CHAPTER 2

PHYTOCHEMISTRY OF MYCORRHIZAL SPECIES: AN APPROACH TO RESEARCH CONDUCTED IN THE BRAZILIAN NORTHEAST

Submission date: 15/08/2024 *Acceptance date: 02/09/2024*

Eduarda Lins Falcão
Laboratório de Análises, Pesquisas e Estudos em Micorrizas – LAPEM and Programa de Pós-graduação em Biologia Celular e Molecular Aplicada, Instituto de Ciências Biológicas, Universidade de Pernambuco, Recife – Pernambuco
https://orcid.org/0000-0003-3141-6466

Brena Coutinho Muniz
Laboratório de Análises, Pesquisas e Estudos em Micorrizas – LAPEM and Programa de Pós-graduação em Biologia Celular e Molecular Aplicada, Instituto de Ciências Biológicas, Universidade de Pernambuco, Recife – Pernambuco
https://orcid.org/0000-0003-2004-2518

Caio Bezerra Barreto
Laboratório de Análises, Pesquisas e Estudos em Micorrizas – LAPEM and Programa de Pós-graduação em Biologia Celular e Molecular Aplicada, Instituto de Ciências Biológicas, Universidade de Pernambuco, Recife – Pernambuco
https://orcid.org/0009-0008-5568-7993

Rita de Cássia Ribeiro da Luz
Laboratório de Análises, Pesquisas e Estudos em Micorrizas – LAPEM and Programa de Pós-graduação em Biologia Celular e Molecular Aplicada, Instituto de Ciências Biológicas, Universidade de Pernambuco, Recife – Pernambuco
https://orcid.org/0009-0002-6296-0667

Fábio Sérgio Barbosa da Silva
Laboratório de Análises, Pesquisas e Estudos em Micorrizas – LAPEM e Programa de Pós-graduação em Biologia Celular e Molecular Aplicada, Instituto de Ciências Biológicas, Universidade de Pernambuco, Recife – Pernambuco
https://orcid.org/0000-0001-7798-5408

ABSTRACT: The Brazilian Northeast is the region with the largest number of studies evaluating the bioactive compound production in plants associated with arbuscular mycorrhizal fungi (AMF), especially in *Pernambuco*. Thus, the most studied botanical families were *Fabaceae* and *Passifloraceae*, highlighting species native to the *Caatinga* biome, which are of medicinal interest, such as *Libidibia ferrea* (Mart. ex Tul.) L. P. Queiroz and *Mimosa tenuiflora* (Willd.) Poir, as well as some cultivated species, including *Passiflora edulis* f. *flavicarpa* Deg. and *Zea mays* L. Mycorrhizal technology was also effective in increasing the production of compounds in other plants, such as *Mentha* x *piperita* L. and *Punica granatum* L., confirming its potential for enhancing the synthesis of plant bioactive compounds. The most

used mycorrhizal isolates were *Acaulospora longula* Spain & N.C. Schenck and *Gigaspora albida* Schenck & G.S. Sm. The studies mainly reported the influence of AMF in improving the biosynthesis of foliar bioactive compounds to add value to this organ that is often thrown away. The Northeast region of Brazil is a reference in research into the potential use of AMF to optimize the production of plant bioactive metabolites of interest to the pharmaceutical, cosmetic, and nutraceutical industries.
KEYWORDS: *Acaulospora*, bioactive compounds, *Fabaceae*.

1. INTRODUCTION

The Northeast region of Brazil covers 18% of the national territory, occupying around 1,551,991 km^2, and includes the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, and Bahia (IBGE, 2019). The climate in this region is characterized by high temperatures, with averages that can reach 30 ºC (INMET, 2024). The variable vegetation is due to the occurrence of *Caatinga*, Atlantic Forest, and *Cerrado* biomes, which occur in the region, in addition to sandbanks and mangroves along the coast (IBGE, 2019).

Moreover, the cultivation of food plants is significant, especially maize, soybeans, sugarcane, cocoa, coffee, tropical fruits (grapes, bananas, mangoes, pineapples, papaya, melons, watermelons, among others), and cassava, which plays a fundamental role in the region's economy (IBGE, 2022).

An approach for growing plants and improving crop production of metabolites is by ameliorating soil factors using mycorrhizal technology (Falcão *et al.*, 2024a). Thus, around 50% of Brazilian phytochemical studies on plants associated with AMF have been carried out in the Northeast region, mainly in Pernambuco (Figure 1). Most of these studies were conducted by the research group on Fungi of Agricultural Importance, registered in the *Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)* and comprising the Laboratory for Analysis, Research and Studies on Mycorrhizae (LAPEM) and the Laboratory for Mycorrhizal Technology (LTM), both at the University of Pernambuco, representing about 49% of Brazilian research in this field.

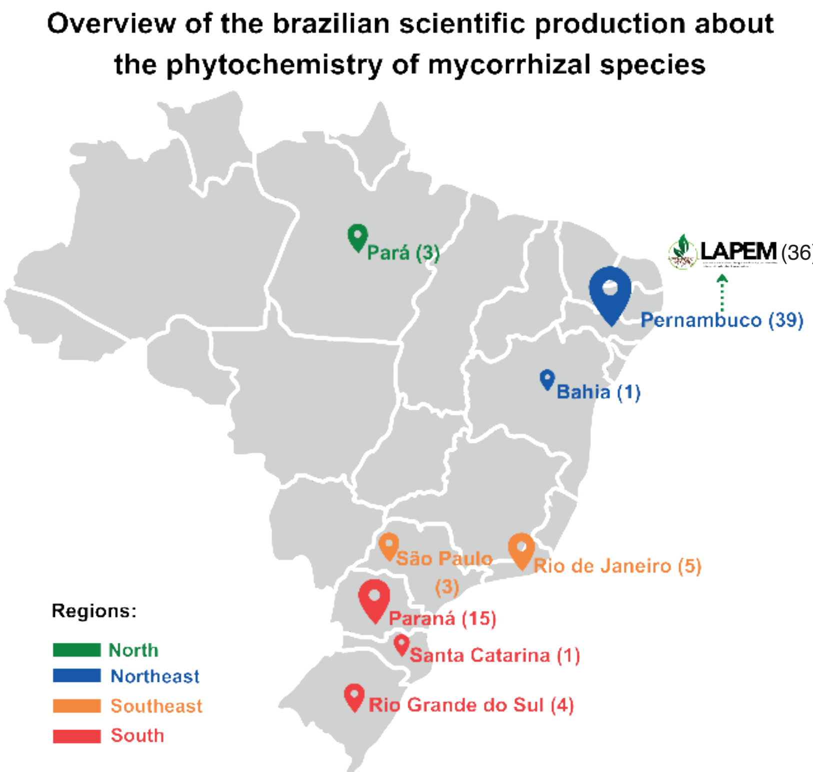

Figure 1. Overview of Brazilian papers on the phytochemistry of mycorrhizal species (Freitas *et al.,* 2004a,b; Andrade *et al*., 2010;2013; Oliveira *et al*., 2013;2015a,b,c;2019a,b;2020;2022; Pedone Bonfim *et al*., 2013;2018; Riter Netto *et al*., 2014; Silva *et al*., 2014a,b,c,d;2018a,b,c;2019;2021a,b,c,d; Lermen *et al*., 2015;2023; Lima *et al*., 2015a,b;2017; Urcoviche *et al*., 2015; Morelli *et al*., 2017; Santos *et al*., 2017;2020;2021b; Silva; Silva, 2017;2020; Almeida *et al*., 2018;2020; Silva; Maia, 2018; Chiomento *et al*., 2019;2021;2022; Cordeiro *et al*., 2019; Cruz *et al*., 2019;2020; Ferrari *et al*., 2020; Merlin *et al*., 2020; Vieira *et al*., 2021; Trindade *et al*., 2021; Muniz *et al*., 2021;2022a,b;2023; Marcolino *et al*., 2021; Falcão; Silva, 2022; Falcão *et al*., 2022;2023b;2024b; Palhares Neto *et al*., 2022; Pinc *et al*., 2022; Souza *et al*., 2022; Luz *et al*., 2023; Nardi *et al*., 2024; Melato *et al.,* 2024).
LAPEM: Laboratório de Análises, Pesquisas e Estudos em Micorrizas da Universidade de Pernambuco

This integrative review aimed to compile phytochemical studies conducted in Northeast Brazil that used mycorrhizal species. To this end, the search for papers was the same as in the first chapter.

2. RESULTS AND DISCUSSION: REGIONAL EVALUATION OF PHYTOCHEMICAL STUDIES ON MYCORRHIZAL SPECIES

Among the studies that have evaluated the phytochemistry of plants associated with AMF in Northeast Brazil, approximately 47% and 23% of the studies investigated species from the *Fabaceae* and *Passifloraceae*, respectively (Pedone Bonfim *et al.,* 2013; Silva *et al.,* 2014a,b;2018a;2021a; Lima *et al.,* 2015a; Oliveira *et al.,* 2015a,b,c;2019;2020; Santos *et al.,* 2017;2020;2021a; Silva; Silva, 2017; Muniz *et al.,* 2021;2022a,b;2023; Falcão *et al.,* 2022; 2023a;2024b; Falcão; Silva, 2022), studies with *Anacardiaceae* (Oliveira *et al.,* 2013; Silva; Maia, 2018), *Lythraceae* (Silva *et al.,* 2014d; Silva; Silva, 2020), *Burseraceae* (Lima *et al.,* 2017), *Poaceae* (Silva *et al.,* 2019), *Myrtaceae* (Marcolino *et al.,* 2021), *Verbenaceae* (Palhares Neto *et al.,* 2022), and *Lamiaceae* (Silva *et al.,* 2014c) were also developed, showing a considerable diversity of studied taxa, with numbers higher than those recorded in other Brazilian regions (Figure 2).

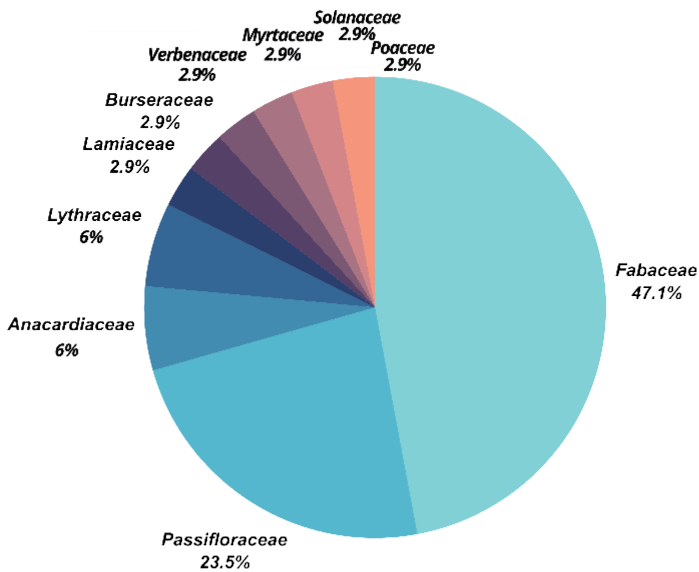

Figure 2. Botanical families studied in Northeast Brazil to evaluate the phytochemistry of mycorrhizal representatives (Pedone Bonfim *et al.,* 2013;2018; Oliveira *et al.,* 2013;2015a,b,c;2019a;2020; Silva *et al.,* 2014a,b,c,d;2018;2019;2021a; Lima *et al.,* 2015a;2017; Santos *et al.,* 2017;2020;2021a,b; Silva; Silva, 2017;2020; Silva; Maia, 2018; Muniz *et al.,* 2021;2022a,b;2023; Falcão; Silva 2022; Falcão *et al.*, 2022;2023a;2024b; Luz *et al.,* 2023).

Among the tree species that occur in the *Caatinga* and whose anabolism is enhanced by mycorrhizal technology, *L. ferrea*, *Commiphora leptophloeos* (Mart.) J.B. Gillett, and *Mimosa tenuiflora* (Wild.) Poir. stand out, as they are used in folk medicine to treat ailments, such as inflammation, flu, and respiratory problems (Albuquerque *et al.,* 2007; Albergaria *et al.,* 2019). Moreover, some are significant because they have a high relative importance index (RI), as the case with *Myracrodruon urundeuva* Allemao, *Amburana cearensis* Allemao, *H. martiana* and *A. colubrina*, due to the broad therapeutic spectrum of preparations using these plants (Albuquerque *et al.,* 2007). Data on mycorrhizal efficiency in trees can encourage the establishment of sustainable crops and help reduce the unplanned extractive use of organs from these species.

Among the studies, conducted in Brazil, on the metabolism of mycorrhizal plants, *A. longula, E. etunicata,* and *G. albida* stood out as the most used in research carried out in the Northeast region (Figure 3). These AMF are found naturally in *Caatinga* soils (Pontes *et* *al.,* 2017), however, they have different colonization strategies: members of *Gigasporaceae* have spores as their only reproductive structure and produce more mycelium in the soil than in the roots; the opposite is observed in taxa of *Acaulosporaceae* and *Entrophosporaceae*, which also propagate from hyphae fragments, with more expressive intraradicular colonization (Hart; Reader, 2002). Additionally, *E. etunicata* can adapt to different soil conditions (Weissenhorn *et al.,* 1994; Dashtebani *et al.,* 2014), perhaps reflecting the fungus choice in the research conducted in the country (Figure 3, Chapter 1).

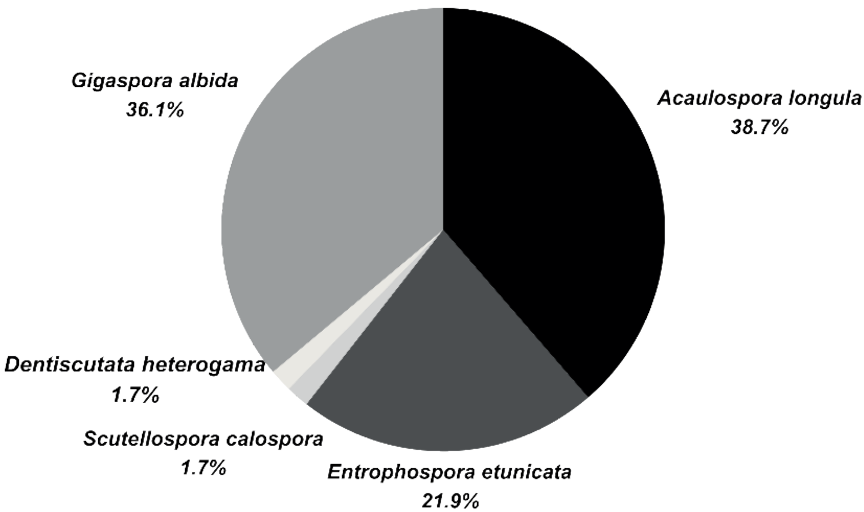

Figure 3. Tested mycorrhizal fungi species in phytochemical studies that used mycorrhizal plants in the Northeast region. *Acaulospora longula* Spain & N.C. Schenck, *Dentiscutata heterogama* (T.H. Nicolson & Gerd.) Sieverd., F.A. Souza & Oehl, *Entrophospora claroidea* (N.C. Schenck & G.S. Sm.) Błaszk., *Entrophospora etunicata* (W.N. Becker & Gerd.) Błaszk., Niezgoda, B.T. Goto & Magurno, *Gigaspora albida* N.C. Schenck & G.S. Sm. e *Scutellospora calospora* (T.H. Nicolson & Gerd.) C. Walker & F.E. Sanders (Pedone Bonfim *et al.*, 2013;2018; Oliveira *et al.*, 2013;2015a,b,c;2019;2020; Silva *et al.*, 2014a,b,c,d;2018a;2019a;2021; Lima *et al.*, 2015a;2017; Santos *et al.*, 2017;2020;2021a,b; Silva; Silva, 2017;2020; Silva; Maia, 2018; Muniz *et al.*, 2021;2022a,b;2023; Falcão; Silva, 2022; Falcão *et al.*, 2022;2023a;2024b; Luz *et al.*, 2023).

The anabolic products of *Fabaceae* trees, in response to mycorrhization, were quantified in *A. cearensis* (Oliveira *et al.,* 2015c), *A. colubrina* (Pedone Bonfim *et al.,* 2013; Falcão *et al.,* 2022;2023a;2024b), *I. vera* (Lima *et al.,* 2015a), *L. ferrea* (Silva *et al.,* 2014a,b; 2018a; 2021a; Santos *et al.,* 2017; 2020; 2021a) and *M. tenuiflora* (Silva; Silva, 2017; Pedone Bonfim *et al.,* 2018). The majority evaluated the foliar phytochemistry (Silva *et al.,* 2014c,d; Lima *et al.,* 2015a; Oliveira *et al.,* 2015c; Silva; Silva, 2017; Pedone Bonfim *et al.,* 2018; Muniz *et al.,* 2021;2022a,b;2023; Falcão *et al.,* 2022;2023a;2024b), with one study using the entire aerial part (Pedone Bonfim *et al.,* 2013) and, of these, only Silva *et al.* (2014d) used leaves obtained from a field experiment. In contrast, the bark of the stem (Santos *et al.,* 2017; Silva *et al.,* 2018) and fruits were the least studied organs (Santos *et al.,* 2020;2021b) (Figure 4).

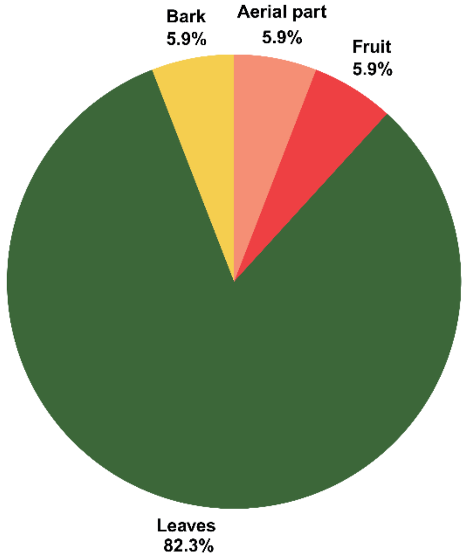

Figure 4. Plant parts used to evaluate the phytochemistry in research conducted in the Northeast using mycorrhizal plants (Pedone Bonfim *et al.*, 2013;2018; Oliveira *et al.*, 2013;2015a,b,c;2019a;2020; Silva *et al.*, 2014a,b,c,d;2018a;2019;2021; Lima *et al.*, 2015a;2017; Santos *et al.*, 2017;2020;2021a,b; Silva; Silva, 2017;2020; Silva; Maia, 2018; Muniz *et al.*, 2021;2022a,b;2023; Falcão *et al.*, 2022;2023a;2024b; Luz *et al.*, 2023).

Soils from *Caatinga* areas have been used in most studies applying AMF to enhance the secondary anabolism of *Fabaceae* (Pedone Bonfim *et al.*, 2013; 2018; Lima *et al.*, 2015a; 2017; Oliveira *et al.*, 2015c; Santos *et al.*, 2017; 2020; 2021b; Silva *et al.*, 2018a; 2021a; Falcão *et al.*, 2022; 2023a; 2024b; Muniz *et al.*, 2023); this substrate is poor (4 to 12.68 mg P dm^{-3}), and because of this, some studies with this family have also investigated the effects of phosphate fertilization (Pedone Bonfim *et al.*, 2013; Silva *et al.*, 2021a; Falcão *et al.*, 2024b), or organic substrates (Muniz *et al.*, 2023) associated with the use of AMF to optimize the biosynthesis of secondary metabolites.

Another plant group that has been widely studied is the genus *Passiflora*. Passion fruits are included in the Brazilian Pharmacopoeia (ANVISA, 2019) and the *Relação Nacional de Plantas Medicinais de Interesse ao Sistema Único de Saúde* (*RENISUS*) (Brasil, 2009) and are commonly used in folk medicine and by the pharmaceutical industry in the preparation of calming and sedative formulations (Klein *et al.,* 2014). The leaves were the only plant organ evaluated in mycorrhizal *Passiflora*, aligning with the Brazilian Pharmacopoeia, which cites this organ as a medically active part of these plants and as the part used to produce herbal medicines (ANVISA, 2019).

In this context, positive results of mycorrhization on foliar metabolism were reported in eight studies with four passion fruit species (*Passiflora alata* Curtis*, Passiflora cincinnata* Mast.*, P. edulis* f. *flavicarpa* Deg.*,* and *Passiflora setacea* DC.) (Oliveira *et al.*, 2015a,b;2019;2020; Muniz *et al.*, 2021;2022a,b; Falcão; Silva, 2022). Most of them used soil collected in the *Caatinga*, with an acid pH (5.6 - 6.1), low phosphorus content (4.26 - 4.92 mg dm^{-3}, Mehlich), which was increased when fertilizers were applied (Oliveira *et al.*, 2015b,c;2019a;2020; Muniz *et al.*, 2022a,b;2023; Falcão; Silva, 2022). Therefore, it is possible to obtain phytomass from mycorrhizal passion fruit vines to integrate the production chain of anxiolytic herbal medicines, since *P. edulis* seedlings inoculated with *A. longula*, for example, had their foliar vitexin production enhanced, making it possible to produce up to 900 tablets with the extract obtained, which is 60% higher than the projected when using extracts from non-mycorrhizal plants (Oliveira *et al.*, 2019a).

All studies with representatives of *Passiflora* were carried out in a greenhouse, under uncontrolled environmental conditions of light and temperature, with a cultivation period varying between 61 and 134 days (Oliveira *et al.*, 2015a,b; 2019a; 2020; Muniz *et al.*, 2021; 2022a,b; Falcão; Silva, 2022). However, it is worth mentioning the importance of field studies to prove symbiotic efficiency in edaphic systems present in more than 45,000 hectares destined for passion fruit cultivation in Brazil (IBGE, 2022).

Other plant species also had their production of compounds favored by AMF inoculation, as was the case with *Mentha* x *piperita* L. var. *citrata* (Ehrh.) Briq. (*Lamiaceae*), and *Punica granatum* L. (*Lythraceae*), medicinal plants that showed an increase in the synthesis of linalool and phenolic compounds, respectively (Silva *et al.*, 2014c,d). The mycorrhizal technology has also favored total flavonoid concentration of *Zea mays* L. (*Poaceae*) leaves, increasing the nutraceutical quality related to flavonoid content (Silva *et al.,* 2019).

In summary, the Northeast is the region with the highest number of studies on the phytochemistry of mycorrhizal species in Brazil, with 40 published studies, 34 of which were experimental. These papers evaluated the influence of five AMF species, with representatives of ten botanical families, in enhancing the synthesis of bioactive compounds, especially foliar phenolics, followed by terpenes and alkaloids. A smaller number of studies have evaluated this mycorrhizal benefit in the bark, fruit, and aerial part, while studies using roots are rare. Details of these research studies are described in Table 1.

Table 1. Phytochemical experimental research conducted in Northeast Brazil using mycorrhizal species

Plant species	Plant part	Evaluated compound group	AMF species	Evaluated mycorrhizal parameters	Reference
Myracrodruon urundeuva M. Allemão	Aerial part	Phenols	*Acaulospora longula* Spain & N.C. Schenck; *Gigaspora albida* N.C. Schenck & G.S. Sm.	Mycorrhizal colonization	Oliveira *et al.* (2013)
Anadenanthera colubrina (Vell.) Brenan	Aerial part	Phenols	*A. longula*; *G. albida*	None	Pedone Bonfim *et al.* (2013)
Punica granatum L.	Leaves	Phenols	*A. longula*; *G. albida*	Mycorrhizal colonization; Glomerospores	Silva *et al.* (2014a)
Mentha × *piperita* L.	Leaves	Terpenes	*Rhizoglomus clarum* (T.H. Nicolson & N.C. Schenck) Sieverd., G.A. Silva & Oehl; *A. longula*; *Scutellospora calospora* (T.H. Nicolson & Gerd.) C. Walker & F.E. Sanders	Mycorrhizal colonization	Silva *et al.* (2014b)
Libidibia ferrea (Mart. ex Tul.) L.P. Queiroz	Leaves	Phenols	*A. longula*; *G. albida; Entrophospora etunicata* (W.N. Becker & Gerd.) Błaszk., Niezgoda, B.T. Goto & Magurno	Mycorrhizal colonization	Silva *et al.* (2014c)
L. ferrea	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization; Glomerospores	Silva *et al.* (2014d)
Inga vera Willd.	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Lima *et al.* (2015)
Amburana cearensis (Allemão) A.C.Sm.	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Oliveira *et al.* (2015a)
Passiflora alata Curtis	Leaves	Phenols	*G. albida*	Mycorrhizal colonization	Oliveira *et al.* (2015b)
P. alata	Leaves	Phenols	*G. albida*	Mycorrhizal colonization	Oliveira *et al.* (2015c)
Commiphora leptophloeos (Mart.) J.B. Gillett	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Lima *et al.* (2017)
L. ferrea	Bark	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization; Glomerospores	Santos *et al.* (2017)
Mimosa tenuiflora (Willd.) Poir.	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Silva; Silva (2017)
M. tenuiflora	Leaves	Phenols	*G. albida; E. etunicata*	Mycorrhizal colonization; Glomerospores	Pedone Bonfim *et al.* (2018)
M. urundeuva	Leaves	Phenols	*A. longula*; *G. albida*	None	Silva; Maia (2018)
L. ferrea	Bark	Phenols	*A. longula*; *G. albida; E. etunicata*	None	Silva *et al.* (2018)

Passiflora edulis f. *flavicarpa* Deg.	Leaves	Phenols; Terpenes	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Oliveira *et al.* (2019a)
Zea mays L.	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata; Dentiscutata heterogama* (Nicolson & Gerd.) Sieverd., F.A. Souza & Oehl	None	Silva *et al.* (2019)
P. edulis	Leaves	Phenols; Terpenes	*A. longula*	Mycorrhizal colonization; Glomerospores	Oliveira *et al.* (2020)
L. ferrea	Fruits	Phenols; Terpenes	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Santos *et al.* (2020)
P. granatum	Leaves	Phenols	*A. longula*; *E. etunicata*	Mycorrhizal colonization	Silva; Silva (2020)
Psidium guajava L.	Leaves	Phenols	*A. longula*	None	Marcolino *et al.* (2021)
P. alata	Leaves	Phenols; Terpenes	*A. longula*; *G. albida*	Mycorrhizal colonization; GRSP	Muniz *et al.* (2021)
L. ferrea	Fruits	Phenols	*A. longula*; *G. albida; E. etunicata*	None	Santos *et al.* (2021b)
L. ferrea	Leaves	Phenols	*A. longula*; *G. albida; E. etunicata*	Mycorrhizal colonization	Silva *et al.* (2021a)
A. colubrina	Leaves	Phenols	*A. longula*; *G. albida*	Mycorrhizal colonization; C-GRSP	Falcão *et al.* (2022)
Passiflora cincinnata Mast.	Leaves	Phenols; Terpenes	*A. longula*; *G. albida*	Mycorrhizal colonization; GRSP	Falcão; Silva (2022)
Passifora setacea DC.	Leaves	Phenols; Terpenes	*A. longula*; *G. albida*	Mycorrhizal colonization; GRSP	Muniz *et al.* (2022a)
P. alata	Leaves	Phenols; Terpenes	*A. longula*	Mycorrhizal colonization; Glomerospores	Muniz *et al.* (2022b)
Lippia alba (Mill.) N.E.Br. ex Britton & P. Wilson	Leaves	Terpenes	*E. etunicata; Fuscutata heterogama* Oehl, F.A. Souza, L.C. Maia & Sieverd.	Mycorrhizal colonization	Palhares Neto *et al.* (2022)
A. colubrina	Leaves	Phenols; Terpenes	*A. longula*; *G. albida*	Mycorrhizal colonization; GRSP	Falcão *et al.* (2023)
Hymenaea martiana Hayne	Leaves	Phenols	*A. longula*; *G. albida*; *E. etunicata*	Mycorrhizal colonization	Muniz *et al.* (2023)
Capsicum chinense Jacq.	Leaves	Phenols; Terpenes; Alkaloids	*A. longula*; *G. albida*; *E. etunicata*	Mycorrhizal colonization; Glomerospores	Luz *et al.* (2023)
A. colubrina	Leaves	Phenols; Terpenes	*A. longula*; *G. albida*	None	Falcão *et al.* (2024b)

GRSP: Glomalin-related soil proteins.

3. CONCLUSIONS

Northeast Brazil is an important hub for research into the phytochemistry of mycorrhizal plants, with a range of native and cultivated species. In this context, studies with the fungi *A. longula*, *G. albida,* and *E. etunicata* deserve to be highlighted, considering the benefits reported to plant anabolism. The cultivation of plants associated with AMF, mainly *Fabaceae* and *Passifloraceae*, which are found in national biomes, increased the production of phytomass with a higher yield of medicinal and cosmetic compounds. Therefore, mycorrhizal technology is a promising strategy for cultivating plants found in the Northeast region.

Furthermore, the relevance of research groups, equipped laboratories, and partnerships with specialists from various fields are crucial for the successful development of mycorrhizal protocols in the region.

REFERENCES

AGÊNCIA NACIONAL DE VIGILÂNCIA SANITÁRIA - ANVISA. **Farmacopeia Brasileira**. 6. ed. Vol. 2: Plantas Medicinais. 2019.

ALBERGARIA, E. T. D.; SILVA, M. V. D.; SILVA, A. G. D. Levantamento etnobotânico de plantas medicinais em comunidades rurais localizadas na Unidade de Conservação Tatu-Bola, município de Lagoa Grande, PE-Brasil. **Revista Fitos**, v. 13, p. 137-154, 2019.

ALBUQUERQUE, U. P. *et al.* Medicinal plants of the Caatinga (Semi-Arid) vegetation of NE Brazil: a quantitative approach. **Journal of Ethnopharmacology**, v. 114, p. 325-354, 2007.

ALMEIDA, C. L.; SAWAYA, A. C. H. F.; ANDRADE, S. A. L. Mycorrhizal influence on the growth and bioactive compounds composition of two medicinal plants: *Mikania glomerata* Spreng. and *Mikania laevigata* Sch. Bip. ex Baker (Asteraceae). **Brazilian Journal of Botany**, v. 41, p. 233-240, 2018.

ALMEIDA, D. J. *et al.* Growth of chamomile *(Matricaria chamomilla* L.) and production of essential oil stimulated by arbuscular mycorrhizal symbiosis. **Rhizosphere**, v. 15, p. 100208, 2020.

ANDRADE, S. A. L. *et al.* Biochemical and physiological changes in jack bean under mycorrhizal symbiosis growing in soil with increasing Cu concentrations. **Environmental and Experimental Botany**, v. 68, p. 198-207, 2010.

ANDRADE, S. A. L. *et al.* Association with arbuscular mycorrhizal fungi influences alkaloid synthesis and accumulation in *Catharanthus roseus* and *Nicotiana tabacum* plants. **Acta Physiologiae Plantarum**, v. 35, p. 867-880, 2013.

BRASIL. Ministério da Saúde. Relação Nacional de Plantas Medicinais de Interesse ao Sistema Único de Saúde RENISUS. 2009. Available at: https://www.gov.br/saude/pt-br/composicao/sectics/daf/pnpmf/ppnpmf/arquivos/2014/renisus.pdf. Accessed on: 02 Oct. 2023.

CHIOMENTO, J. L. T. *et al.* Arbuscular mycorrhizal fungi communities improve the phytochemical quality of strawberry. **The Journal of Horticultural Science and Biotechnology**, v. 94, p. 653-663, 2019.

CHIOMENTO, J. L. T. *et al.* Arbuscular mycorrhizal fungi influence the horticultural performance of strawberry cultivars. **Research, Society and Development**, v. 10, p. e45410716972, 2021.

CHIOMENTO, J. L. T. *et al*. Mycorrhization of strawberry plantlets potentiates the synthesis of phytochemicals during *ex vitro* acclimatization. **Acta Scientiarum**, v. 44, p. e55682, 2022.

CORDEIRO, E. C. N. *et al*. Arbuscular mycorrhizal fungi action on the quality of strawberry fruits. **Horticultura Brasileira**, v. 37, p. 437-444, 2019.

CRUZ, R. M. S. *et al*. Inoculation with arbuscular mycorrhizal fungi alters content and composition of essential oil of sage (*Salvia officinalis*) under different phosphorous levels. **Australian Journal of Crop Science**, v. 13, p. 1617-1624, 2019.

CRUZ, R. M. S. *et al.* Phytochemistry of *Cymbopogon citratus* (D.C.) Stapf inoculated with arbuscular mycorrhizal fungi and plant growth promoting bacteria. **Industrial Crops and Products**, v. 149, p. 112340, 2020.

DASHTEBANI, F.; HAJIBOLAND, R.; ALIASGHARZAD, N. Characterization of salt-tolerance mechanisms in mycorrhizal (*Claroideoglomus etunicatum*) halophytic grass, *Puccinellia distans*. **Acta Physiologiae Plantarum**, v. 36, p. 1713-1726, 2014.

FALCÃO, E. L.; BASTOS FILHO, C. J. A.; SILVA, F. S. B. Arbuscular mycorrhizal fungi enhance the Sun Protection Factor (SPF) biosynthesis in *Anadenanthera colubrina* (Vell.) Brenan leaves. **Rhizosphere**, v. 24, p. 100595, 2022.

FALCÃO, E. L.; SILVA, F. S. B. Arbuscular mycorrhizal fungi and coconut coir dust application enhance the production of foliar secondary metabolites in *Passiflora cincinnata* Mast. seedlings. **JSFA Reports**, v. 2, p. 247-254, 2022.

FALCÃO, E. L.; SILVA, F. S. B. Arbuscular mycorrhizal fungi acting as biostimulants of proanthocyanidins accumulation – What is there to know? **Rhizosphere**, v. 27, p. 100762, 2023.

FALCÃO, E. L*. et al.* Soil microbial respiration and pH modulated by arbuscular mycorrhizal fungi influence the biosynthesis of health-promoting compounds in *Anadenanthera colubrina* (Vell.) Brenan. **Rhizosphere**, v. 26, p. 100685, 2023a.

FALCÃO, E. L. *et al*. Is there space for arbuscular mycorrhizal fungi in the production chain of photoprotective cosmetics? **Rhizosphere**, v. 28, p. 100811, 2023b.

FALCÃO, E. L.; WU, Q-S.; SILVA, F. S. B. Arbuscular mycorrhizal fungi-mediated rhizospheric changes: What is the impact on plant secondary metabolism? **Rhizosphere**, v.30, p. 100887, 2024a.

FALCÃO, E. L. *et al.* No synergy between P and AMF inoculation to improve Sun Protection Factor production in *Anadenanthera colubrina* (Vell.) Brenan leaves. **Rhizosphere**, p. 100916, 2024b.

FERRARI, M. P. S. *et al*. Substrate-associated mycorrhizal fungi promote changes in terpene composition, antioxidant activity, and enzymes in *Curcuma longa* L. acclimatized plants. **Rhizosphere**, v. 13, p. 100191, 2020.

FREITAS, M. S. M. *et al.* Crescimento e produção de fenóis totais em carqueja [*Baccharis trimera* (Less.) DC.] em resposta à inoculação com fungos micorrízicos arbusculares, na presença e na ausência de adubação mineral. **Revista Brasileira de Plantas Medicinais**, v. 6, p. 30-34, 2004a.

FREITAS, M. S. M.; MARTINS, M. A.; VIEIRA, I. J. C. Produção e qualidade de óleos essenciais de *Mentha arvensis* em resposta à inoculação de fungos micorrízicos arbusculares. **Pesquisa Agropecuária Tropical**, v. 39, p. 887-894, 2004b.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Coordenação de Recursos Naturais e Estudos Ambientais Biomas e sistema costeiro-marinho do Brasil: compatível com a escala 1:250 000**. v.45. Rio de Janeiro: ed. IBGE, 2019.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. 2022. Produção Agrícola - Lavoura Permanente. Instituto Brasileiro de Geografia e Estatística. Available at: https://www.ibge.gov.br/explica/producao-agropecuaria/pe. Accessed on: 02 May 2024.

INSTITUTO NACIONAL DE METEOROLOGIA - INMET. Ministério da Agricultura e Pecuária. Como será o clima no Brasil em abril? 2024. Available at: https://www.gov.br/agricultura/pt-br/assuntos/noticias/como-sera-o-clima-no-brasil-em-abril#:~:text=Temperatura,as%20temperaturas%20podem%20ultrapassar%2026%C2%BAC. Accessed on: 24 May 2024.

HART, M. M.; READER, R. J. Taxonomic basis for variation in the colonization strategy of arbuscular mycorrhizal fungi. **New Phytologist**, v. 153, p. 335-344, 2002.

KLEIN, N. *et al.* Assessment of sedative effects of *Passiflora edulis* f. *flavicarpa* and *Passiflora alata* extracts in mice, measured by telemetry. **Phytotherapy Research**, v. 28, p. 706-713, 2014.

LERMEN, C. *et al*. Essential oil content and chemical composition of *Cymbopogon citratus* inoculated with arbuscular mycorrhizal fungi under different levels of lead. **Industrial Crops and Products**, v. 76, p. 734-738, 2015.

LERMEN, C. *et al*. Essential oil of *Bushy lippia* inoculated with arbuscular mycorrhizal fungi under different levels of humic substances and phosphorus. **Rhizosphere**, v. 25, p. 100660, 2023.

LIMA, C. S.; CAMPOS, M. A. S.; SILVA, F. S. B. Mycorrhizal Fungi (AMF) increase the content of biomolecules in leaves of *Inga vera* Willd. seedlings. **Symbiosis,** v. 65, p. 117-123, 2015a.

LIMA, K. B. *et al*. Crescimento, acúmulo de nutrientes e fenóis totais de mudas de cedro-australiano (*Toona ciliata*) inoculadas com fungos micorrízicos. **Ciência Florestal**, v. 25, p. 853-862, 2015b.

LIMA, C. S. *et al.* Mycorrhizal symbiosis increase the level of total foliar phenols and tannins in *Commiphora leptophloeos* (Mart.) J.B. Gillett seedlings. **Industrial Crops and Products**, v. 104, p. 28-32, 2017.

LUZ, R. C. R. *et al. Entrophospora etunicata*: A mycorrhizal biostimulant with the potential to enhance the production of bioactive health-promoting compounds in leaves of *Capsicum chinense* seedlings. **Rhizosphere**, v. 28, p. 100791, 2023.

MARCOLINO, M. C. *et al*. Bioprospection: *in vitro* antimicrobial potential of the leaf extract of mycorrhizal guava infected by *Meloidogyne enterolobii* on *Klebsiella pneumoniae*. **Anais da Academia Brasileira de Ciências**, v. 93, p. e20201559, 2021.

MELATO, E. *et al.* Inoculation of rue with arbuscular mycorrhizal fungi alters plant growth, essential oil production and composition. **Rhizosphere**, v. 29, p. 100856, 2024.

MERLIN, E. *et al.* Inoculation of arbuscular mycorrhizal fungi and phosphorus addition increase coarse mint (*Plectranthus amboinicus* Lour.) plant growth and essential oil content. **Rhizosphere**, v. 15, p. 100217, 2020.

MUNIZ, B. C. *et al. Acaulospora longula* Spain & N.C. Schenck: A low-cost bioinsumption to optimize phenolics and saponins production in *Passiflora alata* Curtis. **Industrial Crops and Products**, v. 167, p. 113498, 2021.

MUNIZ, B. C. *et al*. The application of coir dust modulates the production of phytochemicals in mycorrhizal *Passiflora alata* Curtis. **Rhizosphere**, v. 23, p. 100573, 2022a.

MUNIZ, B. C.; FALCÃO, E. L.; SILVA, F. S. B. Arbuscular mycorrhizal fungi inoculation stimulates the production of foliar secondary metabolites in *Passiflora setacea* DC. **Brazilian Journal of Microbiology**, v. 53, p. 1385-1393, 2022b.

MUNIZ, B. C. *et al.* Arbuscular mycorrhizae increase but vermicompost decrease the sun protection factor (SPF) in leaves of *Hymenaea martiana* Hayne seedlings. **Rhizosphere**, v. 27, p. 100781, 2023.

MORELLI, F. *et al*. Antimicrobial activity of essential oil and growth of *Ocimum basilicum* (L.) inoculated with mycorrhiza and humic substances applied to soil. **Genetics and Molecular Research**, v. 16, p. 16039710, 2017.

NARDI, F. S. *et al.* Mycorrhizal biotechnology reduce phosphorus in the nutrient solution of strawberry soilless cultivation systems. **Agronomy**, v. 14, p. 355, 2024.

OLIVEIRA, M. S. *et al*. Arbuscular mycorrhizal fungi (AMF) affects biomolecules content in *Myracrodruon urundeuva* seedlings. **Industrial Crops and Products**, v. 50, p. 244-247, 2013.

OLIVEIRA, M. S.; CAMPOS, M. A.; SILVA, F. S. B. Arbuscular mycorrhizal fungi and vermicompost to maximize the production of foliar biomolecules in *Passiflora alata* Curtis seedlings. **Journal of the Science of Food and Agriculture**, v. 95, p. 522-528, 2015a.

OLIVEIRA, M. S.; PINHEIRO, I. O.; SILVA, F. S. B. Vermicompost and arbuscular mycorrhizal fungi: An alternative to increase foliar orientin and vitexin-2-*O*-ramnoside synthesis in *Passiflora alata* Curtis seedlings. **Industrial Crops and Products**, v. 77, p. 754-757, 2015b.

OLIVEIRA, P. T. F. *et al*. Foliar bioactive compounds in *Amburana cearensis* (Allemao) A.C. Smith seedlings: Increase of biosynthesis using mycorrhizal technology. **Journal of Medicinal Plant Research**, v. 9, p. 712-718, 2015c.

OLIVEIRA, P. T. F. *et al.* Production of biomolecules of interest to the anxiolytic herbal medicine industry in yellow passionfruit leaves (*Passiflora edulis* f. *flavicarpa*) promoted by mycorrhizal inoculation. **Journal of the Science of Food and Agriculture**, v. 99, p. 3716-3720, 2019a.

OLIVEIRA, J. S. F. *et al.* Effects of inoculation by arbuscular mycorrhizal fungi on the composition of the essential oil, plant growth, and lipoxygenase activity of *Piper aduncum* L. **AMB Express**, v. 9, p. 29, 2019b.

OLIVEIRA, P. T. F. *et al.* Use of mycorrhizal fungi releases the application of organic fertilizers to increase the production of leaf vitexin in yellow passion fruit. **Journal of the Science of Food and Agriculture**, v. 100, p. 1816-1821, 2020.

PALHARES NETO, L. *et al.* Influence of arbuscular mycorrhizal fungi on morphophysiological responses and secondary metabolism in *Lippia alba* (Verbenaceae) under different water regimes. **Journal of Plant Growth Regulation**, v. 42, p. 827-841, 2022.

PEDONE BONFIM, M. V. L. *et al.* Mycorrhizal technology and phosphorus in the production of primary and secondary metabolites in cebil (*Anadenanthera colubrina* (Vell.) Brenan) seedlings. **Journal of the Science of Food and Agriculture**, v. 93, p. 1479-1484, 2013.

PEDONE BONFIM, M. V. L.; SILVA, F. S. B.; MAIA, L. C. Production of secondary metabolites by mycorrhizal plants with medicinal or nutritional potential. **Acta Physiologiae Plantarum**, v. 37, p. 27, 2015.

PEDONE BONFIM, M. V. L. *et al.* Mycorrhizal inoculation as an alternative for the sustainable production of *Mimosa tenuiflora* seedlings with improved growth and secondary compounds content. **Fungal Biology**, v. 122, p. 918-927, 2018.

PINC, M. M. *et al.* Bioprospecting of lemon balm (*Melissa officinalis* L.) inoculated with mycorrhiza under different rates of phosphorus for sustainable essential oil production. **AIMS Agriculture & Food**, v. 7, p. 916-929, 2022.

PONTES, J. S. *et al.* Diversity of arbuscular mycorrhizal fungi in Brazil Caatinga and experimental agroecosystems. **Biotropica**, v. 49, p. 413-427, 2017.

RITER NETTO, A. F. *et al.* Efeito de fungos micorrízicos arbusculares na bioprodução de fenóis totais e no crescimento de *Passiflora alata* Curtis. **Revista Brasileira de Plantas Medicinais**, v. 16, p. 1-9, 2014.

SANTOS, E. L.; SILVA, F. A.; SILVA, F. S. B. Arbuscular mycorrhizal fungi increase the phenolic compounds concentration in the bark of the stem of *Libidibia ferrea* in field conditions. **Open Microbiology Journal**, v. 11, p. 283-291, 2017.

SANTOS, E. L. *et al. Acaulospora longula* increases the content of phenolic compounds and antioxidant activity in fruits of *Libidibia ferrea*. **Open Microbiology Journal**, v. 14, p. 132-139, 2020.

SANTOS, E. L. *et al.* Use of arbuscular mycorrhizal fungi and phosphorus for increase in the concentration of compounds with antioxidant activity in *Libidibia ferrea*. **Research, Society and Development**, v. 10, p. e13010413827, 2021a.

SANTOS, E. L. *et al.* Is AMF inoculation an alternative to maximize the *in vitro* antibacterial activity of *Libidibia ferrea* extracts? **Research, Society and Development**, v. 10, p. e10010111435, 2021b.

SANTOS, E. L.; FALCÃO, E. L.; SILVA, F. S. B. Mycorrhizal technology as a bioinsumption to produce phenolic compounds of importance to the herbal medicine industry. **Research, Society and Development**, v. 10, p. e54810212856, 2021c.

SILVA, F. A.; SILVA, F. S. B.; MAIA, L. C. Biotechnical application of arbuscular mycorrhizal fungi used in the production of foliar biomolecules in ironwood seedlings [*Libidibia ferrea* (Mart. ex Tul.) L.P. Queiroz var. *ferrea*]. **Journal of Medicinal Plants Research**, v. 8, p. 814-819, 2014a.

SILVA, F. A. *et al.* Arbuscular mycorrhizal fungi increase gallic acid production in leaves of field grown *Libidibia ferrea* (Mart. ex Tul.) L. P. Queiroz. **Journal of Medicinal Plants Research**, v. 8, p. 1110-1115, 2014b.

SILVA, V. C. *et al*. Influence of arbuscular mycorrhizal fungi on growth, mineral composition and production of essential oil in *Mentha* × *piperita* L. var. *citrata* (Ehrh.) Briq. under two phosphorus levels. **Journal of Medicinal Plants Research**, v. 8, p. 1321-1332, 2014c.

SILVA, L. G. S.; MARTIN, L. M. V.; SILVA, F.S.B. Arbuscular mycorrhizal symbiosis in the maximization of the concentration of foliar biomolecules in pomegranate (*Punica granatum* L.) seedlings. **Journal of Medicinal Plants Research**, v. 8, p. 953-957, 2014d.

SILVA, F. A.; SILVA, F. S. B. Is the application of arbuscular mycorrhizal fungi an alternative to increase foliar phenolic compounds in seedlings of *Mimosa tenuiflora* (Wild.) Poir., Mimosoideae? **Brazilian Journal of Botany**, v. 40, p. 361-365, 2017.

SILVA, F. A. *et al*. Bark of the stem of *Libidibia ferrea* associated with mycorrhizal fungi: An alternative to produce high levels of phenolic acids. **Open Microbiology Journal**, v. 12, p. 412-418, 2018a.

SILVA, M. F. *et al.* The effect of arbuscular mycorrhizal fungal isolates on the development and oleoresin production of micropropagated *Zingiber officinale*. **Brazilian Journal of Plant Physiology**, v. 20, p. 119-130, 2018b.

SILVA, F. S. B.; MAIA, L. C. Mycorrhization and phosphorus may be an alternative for increasing the production of metabolites in *Myracrodruon urundeuva*. **Theoretical and Experimental Plant Physiology**, v. 30, p. 297-302, 2018.

SILVA, F. A.; MAIA, L. C.; SILVA, F. S. B. Arbuscular mycorrhizal fungi as biotechnology alternative to increase concentrate of secondary metabolites in *Zea mays* L. **Brazilian Journal of Botany,** v. 42, p. 189-193, 2019.

SILVA, F. A. *et al.* Use of arbuscular mycorrhizal fungi and phosphorus for increase in the concentration of compounds with antioxidant activity in *Libidibia ferrea*. **Research, Society and Development**, v. 10, p. e13010413827, 2021a.

SILVA, B. D. A. E. *et al*. Interaction between mycorrhizal fungi and *Meloidogyne javanica* on the growth and essential oil composition of basil (*Ocimum basilicum*). **Australian Journal of Crop Science**, v. 15, p. 416-421, 2021b.

SILVA, M. T. R. *et al*. Arbuscular mycorrhizae maintain lemongrass citral levels and mitigate resistance despite root lesion nematode infection. **Rhizosphere**, v. 19, p. 100359, 2021c.

SILVA, M. T. R. *et al*. Pre-inoculation with arbuscular mycorrhizal fungi affects essential oil quality and the reproduction of root lesion nematode in *Cymbopogon citratus*. **Mycorrhiza**, v. 31, p. 613-623, 2021d.

SILVA, F. S. B.; SILVA, F. A. A low cost alternative, using mycorrhiza and organic fertilizer, to optimize the production of foliar bioactive compounds in pomegranates. **Journal of Applied Microbiology**, v. 128, p. 513-517, 2020.

SOUZA, B. C. *et al*. Inoculation of lemongrass with arbuscular mycorrhizal fungi and rhizobacteria alters plant growth and essential oil production. **Rhizosphere,** v. 22, p. 100514, 2022.

TRINDADE, R. *et al.* Influence on secondary metabolism of *Piper nigrum* L. by co-inoculation with arbuscular mycorrhizal fungi and *Fusarium solani* f. sp. *piperis*. **Microorganisms**, v. 9, p. 484, 2021.

URCOVICHE, R. C. *et al.* Plant growth and essential oil content of *Mentha crispa* inoculated with arbuscular mycorrhizal fungi under different levels of phosphorus. **Industrial Crops and Products**, v. 67, p. 103-107, 2015.

VIEIRA, M. E. *et al*. Arbuscular mycorrhizal fungi and phosphorus in spilanthol and phenolic compound yield in jambu plants. **Horticultura Brasileira**, v. 39, p. 192-198, 2021.

WEISSENHORN, I. *et al.* Differential tolerance to Cd and Zn of arbuscular mycorrhizal (AM) fungal spores isolated from heavy metal-polluted and unpolluted soils. **Plant and Soil**, v. 167, p. 189-196, 1994.

WU, Q-S. *et al.* Arbuscular mycorrhiza-mediated augmentation of plant secondary metabolite production. **Frontiers in Plant Science**, v. 14, p. 1150900, 2023.