Secondary metabolites from endophytic fungus from *Lippia sidoides* Cham.

Talita Pereira de Souza Ferreira¹*, Gil Rodrigues dos Santos², Ilsamar Mendes Soares¹, Sergio Donizeti Ascêncio³, Tarso da Costa Alvim⁴, Chrystian de Assis Siqueira¹ and Raimundo Wagner de Souza Aguiar¹

¹Bioprocess Engineering and Biotechnology, Federal University of Tocantins, University Campus of Gurupi, 77410-530 Gurupi, TO, Brazil.
²Agronomic Engineering, Federal University of Tocantins, University Campus of Gurupi, 77410-530 Gurupi, TO, Brazil.
³Medicine, Federal University of Tocantins, University Campus of Palmas, 77001-090 Palmas, TO, Brazil.
⁴Food Engineering, Federal University of Tocantins, University Campus of Palmas, 77001-090 Palmas, TO, Brazil.

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*Lippia sidoides* Cham. (Verbenaceae) is a species native to the Brazilian northeast, widely used in popular medicine. Its leaves were used for the isolation of endophytic fungi and extraction of metabolites. Among them, three were selected according to fungitoxicity tests against the maize phytopathogenic fungus, *Curvularia lunata* (Wakker). However, the objective of this study was to identify the role of *L. sidoides* extracts associated with their endophytic fungi, necessary to reduce excess of fungicides applied on the maize crop. Metabolites were evaluated for antioxidant activity by 2,2-diphenyl-1-picrylhydrazyl (DPPH), phenols, total flavonoids and one of it endophytic fungus were evaluated for synergism (*Verticillium* sp. and plant extracts). The endophytic fungi and plant extracts evaluated for phenolic content ranged from 0.29 ± 0.05 to 96.94 ± 11.86 mgEAG/g, the content of flavonoids from 14.31 ± 1.56 to 192.33 ± 4.58 mgER/g, and antioxidant activity could only be observed for the plant extract with *EC₅₀* 81 ± 0.3%. The secondary metabolites identified by HPLC in the plant extract were catechin, quercetin, gallic acid and naringin. Naringenin, catechin, epigallocatechin gallate and quercetin were identified in the extract of the fungi viz. *Verticillium* sp. and *Fusarium* sp. Synergistic analysis between a 1:1 proportion of plant and fungal extracts has shown more efficient (79.0%) inhibition of *C. lunata*. Thus, alternative control of phytopathogenic fungi can be accomplished using plant extracts associated with their endophytic fungi, reducing the excess of fungicides applied on the maize crop.

**Key words:** *Curvularia lunata*, endophytic fungal, HPLC, extract, *Verticillium* sp., *Fusarium* sp., *Colletotrichum* sp.

**INTRODUCTION**

Endophytic fungi isolated from plants belonging to tropical regions produce more active secondary metabolites than those from temperate regions, because they are exposed to an environment of greater biodiversity (Bhardwaj et al., 2015). These fungi are recognized as important new sources of bioactive compounds for applications in agriculture, medicine, and the food industry (Yadav et al., 2014b; Sadananda et al., 2011).

Over time, some endophytic fungi have developed the ability to produce the same or similar bioactive
substances to those produced by host plants (Sharma et al., 2016). This lends a great advantage to the study of the relationships between endophytes and their host plants (Fouda et al., 2015). Nevertheless, most of the time, these valuable bioactive compounds are scarce in nature; therefore, the development of a substitute approach for their efficient production is warranted (Kusari et al., 2013).

More recent estimates based on high-throughput sequencing methods suggest that as many as 5.1 million fungal species exist (Taylor et al., 2014). The estimate of known species has almost tripled in the period between 1943 (38000 described species) and the present, amounting to an increase of more than 60000 described species (Blackwell, 2011). Accordingly, endophytes are good sources of genetic diversity and new species belonging to a large group of fungi that colonize tissues of healthy plants without causing apparent symptoms (Fatima et al., 2016). They protect plants against herbivores, insect attack, or invading pathogens by entering this mutually beneficial relationship, according to host habitat conditions (Bhardwaj et al., 2015).

Bioactive products that can be produced by endophytes can be classified as saponins, phenols, flavonoids, steroids, tannins, alkaloids, anthraquinones, terpenoids, and others (Li et al., 2015). These compounds defend the plant against phytopathogenic fungi. For example, flavonoids are well-known substances, and their production involves a variety of processes such as cell signaling, plant growth, and reproduction (Garrido-Arandia et al., 2016).

*Lippia sidoides* Cham. (Verbenaceae), also known as “rosemary pepper” is an aromatic plant of popular medicinal use found in the Caatinga region of the Brazilian Northeast (Santos et al., 2016). It presents insecticidal activity against *Tenebrio molitor* (Lima et al., 2011) and larvae of *Aedes aegypti* (Lima et al., 2013) and acaricide against *Tetranychus urticae* Koch (Soares et al., 2016). When tested against different pathogenic bacteria, such as *Staphylococcus aureus, Pseudomonas aeruginosa,* and *Escherichia coli* (Ratnaweera et al., 2015) and different fungi and yeasts, including *Candida albicans* (Premjana et al., 2016), it demonstrated a strong antimicrobial action. Thus, compounds produced by endophytic fungi of plants with recognized biological activity for biotechnological purposes can be applied in the alternative control of urban and agricultural pests (Dutta et al., 2014), in place of the toxic chemicals sold on the commercial market.

On the other hand, the *Curvularia* spot, a disease caused by the fungus *Curvularia lunata* (Wakker) Boed., has a high incidence in maize (*Zea mays* L.). Since the 1990s, it has caused economic loss in maize crop productivity in China (Gao et al., 2015) and has been progressing in recent years in Brazil (Assunção et al., 2006). The pathogen mainly infects maize leaves, leaf sheaths, and husks and causes soaked or yellow necrotic spots in the early stages, which then expand to round, oval, spindle-shaped, or strip lesions (Hou et al., 2013). The green leaf area of maize is considered the main source of photoassimilates for the plant (Akram et al., 2014) and, according to Liu et al. (2016), a loss in this source may reflect the development of the plant and the production of grains.

In this paper, the objective was the isolation and identification of the endophytic fungus from *L. sidoides*. To this end, antioxidant activity, phenols, and total flavonoids, and the evaluated metabolites were identified by HPLC. The extracts of endophytic fungi and plants were evaluated by the selective test of fungitoxicity and synergism against *C. lunata*.

**MATERIALS AND METHODS**

**Collection of the vegetal material and preparation of the vegetal extract**

*L. sidoides* from Ceará was collected in Gurupi (11°44'48"S latitude, 49°02'55" Longitude O), Tocantins, Brazil. It was then identified and deposited at the Herbarium of the Federal University of São João Del Rei under the reference number 8303. The plant material was sent to the Laboratory Integrated Pest Management of the Gurupi Campus– UFT, where the extracts were dried and obtained according to methodology of Al-Marby et al. (2016). The leaves were dried in the shade at room temperature, subsequently cut and subjected to extraction with cold solvent. Thirty grams of plant were used for 1.5 L of methanol in each extraction for a period of 7 days. After this period, the mixture was filtered and evaporated under reduced pressure to obtain the extracts.

**Cultures of endophytic fungi**

For isolation, fresh leaves of *L. sidoides* were surface washed in tap water and soap to remove impurities. As described by Banhos et al. (2014), leaves were successively immersed in 70% alcohol (1 min), 2.5% sodium hypochlorite (4 min), and 70% alcohol (30 s), followed by washing with autoclaved distilled water (6 min) and drying on sterile filter paper. After washing, 50 μL of the distilled water used in the asepsis of the plant material was removed, then this volume was added (inoculated) in a Petri dish with PDA culture medium (potato, dextrose, and agar) in order to verify the efficiency of the asepsis process. The leaves were fragmented and inoculated into 9-cm diameter Petri dishes containing PDA culture medium. To the culture medium were added 50 μg/mL tetracycline or 100 μg/mL chloramphenicol (antibiotics). For the isolation of pure cultures, sequential peaks were made in Petri dishes containing the same culture medium, using the streaking technique. Subsequently, they were stored in tubes for centrifugation with glycerol at -80°C for the

*Corresponding author. E-mail: cupufer@gmail.com. Tel: +55 63 33113571, +55 63 984621838.”

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preservation of pure cultures. For tentative identification, microscopic slides of each endophyte were prepared (Kohlmeyer and Kohlmeyer, 1972) and examined under a light microscope.

**Curvularia lunata strain**

*C. lunata* fungus was obtained from Federal University of Tocantins, in our laboratory culture collection, previously identified based on morphological and molecular characters. The initial isolation of the fungus was obtained by growth on PDA medium (39 g L\(^{-1}\)) supplemented with ampicillin (500 mg L\(^{-1}\)) for 7 days. Petri dishes were monitored daily and fungal colonies that did not present contaminants were picked and transferred onto new plates with the same culture medium.

**Extraction of secondary metabolites of endophytic fungi**

Two 7-mm diameter mycelial agar discs of the endophytes were inoculated into 200 mL of Czapek fermentation medium to which was added 100 μg mL\(^{-1}\) chloramphenicol (Piotnikov et al., 2016). After 21 days of incubation under constant stirring (120 rpm) at 28 ± 1°C, the culture fluids were separated from the mycelial masses by vacuum filtration, and the extract was obtained following the methodology of Dhankhar et al. (2012). For extractions, organic solvents such as hexane and ethyl acetate were used in order to obtain the largest number of active substances.

**Determination of total phenolic compounds**

The content of phenolic compounds of both the plant extract and three extracts of the endophytic fungi with the best results for fungitoxic activity was determined by the Folin-Ciocalteu method, according to Sánchez-Rangel et al. (2013) with modifications, where gallic acid was used as the standard. Methanol solutions of the extracts were prepared at a concentration of 1 mg mL\(^{-1}\). Then, in 15 mL vials, 0.5 mL of the extract, 5 mL of Milli-Q water, 0.5 mL of Folin-Ciocalteu reagent (1 M) and 0.5 mL of sodium carbonate were added (25%, m/v). The blank was prepared by placing 0.5 mL of distilled water in place of the Folin-Ciocalteu reagent. An analytical curve was also prepared for the standard gallic acid reagent at concentrations from 10 to 100 μg mL\(^{-1}\). For the blank (reference solution) of the curve, 50 μL of distilled water was added instead of gallic acid. All tubes were homogenized with the aid of the test tube agitator. All reactions were performed in triplicate and kept under dark incubation for 1 h. The readings were performed in a spectrophotometer (BioSpectro model SP-220) at 765 nm (Zhou et al., 2009). The results obtained by spectrophotometric analyses of total phenols were expressed as milligram equivalents of gallic acid per gram of extract (mgEAG/g).

**Determination of total flavonoids**

The determination of the total flavonoid content was performed according to the methodology developed by Da Silva et al. (2015). The solutions of the plant extract and the three extracts of endophytic fungi with the best results in the fungitoxic activity were prepared using 1 mg mL\(^{-1}\) of methanol as the solvent. Then, in a 15-mL vial filled with aluminum foil, 0.5 mL of the extract, 0.5 mL of aqueous acetic acid (60%, v/v), 2 mL of pyridine methanolic solution (20%, v/v), 1 mL of aluminum chloride (5%, w/v) and 6 mL of Milli-Q water were combined. The blank (reference solution) was made with all the above-mentioned reagents replacing the aluminum chloride with methanol. All reactions were carried out in triplicate and homogenized in a tube shaker. The reactions were maintained for 1 h in the dark, and the absorbances were measured at 420 nm in a spectrophotometer (BioSpectro model SP-220). The total flavonoid contents were determined by means of an analytical curve containing standards at concentrations of 1 to 10 μg mL\(^{-1}\) of rutin, and the results were expressed in microgram equivalents of rutin per milligram of dry extract (μgER/mg).

**Antioxidant activity**

The antioxidant capacity was measured by the DPPH method, as described by Soares et al. (2014) with modifications. The extracts obtained were prepared using methanol as the solvent at concentrations of 20 to 180 μg mL\(^{-1}\), w/v. In triplicate, 0.5 mL of the extract was added to a methanolic solution of DPPH (3 mL at 40 μg mL\(^{-1}\), w/v). White (reference solution) was made by replacing the DPPH with methanol in each reaction. All test tubes containing the reactions were stirred and held in the dark for 30 min. An analytical curve was performed for this activity using standard (positive controls) ascorbic acid and rutin (20-180 μg mL\(^{-1}\), w/v) also adding it to a methanolic solution of DPPH. Absorbance readings were taken at 517 nm in a spectrophotometer (BioSpectro model SP-220). The absorbance of the DPPH solution at 40 μg mL\(^{-1}\) was also measured and used as a negative control. The antioxidant activity of free radical removal was expressed as the percentage of inhibition determined by the equation

\[
\%AA = \frac{ABS_{nc} - (ABS_{sample} - ABS_{white})}{ABS_{nc}} \times 100,
\]

Where %AA is the percentage of antioxidant activity; ABS\(_{nc}\) is the absorbance of the negative control; ABS\(_{sample}\) is the absorbance of the sample; and ABS\(_{white}\) is the absorbance of white.

Using calibration curves obtained by plotting the different concentrations in relation to the %AAs, the efficient concentration, the amount of sample required to decrease the initial concentration of DPPH by 50% (EC 50), which was expressed in μg mL\(^{-1}\).

**Analysis by high-performance liquid chromatography (HPLC)**

High-performance liquid chromatography (HPLC) was developed in the Laboratory of Scientific Instrumentation, Federal University of Tocantins on a Shimadzu® LC-10 Series Awp Chromatograph, equipped with a pump (LC-10AD), degasser (DGU-14A), UV-VIS detector (SPD-10A) (CTO-10A), Rheodyne hand injector (20 μL loop), and CLASS integrator (LC-10A). Separation was performed by the gradient elution method using a Phenomenex Luna C18 (2) (250 × 4.6 mm) reverse-phase column and pre-column Phenomenex C18 (4 × 3.0 mm) filled with material similar to that in the main column. Mobile phase A was 0.1% phosphoric acid in Milli-Q water and mobile phase B was 0.1% phosphoric acid in Milli-Q water/acetoniitrile/methanol (54:35:11). Program gradient: 0 to 0.01 min, 0% B; 0.01-5 min, 0% B, 5-10 min, 30% B, 10-20 min 40% B, 20-29 min, 40% B, 29-30 min 50% B, 30-50 min 100% B, 50-80 min, 100% B. Flow rate: 1 mL/min; temperature: 22°C. UV detection was done at 280 nm. The compounds were identified by comparing the retention times of samples with the authentic standards, such as gallic acid, catechin, epigallocatechin gallate, naringin, quercetin, and naringenin (Sigma®). The quantities of the compounds were expressed in micrograms per milligram of extract (μg/mg) by correlating the area of the analyte with the calibration curve of standards built in concentrations of 4.5 to 18 μg mL\(^{-1}\).

**Selection according to fungitoxicity against C. lunata**

In order to select the endophytic fungi with the best antibiotic
Activity, the in vitro mycelial growth inhibition capacity of the phytopathogenic C. lunata fungus was previously isolated and identified. According to Carotenuto et al. (2015) with modifications, the evaluation of inhibition of mycelial growth of the phytopathogen was carried out by adding to the surface of the 9 cm diameter Petri dish containing approximately 20 ml of BDA culture medium already solidified, 100 μL of the extracts of the endophytic fungi. The extracts were diluted in Tween 80 and water. Discs 7 mm in diameter containing the mycelia of phytopathogenic fungus from pure colonies with approximately twelve days of growth in PDA were placed in the center of the plates.

Plates were incubated in biochemical oxygen demand (BOD) at 25 ± 1°C and a photoperiod of 12 h of light and 12 h of darkness. After growth, the presence or absence of zones of inhibition was observed.

The bioassays were performed in triplicate, and a plate containing only one disk of micelium agar of the phytopathogen without extract served as a positive control.

**Synergism evaluation**

After selection of endophytic fungi by the in vitro diffusible metabolite test according to the methodology to Mutawila et al. (2015), only one sample was chosen for synergism evaluation. The extract of endophytic fungus was used together with extract of L. sidoides. In accordance with the methodology of Tadtong et al. (2014), five different proportions of the two substances were used: 0:1; 1:3; 1:1; 3:1, and 1:0. Thus, the concentration of each substance was fixed at 7500 μg mL⁻¹. In Petri dishes with already solidified BDA culture medium were placed 100 μL of each proportion, scattered with a handle Drigalsky. Then, a mycelium-agar disk of C. lunata fungus was placed in the center of the plaque.

An evaluation was performed after 10 days of incubation, and the mycelial diameter was measured for comparison with the control (water and Tween 80).

**Statistical analysis**

The data obtained in the experiments were subjected to statistical analysis, such as analysis of variance (ANOVA) and Tukey’s test, with a significance level of α = 0.05, and linear regression. Calculations were performed using Sigmaplot® 12.0 and Assistat® software.

**RESULTS**

Fifteen morphologically distinct endophytic fungi were obtained from the fresh leaf fragments of L. sidoides. Biological tests were carried out using extracts made from both hexane and ethyl acetate against the phytopathogenic fungus of maize plants, C. lunata. The results of the selection according to fungitoxicity are presented in Table 1. Three extracts of different endophytes extracted with ethyl acetate were selected for the analysis of secondary metabolite synthesis. This analysis included the methanolic extract of L. sidoides leaves. These fungi were analyzed morphologically and identified at the genus level as Verticillium sp., Colletotrichum sp., and Fusarium sp. 1 (Table 1).

The three fungi with fungistatic capacity against C. lunata in this work were evaluated in order to identify the antioxidative profile of the respective fungal extracts. The results obtained by spectrophotometric analyzes of total phenols were expressed as milligrams of gallic acid equivalents per gram of extract (mgEAG/g). In this way, the total phenolic content for the plant extract, and extracts of the endophytic fungi Verticillium sp., Colletotrichum sp., and Fusarium sp. 1 were 96.94 ±

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**Table 1.** Mycelial inhibition screening of Lippia sidoides Cham. endophytic fungi against the plant pathogen Curvularia lunata Wakker.

| Fungus             | Extract from ethyl acetate | Extract from hexane |
|--------------------|-----------------------------|---------------------|
| LS-1 (u.f.)        | +                           | +++                 |
| Colletotrichum sp. | +                           | =                   |
| Verticillium sp.   | +++                         | =                   |
| Alternaria sp.     | +                           | =                   |
| LS-5 (u.f.)        | +                           | =                   |
| LS-6 (u.f.)        | +++                         | =                   |
| LS-7 (u.f.)        | ++                          | =                   |
| LS-8 (u.f.)        | =                           | ++                  |
| Colletotrichum sp. | +++                         | =                   |
| Phomopsis sp.      | =                           | +                   |
| Fusarium sp.       | =                           | ++                  |
| Fusarium sp. 1     | +++                         | =                   |
| Fusarium sp. 2     | +++                         | =                   |
| LS-14 (u.f.)       | +++                         | =                   |
| LS-15 (u.f.)       | =                           | +++                 |

LS, Initials of the L. sidoides plant to identify the endophytic fungus in the isolation. u.f., Morphologically unidentified fungus. They were visually classified as mycelial diameter equal to the control (+), smaller than the control (±), much smaller than the control (++), and much, much smaller than the control (++++).
Table 2. Mean values and standard deviations of total phenol content and flavonoids found in *Lippia sidoides* Cham., and endophytic fungi *Verticillium* sp., *Colletotrichum* sp. and *Fusarium* sp. 1.

| Extracts         | Total phenols (mgEAG/g) | Total flavonoids (mgER/g) |
|------------------|-------------------------|---------------------------|
| *L. sidoides*    | 96.94 ± 11.86<sup>a</sup> | 192.33 ± 4.58<sup>a</sup> |
| *Verticillium* sp.| 6.38 ± 1.27<sup>b</sup>  | 21.56 ± 1.14<sup>b</sup>  |
| *Colletotrichum* sp. | 0.29 ± 0.05<sup>c</sup> | 14.31 ± 1.56<sup>c</sup> |
| *Fusarium* sp. 1 | 10.54 ± 1.69<sup>b</sup> | 64.59 ± 1.15<sup>b</sup>  |

<sup>a</sup>mgEAG/g, Milligram equivalents of gallic acid per gram of extract. 
<sup>b</sup>mgER/g, milligram equivalents of rutine per gram of extract. Means followed by the same letter in the column do not differ statistically from each other by the Tukey test (<i>p</i> > 0.05).

It was verified that the total flavonoid content of extracts of the fungi *Verticillium* sp., *Colletotrichum* sp., and *Fusarium* sp. 1 were 21.56 ± 1.14, 14.31 ± 1.56 and 64.59 ± 1.15 mgER/g, respectively (Table 2). These values are lower than that of the plant extract, which was 192.33 ± 4.58 mgER/g (Table 2).

The percentage of antioxidant activity (%AA) was also determined by the DPPH method. The curves are shown in Figure 1, indicating an increase only for the plant extract, with the increase of the amount of extract in the reaction medium. The results were higher than 65% from the concentration of 120 μg mL<sup>-1</sup>, reaching a maximum of 95% for the concentration of 200 μg mL<sup>-1</sup> for *L. sidoides* extract (Figure 1). The effective concentration (EC<sub>50</sub>), that is, the amount of sample required to decrease the initial concentration of DPPH by 50% was also expressed in μg mL<sup>-1</sup>. The EC<sub>50</sub> for the plant extract was 81.03 μg mL<sup>-1</sup> (Figure 1). The %AA for the highest concentration (200 μg mL<sup>-1</sup>) for the fungi *Verticillium* sp., *Colletotrichum* sp., and *Fusarium* sp. was 19, 17 and 21%, respectively. Therefore, the EC<sub>50</sub> calculation could not be performed.

From the HPLC analyses performed for detection and quantification, fingerprints were obtained (Figure 2), which revealed matrices of phenolic compounds and flavonoids. In Figure 2B, the phenolic compound gallic acid 0.37 μg mL<sup>-1</sup> (Rt 16.4 min) was detected, along with the flavonoids catechin 1.67 μg mL<sup>-1</sup> (Rt 23.7 min), naringin 44.77 μg mL<sup>-1</sup> (Rt 43.2), and quercetin 3.08 μg mL<sup>-1</sup> (Rt 52.2 min). A high concentration of the compound naringin in the methanolic extract of the plant is...
Figure 2. High-performance liquid chromatography (HPLC) fingerprints of authentic standards of phenolic compounds mixture (A), methanolic extract of the leaves of L. sidoides (B) and isolated endophytic fungi: Verticillum sp. (C), Colletotrichum sp. (D), Fusarium sp. (E) detected at 280 nm, as described in material and methods. Peak 1: Gallic acid; peak 2: Catechin; peak 3: Epigallocatechin gallate; peak 4: Naringin; peak 5: Quercetin; peak 6: Naringenin.

It was also verified by HPLC in this study which flavonoids could be synthesized by the endophytic fungi and which could be identified and quantified according to the standards in the laboratory where the analysis was performed. According to Figure 2C, it can be seen that the extract of the endophytic fungus Verticillum sp. synthesized a compound identified as naringenin 0.61 μg mL⁻¹ (Rt 55.0 min) in addition to other compounds that could not be identified.

The fungus Colletotrichum sp. also produced secondary metabolites of the flavonoid class, yet it was not possible to compare any peak with laboratory standards. As shown in Figure 2D, the visualization of many uniform peaks indicated that many compounds were synthesized. The fungus Fusarium sp. synthesized (Figure 2E) three substances identified as catechin 0.31 μg mL⁻¹ (Rt 23.3), epigallocatechin gallate, and quercetin 19.73 μg mL⁻¹ (Rt 29.1 min).

A synergism test was also performed between L. sidoides extract and the endophytic extract of Verticillum sp. (Table 3). The curve was fitted to a 2nd degree equation with $R^2 = 0.9999$. The highest inhibitory effect was in the proportion of 50% essential oil and 50% fungal
extract, both of which were at a concentration of 7500 μg mL⁻¹. Proportions of 0:1, 1:3, 1:1, 3:1 and 1:0 (v/v) inhibited 54.8, 43.5, 79.0, 71.3 and 22.4% of the mycelial growth of C. lunata in vitro (Table 3).

**DISCUSSION**

Some previous works found the same endophytic fungi. You et al. (2009) isolated the endophytic fungus Verticillium sp. from the roots of Rehmannia glutinosa by identifying two compounds produced by this fungus: 2,6-dihydroxy-2-methyl-7-(prop-1-enyl)-1-benzofuran-3(2H)-one, reported for the first time, and the ergosterol peroxide, which inhibited the growth of pathogenic fungi. Suradkar et al. (2014) were able to isolate the endophyte Verticillium albo-atrum from Withania somnifera (L.) and Ocimum sanctum L.

The fungi Colletotrichum sp. and Fusarium sp. were also found in other studies isolating endophytic fungi. Alternaria alternata, Colletotrichum gloeosporioides, Drechslera dematiodia, Guignardia bidwellii, Fusarium lateritium, and Phomopsis archeri were endophytic fungi isolated from L. sidoides and identified by Siqueira (2011). In this work, the author isolated 15 endophytic fungi from L. sidoides, the same number of isolates in the present work. Similar results were verified, where the fungi Fusarium, Colletotrichum, Phomopsis, and Alternaria were also present in the work of Siqueira (2011).

Among the metabolites produced by Colletotrichum sp.: fusaretine 6,7-dimethyl ether, monocerin, and colletotrialide (Tianpanich et al., 2011), stigmasterol, sitostenone, squalene, ergosterol and ergosterol peroxide (Carvalho et al., 2016) were identified. Colletotrichum species have been identified to produce a variety of secondary metabolites genes, including flavones, peptides and terpenes (Crouch et al., 2014) and many other metabolites as Jayawarden et al. (2016) shows.

The genus Fusarium is also widely known as a producer of a variety of chemical compounds derived from its secondary metabolism (Nongalleima et al., 2013). Wang et al. (2011) reported anticancer activity against human PC-3 (prostate), PANCh-1 (pancreas) and A549 (lung) cells from a secondary metabolite called beavercin isolated from the endophytic Fusarium oxysporum of the Cinnamomum kanehirae plant. This same endophyte, F. oxysporum, nonpathogenic strains, isolated by Kundu et al. (2016), produced , bikaverin (1), 3-O-methyl-8-O-methyl fusarubin (2), 8-O-methyl fusarubin (3), anhydrofusarubin (4) and fusarubin (5).

In addition, the methanolic extract of Fusarium proliferatum prepared by Mohana et al. (2012), endophytic of Dysoxylum binaeciferum demonstrated cytotoxic activity in HCT-116 (colon) and MCF-7 (breast) human cancer cells.

The results confirm that both the plant and endophytic fungi produce compounds of a phenolic nature. Some studies corroborate our results, even though some previously reported fungal extracts contained more total phenols than ours. Yadav et al. (2014a) verified the phenolic compound content of endophytic fungi extracts obtained from ethyl acetate. The highest concentration of phenols was observed in the extract of Chaetomium sp. (60.13 ± 0.41 mgEAG/g), followed by that of Aspergillus niger. The total phenol concentration values of the 21 endophytic fungi studied ranged from 4.20 to 60.13 mgEAG/g. Srinivasan et al. (2010) obtained values of 18.33 ± 0.68 mgEAG/g of total phenols from the extract of the endophytic fungus Phyllosticta sp.

In order to confirm the synthesis of total flavonoids by the endophytic fungi present in the L. sidoides and plant extract (Table 2), extracts were obtained with the solvent ethyl acetate (AcOE) to extract compounds with recognized antimicrobial activity, such as phenols and flavonoids (Baba and Malik, 2015).

However, even if they are smaller, it can be verified that the endophytic fungi contribute to the plant in the production and synthesis of secondary metabolites for its protection. Hence, an appreciable amount of flavonoids produced by the endophytic fungi may be present in the plant; moreover, they contributed to its synthesis.

Huang et al. (2007) isolated 42 endophytic fungi from Nerium oleander and found flavonoids among the main bioactive compounds of some cultures. They also clarified that some phenolic compounds are produced so
that certain endophytic fungi survive along with their host plants. Qiu et al. (2010) found flavonoid contents of 0.01162 ± 0.0014 and 0.01256 ± 0.00378 mg ER/mL in extracts of Aspergillus nidulans, Aspergillus oryzae, and Ginkgo biloba endophytes, respectively. Their values were lower than those of the present work; however, different fungi were used.

The data obtained in the determination of this bioactivity is significant when compared with others obtained in the work of Almeida et al. (2010). At a concentration of 100 μg mL⁻¹ (or 1 mg mL⁻¹ as reported), there was an antioxidative activity of 99.5% and an EC₅₀ of 16.3 μg mL⁻¹ in the ethanolic extract of L. sidoides. The results obtained in the present study were lower; however, the solvent used for the extraction may have been the source of this difference. They also assayed the DPPH activity of plant-isolated substances such as tecomoquinone and naringenin. At a concentration of 1 mg mL⁻¹, %AA was 64.7% and the EC₅₀ was 720 μg mL⁻¹ for the flavonoid naringenin. The compound tecomoquinone did not display any activity.

As for the antioxidant activity of the extracts of endophytic fungi, they showed a low capacity to sequester free radicals, as there was no negative effect on the measured absorbance. Initial values remained essentially unchanged at all concentrations tested. It can be said that there was activity; however, compared with the results obtained from the plant extract, it was much lower than expected. It is believed that perhaps the cultivation conditions used did not promote the biosynthesis of antioxidant molecules that are detectable by this method. In addition, there was no change in the amount of free radicals as the concentration of fungal extract varied.

Observing the work of Devi and Singh (2015), they also did not obtain positive results of a significant amount of free radical sequestration by DPPH in extracts of Verticillium. However, they reported an antioxidative activity 95% in Alternaria sp. 2 made from ethyl acetate. Yadav et al. (2014a) carried out tests with extracts of endophytic fungi, including the genus Fusarium sp. They identified antioxidant activity by DPPH of Aspergillus peyronellii and Aspergillus niger of 71 and 72%, respectively, but identified low activity in extracts of Fusarium sp. Nath et al. (2014) also reported a strong activity in the sequestration of free radicals in ethanolic extracts of Colletotrichum gloeosporioides of 0.67 ± 0.05, 47.89 ± 0.06, 73.84 ± 0.08, 60.09 ± 0.08, and 52.77% ± 0.06% at concentrations of 10, 25, 50, 75 and 100 μg mL⁻¹, respectively.

Endophytic fungi and plants can produce flavonoids together, varying their biological activities, such as the genus Bauhinia variegata (cow’s foot), which had antidiabetic activity confirmed by the metabolic profiles of both the plant and the associated endophytic fungi (Costa, 2005).

These analyzes by HPLC allowed us to identify phenolic constituents described in the literature as important in several biological functions. Phenolic acid has a strong anti-inflammatory, antimutagenic, and antitumor action, inhibiting genes related to the cell cycle, metastasis, angiogenesis, and apoptosis (Verma et al., 2013). The detection of three types of flavonoids, catechin, naringin, and quercetin, in the L. sidoides plant (Figure 2B) also allows presenting and confirm the possibility of harnessing its leaves for biological applications. Several studies have already demonstrated the potential and ability of these metabolites to act to reduce the risks associated with pathologies such as intestinal inflammation, bacterial infections, diabetes, cardiovascular diseases, and cancer, among others (Clemensen et al., 2017; Macheleidt et al., 2016). In the present study, however, antifungal activities of the extracts are related to the antioxidative activity of flavonoids present in considerable amounts (Funari et al., 2012).

Many studies report the capacity of flavonoid production by plants, such as those found in the leaves of Euphorbia neriifolia (pencil-tree), where Sharma et al. (2014) identified a flavonoid as quercetin by HPLC. This substance and other flavonoids are credited with antioxidative and anticarcinogenic activity. Naringenin is a flavonoid of the flavanone subclass, found mainly in citrus fruits (Dou et al., 2013), with a beneficial antioxidative and neuroprotective effect (Raza et al., 2013). Among these, the flavonoids catechin and quercetin were also found in plant extracts. Thus, it can be confirmed that these two metabolites were probably synthesized by the endophytic fungi in conformation with the plant-fungus mutualistic interactions. In addition, as endophytic fungi produce the same compounds present in the plant, it can be inferred that fungi produce these compounds for the plant as a way of assisting them in their defense. These substances contribute greatly to the antioxidative activities credited to L. sidoides plants (Funari et al., 2012).

Kumar et al. (2013) characterized the vinblastine alkaloid from the extract of the endophytic fungus F. oxysporium, isolated from Catharanthus roseus. By HPLC analyzes, they obtained 76 μg L⁻¹ of the compound. Also Zaiyou et al. (2015) found in the extract of the endophyte Fusarium sp. The compound paclitaxel at the concentration of 0.0153 mg L⁻¹.

Besides, Chapla et al. (2014) also identified eight compounds synthesized by the endophyte Colletotrichum gloeosporioides, a new compound 2-phenylethyl 1H-indol-3-yl-acetate (1) and seven other known compounds: Uracil (2), cyclo-(S*(S)-Pro-S*-Val) (4), 2-(2-aminophenyl)acetic acid (5), 2-(4-hydroxyphenyl)acetic acid (6), 4-hydroxy-benzamide (7), and 2-(2-hydroxyphenyl)acetic acid (8). Table 4 shows the compounds identified by HPLC from extracts of both the plant L. sidoides and the endophytic fungi isolated from it.
Table 4. Identified compounds from samples of plant extracts and endophytic fungi identified and analyzed by HPLC with their respective peaks, concentrations, and retention times.

| Sample (extract) | Compound identified | Peak | Concentration (mg mL⁻¹) | Retention time (min) |
|------------------|---------------------|------|-------------------------|---------------------|
| L. sidoides      | Gallic acid         | 2    | 0.37                    | 16.4                |
|                  | Catechin            | 8    | 1.67                    | 23.7                |
|                  | Naringin            | 21   | 44.77                   | 43.2                |
|                  | Quercetin           | 27   | 3.08                    | 52.0                |
| Verticillium sp. | Naringenin          | 11   | 0.61                    | 55.0                |
| Colletotrichum sp.| N.I. *              | -    | -                       | -                   |
| Fusarium sp. 1   | Epigallocatechin gallate | 10 | 0.94                  | 28.9                |
|                  | Quercetin           | 17   | 19.73                   | 52.2                |

N.I.* = compound not identified

The production of compounds that possess biological activity by endophytic fungi can be stimulated in the plant, by the host plant extract, and in this case, by the extracts of fermented fungi without contact with any part or extract of the plant (Dos Santos et al., 2015). When grown in vitro, fungi continued to produce metabolites. Further studies must be carried out to find out if the fungi would cease production for some time or if, in the presence of the plant extract or any part of it, the synthesis would continue, that is, what factors could encourage this production. No reports were found in the scientific literature on the inhibition of mycelial growth of phytopathogenic fungi using extracts of endophytic fungi and of plants with synergistic effects. However, in the work of Oliveira et al. (2014), synergistic activity was found between a butanolic fraction of Lippia alba extract with commercial antifungal agents against Candida glomerata. The minimum inhibitory concentration was 0.062 μg mL⁻¹. This may be a potential alternative in the treatment for candidemia caused by yeast species.

The synergistic effect of the endophytic fungal extracts of Aspergillus awamori, Penicillium sp., and C. gloeosporioides with standard antibiotics was studied against the four test bacterial strains viz. Streptococcus pyogenes, Escherichia coli, Enterococcus faecalis, and Salmonella enterica ser paratyphi. A significant increase in the diameter of inhibition zones was observed when the fungal extracts in combination with the antibiotic Norfloxacin was used against the test pathogens. Crude extract of A. awamori in combination with Norfloxacin showed antimicrobial activity (25 and 31-mm inhibition zones) against E. coli and E. faecalis, respectively (Nath et al., 2013).

The secondary metabolites act on the fungus through cytoplasmic granulation, disorganization of cellular contents, and inactivation of enzymes, which inhibits germination, germinative tube elongation, and mycelial growth (Lo et al., 1996). Thus, it can be inferred that the best result of mycelial inhibition was determined by the joint action of the extract of L. sidoides and extract of the endophytic fungus Verticillium sp. However, it was only a preliminary test, and other tests should be performed in order to obtain results on the best concentration of the metabolites, test the efficiency of the other fungi along with the plant extract, and add another type of extract.

Recent discoveries, as exemplified in this work, have associated endophytic fungi with medicinal plants, important sources of secondary metabolites of pharmaceutical, agricultural, and industrial interest. Brazil has a wide potential source of plants, due to the varied biomes, and a study of plant-endophytic interactions is necessary. The discovery of metabolites with recognized bioactive action produced by endophytes can help to stop the excessive exploitation of plants and consequently, the whole set of endophytes associated with it (Pusztahelyi et al., 2015). Thus, the study of fungal endophytes is becoming a great necessity, because, as in the present work, they assist their host plants in the synthesis of metabolites with recognized bioactivity. This property of endophytes will help to diminish the exploitation of plant biodiversity for drug extraction. Consequently, conservation strategies will be more efficient.

Conclusions

The analyses of the study showed the presence of phenols and flavonoids in all extracts and high antioxidant activity was only observed in the plant extract. Secondary metabolites were identified and quantified by HPLC. The best result for mycelial inhibition by the synergism test was determined by the joint action of the extract of L. sidoides and that of the endophytic fungus Verticillium sp. against C. lunata.

Conflict of Interests

The authors have not declared any conflict of interests.
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