 5 min, followed by two times wash with distilled water; 70% ethanol (3 min), two times wash with distilled water; 4% sodium hypochlorite solution (3 min) and washed thoroughly 4–5 times with distilled water to remove traces of surfactants [30]. The edges of the leaves were trimmed and placed onto the petri plates containing potato dextrose agar (PDA) media and incubated at room temperature for 8–9 days. The endophytic fungi emerging after fourteen days in the culture media were transferred to fresh PDA to obtain the pure culture. The morphological characters of the endophytic fungi were studied based on the macroscopic and microscopic observations.

2.4. Characterization of Endophytic Fungi

The genomic DNA extraction from endophytic fungi was carried out by following the [31]. Extracted DNA was subjected to PCR amplification using forward (ITS1-F CTTG-GTCATTAGAGGAAGTAA) and reverse (ITS4-R TCCGTAGGTGAACCTGCGG) primers. The PCR products were run on agarose gel (0.8%) and the bands were purified using the Nucleo-pore PCR Clean-up Gel Extraction kit (Genetix Biotech Asia Pvt. Ltd., Delhi, India). The amplified DNA was subjected to sequencing using the 3130XL genetic analyzer (Applied Biosystems, Waltham, MA, USA). The DNA sequences of endophytic fungi were aligned using Clustal W and Bio Edit tool version 7.0 and the phylogenetic tree was constructed. The DNA sequences of endophytic fungi were deposited in the NCBI Gen Bank.

2.5. Extraction of Secondary Metabolites

The endophytic fungi were mass cultured using 250 mL of potato dextrose broth (PDB) without supplementing the host plant extract (control—axenic culture) and incubated at room temperature for 21 days under static conditions. The broth culture was filtered through Whatman filter paper grade no. 1 and the filtrate obtained was subjected to extraction using ethyl acetate as the solvent system (1:2). The mixture was subjected for 20 min and was kept aside until two immiscible layers were formed. The ethyl acetate layer was collected using a separating funnel. The extract was concentrated under reduced pressure and evaporated to dryness at 40 °C using the rotary vacuum evaporator, further mixed with 1 mL of ethyl acetate before storing at 4 °C.

The endophytic fungi supplemented with host plant extract (test—an-axenic culture) (5%, 10%, 15% and 20%), were mass cultured using 250 mL of PDB medium under static conditions and incubated at room temperature for 21 days. The broth culture was filtered through Whatman filter paper grade no. 1 and the filtrate obtained was subjected to extraction using ethyl acetate as the solvent system (1:2). The mixture was subjected to mixing for 20 min and was kept aside until two immiscible layers were formed. The extract was concentrated under reduced pressure and evaporated to dryness at 40 °C using the rotary vacuum evaporator and mixed with 1 mL of ethyl acetate before storing at 4 °C. The experiments were conducted in three replicates.

2.6. Phytochemical Analysis

The plant and fungal extracts (F1 and F2) were analyzed for the presence of phytochemical compounds using standard methods [32,33] and screened for the presence of secondary metabolites.

Alkaloids (Wagner’s reagent): About 1 mL plant extract was treated with 4–5 drops of Wagner’s reagent and observed for the formation of a reddish-brown precipitate. Wagner’s reagent is a mixture of 1.27 g of iodine and 2 g potassium iodide in 100 mL of water [34].

Tannins: The fungal crude extract was treated with alcoholic FeCl3 reagent. A bluish-black color, which disappears on the addition of a drop of dilute H2SO4 was followed by the formation of yellowish-brown precipitate [35].
Saponins (foam test): About 6 mL of water was added to 2 mL of extract in a test tube. The mixture was shaken vigorously and observed for the formation of persistent foam confirming saponins’ presence [36].

Terpenoids (Salkowski’s test): About 1 mL of chloroform was added to 2 mL of extract. A reddish-brown precipitate is formed immediately on the addition of a few drops of concentrated HCl [37].

Quinones: About 2 mL of the fungal extract was treated with concentrated HCl. The formation of yellow precipitate or coloration indicated the presence of quinones [38].

Phenols: About 2 mL of fungal extract was taken and mixed with aqueous 5% FeCl₃ and observed for deep blue or black color formation [39].

Flavonoids: About 0.5 mL of crude extract was taken in a test to which 5–10 drops of diluted HCl and a small piece of zinc were added and the solution was boiled for a few minutes. Reddish-pink or brown color precipitate indicates the presence of flavonoids [40].

2.7. Gas Chromatography and Mass Spectroscopy-(GC-MS)

The GC-MS analysis of the extracts of endophytic fungi and the host plant was carried out at Kerala Forest Research Institute (KFRI), Kerala. The analysis was carried out on Shimadzu GC-MS gas chromatogram QP2010S using two capillary columns (0.25 mmID), one coated with dimethylsiloxane and the other with Carbowax 30M. Nitrogen was used as a carrier gas at 65.2 kpa inlet pressure and organized the temperature between 26 to 28 °C for 6 °C/min under the dimethylsiloxane column. The split ratio used was 1:50. Helium was used as a carrier gas (1 mL/min) along with the ion source temperature of 20 °C. The identification of the compounds was made by analogizing the relative retention indices of the peaks with literature data ±10 and peak development co-injection with authentic original samples. Mass spectral data were compared against NIST05 (National Institute of Standards and Technology, Washington, DC, USA), WILEY 8 and FFNSCI.3 (Flavour and Fragrance Natural and Synthetic Compounds) libraries for the identification of bioactive compounds.

3. Results

3.1. Isolation and Identification of Endophytic Fungi

A total of eight isolates of endophytic fungi such as Alternaria species, Aspergillus species, Fusarium species, Trichoderma species, Curvularia species and Cladosporium species were isolated from the inoculants at different seasons of the year. Of the eight isolates, two endophytic fungi such as Cladosporium cladosporioides (F1) and Cladosporium tenuissimum (F2) were isolated consistently at different seasons of the year and hence selected for further studies. The morphological studies and molecular characterization confirmed that the fungi were the Cladosporium species belonging to the Dothideomycetes group of Cladosporiaceae family. Endophytic fungi F1 produced olivaceous colonies with diffused aerial mycelia, woolly-mat finished texture, in reverse of its olive-black color. Conidiophores were straight solitary, unbranched terminal or lateral mycelia bearing 8–9 conidia in chains. Conidia were limoniform, ovoid, light brown and aseptate. Whereas F2 produced velvety, olive grey with white margins, reversed with its reddish-white color; conidiophores were straight, solitary, unbranched, terminal mycelia bearing 3–4 conidia in chains. Conidia were limoniform, ovoid, aseptate and stained blue. The results of the ITS sequences from the genomic DNA were submitted to NCBI Gen Bank with accession nos. F1-MH810309 and F2-MN715834, respectively (Figures 1 and 2). The phylogenetic tree for the same was constructed using the Clustal W tool (Figure 3).
3.2. Phytochemical Screening of Endophytic Fungi

The phytochemical analysis of fungal extracts (F1 and F2) revealed the presence of alkaloids, flavonoids, phenols, terpenoids and tannins (Table 1).
Table 1. Phytochemical analysis of the extracts from endophytic fungi and host plant.

| Sl No. | Test        | Host Plant Extract (C. martini) | PDB (Control) (without Supplementation of Plant Extract) | PDB (Test) (with Supplementation of Plant Extract) |
|--------|-------------|---------------------------------|--------------------------------------------------------|---------------------------------------------------|
|        |             |                                 |  Cladosporium cladosporioides (F1)                      |  Cladosporium tenuissimum (F2)                       |  Cladosporium cladosporioides (F1)                      |
| 1      | Alkaloid    | +ve                             | +ve                                                    | +ve                                                | +ve                                                |
| 2      | Flavonoid   | +ve                             | +ve                                                    | +ve                                                | +ve                                                |
| 3      | Phenol      | +ve                             | +ve                                                    | +ve                                                | +ve                                                |
| 4      | Tannin      | +ve                             | +ve                                                    | −ve                                                | +ve                                                |
| 5      | Terpenoid   | +ve                             | +ve                                                    | +ve                                                | +ve                                                |
| 6      | Quinine     | +ve                             | −ve                                                    | −ve                                                | −ve                                                |
| 7      | Essential oil | +ve                           | +ve                                                    | −ve                                                | +ve                                                |

(+) Presence, (−) Absence.

3.3. Analysis of Secondary Metabolites (GC-MS)

The GC-MS analysis of F1 (control—axenic culture) showed the presence of important compounds like hexadecane (19.4%), octadecane (20.99%), eicosane (10.69%), 2,4-ditert-butyl-phenol (9.34%), hexadecanal (9.01%), heptadecanal (6.78%), tricosane (5.23%), geraniol (1.2%), geranyl acetate (0.91%) and cubenol (0.39%). F2 (control—axenic culture) showed the presence of compounds like 4,5,7-trihydroxy-2-octanoic acid (42.26%), 3-(tert-butyl dimethyl silyl) oxyiminobutan-2-one (12.48%), 1,2-benzenedicarboxylic acid (6.24%), cyclo-octanone (7.01%) and hexadecane (4.59%) (Figure 4; Table 2). The GC-MS analysis of the host plant extract also revealed the presence of compounds such as geranyl acetate (21.44%), geraniol (5.45%), heptadecane (30.39%), hexadecane (10.95%), cubenol (9.81%), bornyl acetate (3.73%), tridecane (4.39%) and beta-caryophyllene epoxide (3.09%) in higher percentages along with the production of other compounds.

Figure 4. Gas chromatogram of ethyl acetate extract (a). Host plant (b). Endophytic fungus (F1) (c). Endophytic fungus (F2).
Table 2. GC-MS analysis of the extracts of endophytic fungi (F1a and F2) without supplementation of host plant extract.

| Sl No. | Compound                     | Extract of Plant C. martinii | Extract of Endophytes F1a | F2 |
|--------|------------------------------|------------------------------|---------------------------|----|
| 1      | Tetradecane                  | 2.08                         | 0.97                      | 2.12 |
| 2      | Dodecane                     | 2.88                         | -                         | -   |
| 3      | 1S-Eno-bornyl acetate        | 3.73                         | -                         | -   |
| 4      | Tridecane                    | 4.39                         | -                         | -   |
| 5      | Geraniol                     | 5.45                         | 1.2                       | -   |
| 6      | Farnesane                    | 0.34                         | -                         | -   |
| 7      | Geranyl acetate              | 21.44                        | 0.91                      | -   |
| 8      | Heptadecane                  | 30.39                        | 3.17                      | -   |
| 9      | (-)-Beta-caryophyllene       | 0.63                         | -                         | -   |
| 10     | Decane, 2,3,5,8-tetramethyl-  | 4.44                         | -                         | -   |
| 11     | Hexadecane                   | 10.95                        | 19.4                      | 4.59 |
| 12     | Gamma-cadinene               | 0.63                         | -                         | -   |
| 13     | 2-(3-Isopropenyl-4-methyl-4-vinylcyclohexyl)-2-propanol | 0.50 | - | - |
| 14     | (-)-Beta-caryophyllene epoxide | 3.09                     | -                         | -   |
| 15     | Tridecane                    | 2.07                         | -                         | -   |
| 16     | Cubenol                      | 9.81                         | 0.39                      | -   |
| 17     | (-)-Guaiol                   | 0.83                         | -                         | -   |
| 18     | Agarospirol                  | 1.79                         | -                         | -   |
| 19     | Beta-eudesmol                | 0.94                         | -                         | -   |
| 20     | Globulol                     | 3.07                         | -                         | -   |
| 21     | 2,4-Ditert-butylphenol       | -                            | 9.34                      | -   |
| 22     | E-14-Hexadecanal             | -                            | 9.01                      | -   |
| 23     | Octadecane                   | -                            | 20.99                     | -   |
| 24     | 7,9-Di-tert-butyl-1-oxaspio (4,5) deca-6,9-diene-2,8-diene | - | 2.10 | 1.40 |
| 25     | Heneicosane, 4-cyclohexyl-    | -                            | 2.20                      | -   |
| 26     | E-15-heptadecenal            | -                            | 6.78                      | -   |
| 27     | Eicosane                     | -                            | 10.69                     | -   |
| 28     | Decane 4-cyclohexyl-, 4-cyclohexyl- | - | 1.25 | - |
| 29     | Tricosane                    | -                            | 5.23                      | -   |
| 30     | 1-Heneicosanol               | -                            | 1.96                      | -   |
| 31     | Tetracosane                  | -                            | 2.28                      | -   |
| 32     | 1,2-Benzenedicarboxylic acid | -                            | 3.62                      | 6.24 |
| 33     | Cyclooctacnone               | -                            | -                         | 7.01 |
| 34     | Cycloheptanone               | -                            | -                         | 2.66 |
| 35     | 3-Methyl-2-butenoic acid, pentadecyl ester | - | - | 2.61 |
| 36     | Valeric acid, 2-pentadecyl ester | - | - | 1.21 |
| 37     | 3-(tert-Butyl dimethylsilyl) oximinobutan-2-one | - | - | 12.48 |
| 38     | Pentadecane                  | -                            | -                         | 3.12 |
| 39     | 4,5,7-Trihydroxy-2-octenoic acid | - | - | 42.26 |
| 40     | Erythro-cis (1,4), trans (1,4)-4,4-dihydroxobicyclooctyl | - | - | 9.04 |
| 41     | Nonadecane                   | -                            | -                         | 1.37 |

Test organism F1 (an-axenic culture) supplemented with different concentrations of the host plant extract (5%, 10%, 15% and 20%) produced a higher number of secondary
metabolites when compared to control (Figure 5; Table 3). With supplementation of 5 mL (5%) of the host plant extract, the fungi produced compounds such as exo-nor borneol (0.15%), cedrol acetate (2.92%), hydroxy menthol (0.11%), nonadecene (12.6%), hexadecenoic acid (20.98%), 1,4-epoxynaphthalene-1(2H)-menthol (1.63%) and more (Table 4); with 10 mL (10%) supplementation it produced 2-hydroxymenthol (0.14%), oxo-borneol (0.28%), alpha cyclo geraniol (0.4%), cetonal (0.36%), phthalic acid (14.64%), hexadecenoic acid (7.45%), campesterol (0.41%), 1,4-epoxynaphthalene-1(2H)-menthol (0.55%), gamma-elestatol (21.69%), dibutyl phthalate (11.7%) along with other compounds (Table 6); and 20 mL (20%) supplementation produced limonene (0.4%), beta-cyclo homo geraniol (0.13%), linalool oxide (0.24%), 2,3-bornanediol (1.4%), nor borneol (0.38%), 2,3-pinanediol (0.1%), epiglobulol (0.84%), di isobutyl phthalate (7.9%), hexadecenoic acid (8.03%), phthalic acid (9.23%) and citronellyl tiglate (1.11%) along with many other compounds (Table 7).

![Figure 5. Biosynthesis of monoterpenoids in Cladosporium cladosporioides (F1-MH810309) with host plant by cross-talk. The green color represents compounds produced by F1 in support of the plant extract. Orange color indicates the enzymes involved: GPP geraniol diphosphate, LS linalool synthase, GI geraniol isomerase, UN unclear reaction, ADH alcohol dehydrogenase, ORD oxidoreductase, BS bornyl synthase, BPH bornyl pyrophosphate hydrolase, AOXD asymmetric oxidase, BEDH borneol dehydrogenase, CH camphor hydroxylase, HCeDH hydroxy camphor dehydrogenase, LO limonene-3-monoxygenase, IPEDH iso-piperitenol dehydrogenase, IPRed iso-piperitone reductase, IS isomerase, PRed pulegole reductase and MEDH menthol dehydrogenase, UN unclear reaction.](image)

| Sl No. | Compound                | Area %       |
|-------|-------------------------|--------------|
|       |                         | 5 mL | 10 mL | 15 mL | 20 mL | 25 mL | 30 mL | 35 mL | 40 mL |
| 1.    | 2-Hydroxy menthol        | 0.11 | 0.14  | 0.15  | -     |       |       |       |       |
| 2.    | Nor-borneol              | 0.15 | 0.28  | -     | 0.38  |       |       |       |       |
| 3.    | Cedrane                  | 0.14 | -     | 1.06  | -     |       |       |       |       |
| 4.    | Cedral acetate           | 2.92 | -     | -     | -     | -     |       |       |       |
| 5.    | Alpha cyclo geraniol     | -    | 0.4   | -     | -     |       |       |       |       |
| 6.    | Campesterol              | -    | 0.41  | -     | -     |       |       |       |       |
### Table 3. Cont.

| Sl No. | Compound                          | Area % | 5 mL | 10 mL | 15 mL | 20 mL |
|--------|-----------------------------------|--------|------|-------|-------|-------|
| 7.     | 1,4-Epoxynaphthalene-menthol      |        |      | -     | -     | -     |
| 8.     | Elemicin                          |        |      | -     | 1.26  | -     |
| 9.     | Cetonal                           |        |      | -     | 0.35  | -     |
| 10.    | Limonene 1,2-diol                 | -      | -    | -     | -     | 0.4   |
| 11.    | Beta-cyclo homo geraniol          | -      | -    | -     | -     | 0.13  |
| 12.    | Linalool oxide                    | -      | -    | -     | -     | 0.24  |
| 13.    | 2,3-Bornanediol                   | -      | -    | -     | -     | 1.4   |
| 14.    | 2,3-pinanediol                    | -      | -    | -     | -     | 0.11  |
| 15.    | Epiglobulol                       | -      | -    | -     | -     | 0.84  |
| 16.    | Calamenene                        | -      | -    | -     | -     | 0.66  |
| 17.    | Citronellyl tiglate               | -      | -    | -     | -     | 1.11  |

### Table 4. GC-MS analysis of endophytic fungus F1 (cultured with 5 mL host extract).

| Sl No. | Compound                      | Area % | RT    |
|--------|-------------------------------|--------|-------|
| 1.     | Nonanal                       | 0.04   | 6.074 |
| 2.     | 1,3-Butanediol, diacetate     | 0.03   | 6.361 |
| 3.     | 3-tert-Butyl-2-pyrazolin-5-one | 0.06   | 8.167 |
| 4.     | Nonanoic acid                 | 0.05   | 8.292 |
| 5.     | 1-Tetradecene                 | 0.08   | 9.964 |
| 6.     | 2-hydroxy menthol             | 0.11   | 10.054|
| 7.     | Cyclohexane butanal           | 0.6    | 10.14 |
| 8.     | exo-nor borneol               | 0.15   | 10.283|
| 9.     | Phenol                        | 0.23   | 11.542|
| 10.    | Benzoic acid                  | 0.05   | 11.75 |
| 11.    | 1,7-Dioxaspiro [5.5] undec-2-ene | 0.06   | 11.918|
| 12.    | Dodecanoic acid               | 0.18   | 12.076|
| 13.    | 1-Heptadecene                 | 0.85   | 12.431|
| 14.    | Octadecane                    | 0.63   | 12.512|
| 15.    | Oxirane                       | 1.44   | 12.816|
| 16.    | Cedrane                       | 0.14   | 13.547|
| 17.    | Tridecanal                    | 0.08   | 13.859|
| 18.    | E-8-Methyl-9-tetradecen-1-ol acetate | 0.92   | 14.334|
| 19.    | 1-Nonadecene                  | 12.61  | 14.662|
| 20.    | Spiro [4.5] decan-7-one       | 0.29   | 15.334|
| 21.    | Cedrol acetate                | 2.92   | 16.019|
| 22.    | Widdrol hydroxyether          | 1.43   | 16.295|
| 23.    | n-hexa decanoic acid          | 20.98  | 16.447|
| 24.    | Oleic Acid                    | 3.32   | 17.276|
| 25.    | 1-Octadecanol                 | 0.27   | 17.568|
### Table 4. Cont.

| Sl No. | Compound                                    | Area % | RT  |
|-------|---------------------------------------------|--------|-----|
| 26.   | Octadecanoic acid                           | 7.9    | 18.307 |
| 27.   | Decanoic acid,                              | 0.37   | 19.100 |
| 28.   | 1-Tetracosanol                              | 1.38   | 20.234 |
| 29.   | Octadecanal                                 | 0.3    | 20.553 |
| 30.   | 2-palmitoyl glycerol                        | 1.72   | 21.228 |
| 31.   | 1,2-Benzenedicarboxylic acid, mono (2-ethylhexyl) | 1.32   | 21.553 |
| 32.   | 1-Triacontanol                              | 1.86   | 21.805 |
| 33.   | 10,12,14-Nonacosatriynoic acid              | 0.72   | 22.263 |
| 34.   | Abietic acid                                | 1.3    | 22.385 |
| 35.   | Retinoic acid                               | 0.43   | 22.544 |
| 36.   | Glyceryl mono acetate                       | 3.99   | 22.629 |
| 37.   | Stearin                                     | 0.97   | 22.787 |
| 38.   | Squalene                                    | 0.93   | 23.568 |
| 39.   | Corticosterone 21-acetate                  | 0.63   | 23.796 |
| 40.   | Trans-beta-Ionone                           | 0.58   | 23.934 |
| 41.   | Dehydroergosterol 3,5-dinitrobenzoate       | 0.92   | 24.848 |
| 42.   | Cholest-5-en-3-ol (3. beta)                 | 0.24   | 26.134 |
| 43.   | Cycloeucalenol                              | 0.36   | 26.73 |
| 44.   | Stigmasta-4,7,22-trien-3. alpha-ol          | 0.88   | 30.15 |
| 45.   | Hexa decanoic acid                          | 1.42   | 30.562 |
| 46.   | Rhodopin                                    | 0.83   | 31.201 |
| 47.   | 1,4-Epoxynaphthalene-1(2H)-methanol         | 1.63   | 32.554 |
| 48.   | Ergosta-8,24(28)-dien-3-ol, 14-methyl-, (3. beta,5. alpha) | 1.79   | 33.576 |

Red color indicates the compounds with high percentages. Bold indicates similar compounds present in the essential oil of the host plant. RT: retention time.

### Table 5. GC-MS analysis of endophytic fungus F1 (cultured with 10 mL host extract).

| Sl No. | Compound                                    | Area % | R Time |
|-------|---------------------------------------------|--------|--------|
| 1.    | 1-Tetradecene                               | 0.1    | 9.951  |
| 2.    | 2-hydroxymenthol                            | 0.14   | 10.041 |
| 3.    | 2-hydroxybutyl acrylate                     | 0.45   | 10.129 |
| 4.    | Oxo-borneol                                 | 0.28   | 10.271 |
| 5.    | 1-Heptadecene                               | 0.93   | 12.418 |
| 6.    | Alpha-cyclo geraniol                        | 0.4    | 14.319 |
| 7.    | 1-Nonadecene                                | 2.12   | 14.649 |
| 8.    | 2,11-Dodecadiene                            | 0.4    | 14.906 |
| 9.    | Cetonal                                     | 0.36   | 15.318 |
| 10.   | diisobutyl phthalate                        | 19.28  | 15.547 |
| 11.   | l-(-)-Ascorbic acid 2,6-dihexadecanoate     | 1.12   | 16.297 |
| 12.   | n-Hexadecanoic acid                         | 7.45   | 16.389 |
| 13.   | Dibutyl phthalate                           | 12.3   | 16.494 |
Table 5. Cont.

| Sl No. | Compound                           | Area % | R Time |
|--------|------------------------------------|--------|--------|
| 14.    | Phthalic acid,                      | 14.64  | 16.69  |
| 15.    | Oleic Acid                         | 6.87   | 18.074 |
| 16.    | Benzenedicarboxylic acid           | 2.51   | 17.017 |
| 17.    | 9-Tricosene                        | 2.52   | 18.522 |
| 18.    | 1-Tetracosanol                     | 1.22   | 20.219 |
| 19.    | 1-Triacontanol                     | 0.61   | 21.793 |
| 20.    | Oleoyl chloride                    | 0.86   | 22.617 |
| 21.    | Tetrapentacontane                  | 0.49   | 23.255 |
| 22.    | Tetracosamethyl-cyclododecasiloxane| 1.92   | 24.362 |
| 23.    | Dehydroergosterol 3,5-dinitrobenzoate| 0.36 | 24.838 |
| 24.    | Dithianone                         | 0.37   | 25.048 |
| 25.    | Cyclononasiloxane                  | 0.88   | 25.359 |
| 26.    | Stigmaster-5-en-3-ol               | 1.64   | 25.909 |
| 27.    | Isoindole-1,3(1H,3H)-dione         | 0.78   | 27.085 |
| 28.    | Campesterol                        | 0.41   | 27.241 |
| 29.    | Chondrillasterol                   | 0.57   | 27.581 |
| 30.    | gamma-Sitosterol                   | 2.22   | 28.297 |
| 31.    | 1,4-Epoxynaphthalene-1(2H)-methanol | 0.55 | 32.525 |

Red color indicates the compounds in high percentages. Bold indicates similar compounds present in the essential oil of host plant.

Table 6. GC-MS analysis of endophytic fungus F1 (cultured with 15 mL host extract).

| Sl No. | Compound                           | Area % | R Time |
|--------|------------------------------------|--------|--------|
| 1.     | Propanoic acid                     | 0.35   | 5.478  |
| 2.     | Malic acid                         | 0.18   | 5.68   |
| 3.     | Butanedioic acid                   | 0.13   | 5.856  |
| 4.     | 2-Octenoic acid                    | 0.4    | 7.513  |
| 5.     | 2-Decenoic acid                    | 11.95  | 9.538  |
| 6.     | 1-Tetradecene                      | 0.12   | 9.958  |
| 7.     | 2-Hydroxymenthol                   | 0.15   | 10.05  |
| 8.     | Elemicin                           | 1.26   | 12.069 |
| 9.     | 1-Hexadecanol                      | 1.46   | 12.438 |
| 10.    | Cyclodecanamine                    | 3.46   | 12.629 |
| 11.    | D-Galactose                        | 0.54   | 12.945 |
| 12.    | Cedrane                            | 0.1    | 13.547 |
| 13.    | 9,10-Dimethyltricyclo [4.2.1.1(2,5)]decane-9,10-diol | 0.87 | 14.333 |
| 14.    | 1-Nonadecene                       | 1.54   | 14.658 |
| 15.    | 2-Cyclohexen-1-one                 | 0.18   | 14.83  |
| 16.    | 3alpha,7 beta-Dihydroxy-5 beta,6 beta-epoxycholestone | 0.1  | 15.127 |
| 17.    | 6-Isopropenyl-4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-naphthalen-2-ol | 0.04 | 15.24  |
| Sl No. | Compound                          | Area % | R Time   |
|-------|-----------------------------------|--------|----------|
| 18.   | Cetonal                           | 0.35   | 15.327   |
| 19.   | Di isobutyl phthalate             | 7.35   | 15.556   |
| 20.   | Phthalic acid                     | 21.69  | 16.236   |
| 21.   | n-Hexadecanoic acid               | 9.16   | 16.417   |
| 22.   | Dibutyl phthalate                 | 11.78  | 16.505   |
| 23.   | Oleic acid                        | 7.73   | 17.261   |
| 24.   | Acetophenone                      | 0.49   | 18.384   |
| 25.   | Pentaerythritol tetrachloride     | 0.36   | 18.815   |
| 26.   | 4-Bromobutanoic acid              | 0.29   | 19.057   |
| 27.   | Pentaerythritol tetrachloride     | 0.91   | 19.826   |
| 28.   | 1-Tetracosanol                    | 0.36   | 20.226   |
| 29.   | Carbamazepine                     | 0.33   | 20.651   |
| 30.   | 1-Triacontanol                    | 0.55   | 21.795   |
| 31.   | glyceryl mono oleate              | 2.36   | 22.621   |
| 32.   | 1-Hexacosanol                     | 0.35   | 23.255   |
| 33.   | 1-Nonadecene                      | 2.01   | 18.53    |

Red color indicates the compounds in high percentages. Bold indicates similar compounds present in the essential oil of host plant.

| Sl No. | Compound                                      | Area % | R Time   |
|-------|-----------------------------------------------|--------|----------|
| 1.    | Glycerine                                      | 0.11   | 4.264    |
| 2.    | 2-Nonadecanone                                 | 0.13   | 7.756    |
| 3.    | Limonene glycol or P-menth-8-ene               | 0.4    | 9.191    |
| 4.    | Beta-cyclohexomo geraniol                      | 0.13   | 9.487    |
| 5.    | Linalool oxide                                 | 0.24   | 9.56     |
| 6.    | 2,3-Bornanediol                                | 1.4    | 10.046   |
| 7.    | Cyclohexanebutanal                             | 1.15   | 10.146   |
| 8.    | 2-Norborneol                                   | 0.38   | 10.278   |
| 9.    | Alpha-campholene aldehyde                      | 0.18   | 10.418   |
| 10.   | Lomustine                                      | 0.13   | 10.637   |
| 11.   | Cyclohexanol                                   | 0.14   | 10.754   |
| 12.   | 10-Methyl-8-tetradecen-1-ol acetate            | 0.18   | 11.021   |
| 13.   | 4-Nonanone                                     | 0.22   | 11.245   |
| 14.   | Benzoic acid, 4-ethoxy-, ethyl ester           | 0.11   | 11.742   |
| 15.   | 1,7-Dioxaspiro [5,5] undec-2-ene               | 0.58   | 11.908   |
| 16.   | 1-Heptadecene                                  | 1.12   | 12.427   |
| 17.   | 6-Acetyl-4,4,7-trimethylbicyclo [4.1.0] heptan-2-one | 0.42 | 12.735 |
| 18.   | 2,3-pinanediel                                 | 0.1    | 13.03    |
| 19.   | Bicyclo(3.1.1)heptane-2,3-diol, 2,6,6-trimethyl- | 0.67   | 13.544   |
| 20.   | 1H-Benzocyclohepten-7-ol, 2,3,4,4a,5,6,7,8-octahydro-1,1,4a,7-tetramethyl- | 0.23   | 14.18    |
Table 7. Cont.

| Sl No. | Compound                                                                 | Area % | R Time  |
|--------|---------------------------------------------------------------------------|--------|---------|
| 21.    | 1-Cyclohexanone; 2-methyl-2-(3-methyl-2-oxobutyl)                         | 7.3    | 14.337  |
| 22.    | 1-Nonadecene                                                             | 3.41   | 14.662  |
| 23.    | 2,5,9-Tetradecatriene; 3,12-diethyl-                                     | 0.23   | 14.839  |
| 24.    | 2-Dodecen-1-y 1 ( ) succinic anhydride                                    | 1.57   | 14.998  |
| 25.    | Epiglobulol                                                              | 0.84   | 15.131  |
| 26.    | 6-Isopropenyl-4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-                   | 1.28   | 15.246  |
|        | naphthalen-2-ol                                                          |        |         |
| 27.    | Spiro [4,5] decan-7-one; 1,8-dimethyl-8,9-epoxy-4-isopropyl-              | 0.42   | 15.326  |
|        | Ditosobutyl phthalate                                                    | 7.91   | 15.556  |
| 28.    | 3-Methyl-5-(1,4,4-trimethylcyclohex-2-enyl) pentan-1-ol                   | 1.72   | 15.666  |
| 29.    | Calamene                                                                 | 0.66   | 15.780  |
| 30.    | 2,6-Bis-(acetamido)-pyridine                                             | 0.93   | 16.115  |
| 31.    | Phthalic acid, isobutyl 2-pentyl ester                                   | 1.21   | 16.231  |
| 32.    | Widdrol hydroxyether                                                     | 3.35   | 16.302  |
| 33.    | n-Hexadecanoic acid                                                      | 8.03   | 16.429  |
| 34.    | Dibutyl phthalate                                                        | 4.65   | 16.504  |
| 35.    | 1,2-Benzenedicarboxylic acid, butyl decyl ester                          | 1.53   | 16.579  |
| 36.    | Phthalic acid, isobutyl octadecyl ester                                  | 9.23   | 17.097  |
| 37.    | 2,4,7,14-Tetramethyl-4-vinyl-tricyclo [5.4.3.0(1,8)]t                   | 1.38   | 17.274  |
| 38.    | 1,2-Benzenedicarboxylic acid, butyl 8-methylnonyl ester                  | 0.79   | 17.024  |
| 39.    | 2-naphthalene butanoic acid                                              | 5.94   | 17.161  |
| 40.    | 2-Methyl-5-(2,6,6-trimethyl-cyclohex-1-enyl)-pentane-2,3-diol            | 0.35   | 17.336  |
| 41.    | Phthalic acid, isobutyl 2-pentyl ester                                   | 0.56   | 17.416  |
| 42.    | 2-[4-methyl-6-(2,6,6-trimethylcyclohex-1-enyl)-                        | 1.11   | 17.516  |
|        | hexa-1,3,5-triencyl][cy                                               |        |         |
| 43.    | Citronellyl tiglate                                                      | 1.11   | 17.761  |
| 44.    | Oleic acid                                                               | 5.41   | 18.110  |
| 45.    | Octadecanoic acid                                                       | 1.68   | 18.288  |
| 46.    | Benzo[b]dihydropyran, 6-hydroxy-4,4,5,7,8-pentamethyl-                  | 1.6    | 18.390  |
| 47.    | 1-Tricosanol                                                             | 2.78   | 18.529  |
| 48.    | Beta-sitosterol                                                          | 0.17   | 18.867  |
| 49.    | 1-Tetrascano              | 1.67 | 20.226  |
| 50.    | Oxirane, hexadecyl                                                      | 0.15   | 20.546  |
| 51.    | Hexadecanoic acid,                                                      | 0.41   | 21.223  |
| 52.    | 1,2-Benzenedicarboxylic acid,                                           | 3.68   | 21.548  |
| 53.    | 1-Triacontanol                                                          | 1.06   | 21.795  |
| 54.    | 10,12,14-Nonacosatriynoic acid                                          | 0.24   | 22.259  |
| 55.    | Glyceryl monooleate                                                     | 1.73   | 22.620  |
| 56.    | 1-Hexacosanol                                                           | 0.77   | 23.252  |
| 57.    | 2,6,10,14,18,22-Tetracosahexaene, 2,6,10,15,19,23-hexamethyl-            | 0.21   | 23.559  |
Table 7. Cont.

| Sl No. | Compound | Area % | R Time |
|--------|----------|--------|--------|
| 59.    | Dehydroergosterol 3,5-dinitrobenzoate | 0.44   | 24.836 |
| 60.    | 9,19-Cycloergost-24(28)-en-3-ol, 4,14-dimethyl- | 0.18   | 26.716 |
| 61.    | Ergosta-5,8,22-trien-3-ol, (3 beta,22E) | 0.54   | 27.008 |
| 62.    | Anthraergostetraenol | 0.13   | 27.239 |
| 63.    | Stigmasta-7,25-dien-3-ol, (3 beta, 5 alpha) | 0.11   | 27.831 |
| 64.    | 17-Pentatriacontene | 0.14   | 28.588 |
| 65.    | Rhodopin | 0.96   | 31.174 |
| 66.    | 1,4-Epoxynaphthalene-1(2H)-methanol, 4,5,7-tris(1,1-dimethylethyl)-3 | 0.72   | 32.520 |
| 67.    | Cholesta-8,14-dien-3-ol, 4,4-dimethyl- | 0.43   | 33.532 |

Red color indicates the compounds in high percentages. Bold indicates similar compounds present in the essential oil of host plant.

4. Discussion

During the present study, six endophytic fungal species like *Alternaria*, *Aspergillus*, *Fusarium*, *Trichoderma*, *Curvularia* and *Cladosporium* were isolated from wild *Cymbopogon martinii* (MT90507). Furthermore, the Cladosporium species were studied (*C. cladosporioides* and *C. tenuissimum*) based on their consistent growth throughout the year. The *C. cladosporioides* is also reported as endophytic fungi in the genus *Cymbopogon* such as *C. citratus*, *C. flexuosus* and *C. caesius* [41,42] expressing tremendous ecological adaptability [43].

The phytochemical analysis of *C. cladosporioides* (F1) and *C. tenuissimum* (F2) showed the presence of secondary compounds belonging to alkaloids, flavonoids, phenols, terpenoids and tannins which are similar to those of the host plant (wild *C. martinii*). The GC-MS analysis of ethyl acetate extracts of endophytic fungi F1 and F2 (control-without adding host plant extract) revealed the presence of compounds like 1-octen-3-ol, 3-methyl-1-butanol, hexanol, trans-2-octanol and hexadecanol in similarity with the host plant extract. These compounds are known to possess antimicrobial, anti-inflammatory and antioxidant activities [44]. Sharing of the above mentioned similar secondary metabolite compounds between endophytic fungi and the host plant has been reported earlier [9,45]. Likewise, common compounds were shared between endophytic fungi F1 (control) and the host plant such as octadecane, eicosane, hexadecane, heptadecane and 2,4-ditert-butyl phenol coming under alkanes producing in higher percentages along with the production of geranyl acetate, cubenol and geraniol belonging to monoterpenoids. The production of such an alkane group of compounds has been reported in endophytic fungi including also *C. cladosporioides* and *C. tenuissimum* and these are known to possess potential biological activities [46–48]. Under in vitro conditions, the endophytic fungus F1 having a pre-existing terpenoid pathway could produce compounds similar to that of the host plant. The transcriptome studies made on endophytic fungus *C. cladosporioides* expressed the presence of a pathway for terpenoid biosynthesis [49–51].

The endophytic fungus F1 (test) produced a large number of plant derived secondary metabolites belonging to hydrocarbons, hydrocarbons esters and monoterpenoid. There are reports on *C. cladosporioides* as endophyte producing compounds belonging to a monoterpenoid group [26,52–55]. Studies made on *C. cladosporioides* isolated from *Taxus brevifolia*, *T. baccata*, *H. serrata* and Tobacco species expressed the production of monoterpenoid compounds similar to that of host plants [28,29,56,57]. Supplementation of the host plant extract at different concentrations (5–20%) to broth culture resulted in variation in monoterpenoid compound production in the endophytic fungi (Table 3). The F1 (test) might utilize the precursor components from the host plant extract and convert them into biotransformed monoterpenoid compounds (Figure 5), and similar studies have been made earlier (Vijay Lakshmi et al., 2019, 56). These monoterpenoid compounds were produced in low percent-
ages due to the poor catalytic activity of plant derived enzymes in the endophytic system (Sun et al., 2019). The monoterpenoid compounds and their precursors are known to express antioxidant, anticancer and antimicrobial activities [7,58,59]. The present study revealed that the endophytic fungus F1\(^1\) (C. cladosporioides) and the host plant share common Mevalonate (MVA) and Phenylpropanoid (PP) pathways as also documented in earlier studies [7,50].

The endophytes show a strong relationship and long-term association with the host plant and thus mimic the plant for secondary metabolite production [60]. The relationship shared between endophyte and plant could lead to coevolution and adaptation [61], which results in horizontal gene transfer, establishes cross-talk between gene clusters and helps in the biosynthesis of common terpenoid compounds [43,51,62]. There are several reports on revealing the capability of C. cladosporioides for adaptation within the host plant environment thus producing secondary metabolites similar to the host plant [9,21,43,63,64]. The in vitro cultured endophytic fungus F2 (C. tenisimum) could not produce secondary metabolites similar to F1 (C. cladosporioides) or the host plant as the metabolites were produced for their basic survival activity within the host system and thus were not involved in cross-talk with the plant [65].

In the current study, the endophytic fungus F1 has expressed high adoptability and a stronger relationship with the wild genotype of C. martinii and has been successful in producing secondary metabolites similar to the host plant. Further, the mechanism of the molecular interactions happening during secondary metabolite production between endophytic fungi and the host plant needs elaborate studies using ‘omic’ approaches. The interaction of the endophytic fungi with the host plant explains the vital activities taken up by the sessile natured plant.

Author Contributions: H.J. wrote the original manuscript. V.M. contributed for tables, figures and manuscript editing. K.J.T.S. revised the whole manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research did not receive any specific grant from any funding agencies in public, commercial, or not-for profit sectors.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare that they have no conflict of interest.

References
1. Bor, N.L. The genus Cymbopogon Spreng. India, Burma and Ceylon, Part. I. J. Bombay Nat. Hist. Soc. 1953, 51, 890–916.
2. Promila, P. A review on the medicinal and aromatic plant Cymbopogon martini (Roxb.) Watson (Palmarosa). Int. J. Chem. Stud. 2018, 6, 1311–1315.
3. Ashwini Murthy, A.; Thara Saraswathi, K.T. Chemical profiling of leaf extract and essential oil in wild Cymbopogon martini (Roxb.) collected from Devarayanadurga hills (Tumkur, Karnataka). Int. J. Sci. Res. Rev. 2019, 8, 1–9.
4. Smitha, G.R.; Dhaduk, H.L. A new chemotype of palmarosa [Cymbopogon martini (Roxb.) W. Watson] identified from ‘The Aravali Range’ of Rajasthan, India. Med. Plants 2018, 10, 203–209. [CrossRef]
5. Grenera. Nutrients: Lemon Grass Oil. Retrieved from Essential Oil. 2008.
6. Farh, M.E.; Jeon, J. Roles of fungal volatiles from perspective of distinct lifestyles in filamentous fungi. Plant Pathol. J. 2020, 36, 193–203. [CrossRef] [PubMed]
7. Chen, Y.; Hu, B.; Xing, J.; Li, C. Endophytes: The novel sources for plant terpenoid biosynthesis. Appl. Microbiol. Biotechnol. 2021, 105, 4501–4513. [CrossRef] [PubMed]
8. Pagare, S.; Bhatia, M.; Tripathi, N.; Pagare, S.; Bansal, Y.K. Secondary metabolites of plants and their role: Overview. Curr. Trends Biotechnol. Pharm. 2015, 9, 293–304.
9. Roy, S.; Banerjee, D. Volatile Organic Compounds from Endophytic fungi. In Recent Advance in White Biotechnology through Fungi, Fungal Biology; Springer: Cham, Germany, 2019; pp. 149–176.
10. Singh, A.; Singh, D.K.; Kharwar, R.N.; White, J.F.; Gond, S.K. Fungal endophytes as efficient sources of plant-derived bioactive compounds and their prospective applications in natural product drug discovery: Insights, avenues and challenges. *Microorganisms* 2021, 9, 197. [CrossRef] [PubMed]

11. Shah, G.; Shri, R.; Panchal, V.; Sharma, N.; Singh, B.; Mann, A.S. Scientific basis for the therapeutic use of *Cymbopogon citratus*, stap (lemon grass). *J. Adv. Pharm. Technol. Res.* 2011, 2, 3–8. [CrossRef]

12. Singh, R.P.; Sharad, S.; Kapur, S. Free radicals and oxidative stress in neurodegenerative diseases: Relevance of dietary antioxidants. *J. Indian Acad. Clin. Med.* 2004, 5, 218–225.

13. Balakrishnan, B.; Paramasivam, S.; Aruilkumar, A. Evaluation of the lemongrass plant (*Cymbopogon citratus*) extracted in different solvents for antioxidant and antibacterial activity against human pathogens. *Asian Pac. J. Trop. Dis.* 2014, 4, 134–139. [CrossRef]

14. Rodriguez, R.J.; Henson, J.; Van Volkenburgh, E.; Hoy, M.; Wright, L.; Beckwith, F.; Kim, Y.O.; Redman, R.S. Stress tolerance in plants via habitat-adapted symbiosis. *ISME J.* 2008, 2, 404. [CrossRef]

15. Ali, S.; Duan, J.; Charles, T.C.; Glick, B.R. A bioinformatics approach to the determination of genes involved in endophytic behavior in Burkholderia spp. *J. Theor. Biol.* 2014, 343, 193–198. [CrossRef] [PubMed]

16. Gouda, S.; Kerry, R.G.; Das, G.; Paramithiotis, S.; Shin, H.S.; Patra, J.K. Revitalization of plant growth-promoting rhizobacteria for sustainable development in agriculture. *Microbiol. Res.* 2016, 206, 131–140. [CrossRef] [PubMed]

17. Chowdappa, S.; Jagannath, S.; Konappa, N.; Udayashankar, A.; Jogaiah, S. Udayashankar and Sudisha Jogaiah. Detection and Characterization of antibacterial siderophores secreted by endophytic fungi from *Cymbopogon citratus*. *Biomolecules* 2020, 10, 1412. [CrossRef]

18. Ganjewala, D.; Gupta, A.K. Lemongrass (*Cymbopogon flexuosus*). Stud. Wats essential oil: Overview and biological activities. *Recent Prog. Med. Plants* 2013, 37, 235–271.

19. Khare, E.; Mishra, J.; Arora, N.K. Multifaceted interactions between endophytes and plant: Developments and prospects. *Front. Microbiol.* 2018, 9, 2732. [CrossRef] [PubMed]

20. Potshang Bam, M.; Devi, S.I.; Sahoo, D.; Strobel, G.A. Functional characterization of endophytic fungal community associated with *Oryza sativa* L. and *Zea mays* L. *Front. Microbiol.* 2017, 8, 325. [CrossRef]

21. Morath, S.U.; Hung, R.; Bennett, J.W. Fungal volatile organic compounds: A review with emphasis on their biotechnological potential. *Fungal Biol. Rev.* 2012, 30, 73–83. [CrossRef]

22. Strobel, G.; Daisy, B. Bioprospecting for microbial endophytes and their natural products. *Microbiol. Mol. Biol. Rev.* 2003, 67, 491–502. [CrossRef]

23. Gouda, S.; Das, G.; Sen, S.K.; Shin, H.-S.; Patra, J.K. Endophytes: A treasure house of bioactive compounds of medicinal importance. *Front. Microbiol.* 2016, 7, 1538. [CrossRef] [PubMed]

24. Luftia, A.; Munir, E.; Yurnalova, Y.; Basyuni, M. Chemical analysis and anticancer activity of sesterterpenoid from an endophytic fungus *Hypomontagnella monticulosa* Zg15SU and its host *Zingiber officinale* Baker. *Heliyon* 2021, 7, e06292. [CrossRef]

25. Kusari, S.; Zühlke, S.; Spiteller, M. An endophytic fungus from *Cinnamomum camphora* var. borneol. *China J. Chin. Mater. Med.* 2011, 36, 3217–3221. [CrossRef]

26. Steriel, A.; Steriel, D.; Steriel, S. Bioactive compounds from four endophytic *Penicillium* sp. of a northwest pacific yew tree. *Nat. Prod. Chem.* 2000, 24, 933–977.

27. Zhu, D.; Wang, J.; Zeng, Q.; Zhang, Z.; Yan, R. A novel endophytic Huperzine A-producing fungus *Shiria* sp. SLf14, isolated from *Huperzia serrata*. *J. Appl. Microbiol.* 2010, 109, 1469–1478. [CrossRef]

28. Kasea, A.; Mobini-Dehkordi, M.; Mahjoubi, F.; Saffar, B. Isolation of Taxol-producing endophytic fungi from Iranian yew through novel molecular approach and their effects on human breast cancer cell line. *Curr. Microbiol.* 2017, 74, 702–709. [CrossRef]

29. Pimentel, I.C.; Glienke-Blanco, C.; Gabardo, J.; Stuart, R.M.; Azevedo, J.L. Identification and colonization of endophytic fungi from soybean (*Glycine max*) under different environmental conditions. *Braz. Arch. Biol. Technol.* 1998, 49, 705–711.

30. Landum, M.C.; do Rosário Félix, M.; Alho, J.; Garcia, R.; Cabrita, M.J.; Rei, F. Antagonistic activity of fungi of *Olea europaea* L. against *Calletotrichum acutatum*. *Microbiol. Res.* 2016, 183, 100–108. [CrossRef] [PubMed]

31. Sofowora, A. *Medicinal Plants and Traditional Medicine in Africa*, 2nd ed.; Scientific Research; Spectrum Books Limited: Ibadan, Nigeria, 1993; pp. 1–153.

32. Harborne, A.J. *Phytochemical Methods—A Guide to Modern Techniques of Plant Analysis*; Springer Science & Business Media: Dordrecht, The Netherlands, 1973.

33. Danmalam, U.H.; Hanwa, U.A.; Abdurrazak, A.; Hassan Maidoki, A.L.; Ambi, A.A. Phytochemical analysis of some crotalaria species growing in Samaru-zaria, Nigeria for the presence of pyrrolizidine alkaloids. *Trends Sci. Technol.* 2017, 2, 1035–1037.

34. Desire, M.H.; Bernard, F.; Forsah, M.R.; Assang, C.T.; Denis, O.N. Enzymes and qualitative phytochemical screening of endophytic fungi isolated from Lantana camara Linn. *J. Appl. Biol. Biotechnol.* 2014, 2, 1–6.

35. Escrivan, J.; Cabanes, J.; Jiménez-Atiénzar, M.; Ibáñez-Tremolada, M.; Gómez-Pando, L.R.; García-Carmona, F.; Gandía-Herrero, F. Characterization of betalains, saponins and antioxidant power in differently colored quinoa (*Chenopodium quinoa*) varieties. *Food Chem.* 2017, 234, 285–294. [CrossRef]
