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## Original Research Article

# Control of *Alternaria alternata* using Melaleuca essential oil (*Melaleuca alternifolia*)

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### ABSTRACT

**Aims:** This study aimed to evaluate the fungitoxic potential of Melaleuca essential oil on the mycelial growth of *Alternaria alternata* under *in vitro* condition and the treatment of cowpea beans.

**Study desing:** The experiments comprised completely randomized designs: Eleven treatments with five replicates on *in vitro* test; and six treatments with five replicates on *in vivo* test.

**Place and Duration of Study:** The work was carried out at the Center for Agrifood Science and Technology of the Federal University of Campina Grande, Pombal, Brazil, between February 2018 to February 2019.

**Methodology:** In the *in vitro* experiment, the essential oil was incorporated into the culture medium and poured into Petri dishes. The treatments consisted of different concentrations of the oil (0.0125, 0.025, 0.05, 0.1, 0.2, 0.25, 0.50, 0.75, and 1.0%), a negative control (0.0%), and a positive control (Thiram). Discs of culture medium with fungal mycelia were inoculated in the center of the plates and incubated for seven days at 27±2°C. We calculated the percentage of mycelial growth inhibition (PGI) and the index of mycelial growth speed (IMGs) to verify the difference between treatments. In the *in vivo* experiment, the bean seeds were treated with different concentrations of oil (0.0, 0.2, 0.5, 1.0, and 5.0%), a negative control (0.0%), and positive control (Thiram). Seeds were inoculated with colonies of the fungus for 48 hours, and after that, we performed the seed sanity test.

**Results:**— Under *in vitro* conditions, all concentrations of melaleuca essential oil reduced the mycelial growth of *A. alternata*. The oil reached complete inhibition of fungal growth from 0.2% concentration and above. In the cowpea treatment, the essential oil had no significant control over the percentage of infected seeds.

**Conclusion:** The melaleuca essential oil had a fungitoxic effect on the *A. alternata* under *in vitro* conditions. However, using the adopted methodology, on the cowpea bean seed treatment, the essential oil had was not reduce the incidence of *A. alternata*.

**Keywords:** Alternative control, Cowpea bean, Mycelial growth, Phytopathogenic fungi, Tea-tree, Seeds disease, *Vigna unguiculata*.

## 1. INTRODUCTION

Cowpea bean (*Vigna unguiculata* (L.) Walp), popularly known as the string bean or macaçar bean, is a source of protein and staple food for a large part of the population of the North and Northeast of Brazil, thus one of the most important crops in the country [1]. According to CONAB [2], Brazil occupies the third position in world bean production with a cultivation area of approximately one million hectares, with the North and Northeast regions accounting for about 90% of the cultivated area [3].

25 Cowpea cultivation has a very competitive production cost, a factor that has increased the farmers' interest in the crop. In  
26 addition, Brazilian production is of high quality, enabling the product to have good acceptance in all members of its  
27 production chain [4]. However, diseases represent a limiting factor to income expansion.  
28

29 Fungi are the main phytopathogens that cause economic losses in bean crop. When present in the seed, they can cause  
30 miscarriages, deformations and discoloration of the bark, which always leads to the reduction of seed germination  
31 potential and vigor, and when allocated in the field will result in low or no yielding uneven plant stands [5]. Diseases  
32 caused by fungi with the greatest economic impact on bean crop are caused by *Macrophomina phaseolina* [6], *Fusarium*  
33 spp. [7], *Rhizoctonia solani* [8], *Curvularia* spp., *Trichoderma* spp. [9], *Alternaria* spp. [10], *Aspergillus* sp. and *Penicillium*  
34 sp. [11].  
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36 Considering bean pathogen control practices, treatment with synthetic agrochemicals has been a conventionally used.  
37 However, the use of these products has been associated with significant damage to human health and the environment  
38 due to their high toxicity [12,13] besides favoring the emergence of resistant strains [14].  
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40 In this scenario, it is necessary to use alternative products to chemical pesticides that have similar efficacy but are not  
41 harmful to human health and the environment. Among the products studied are essential oils extracted from aromatic  
42 plants, which have fungitoxic properties on phytopathogens [15,16,17].  
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44 Melaleuca essential oil (*Melaleuca alternifolia*) has been studied for some years and its antimicrobial activity has been  
45 well documented. The main components of this oil are: terpineol, cineol, terpenene, cymene, limonene and sabinene [18].  
46 Most compounds have inhibitory activity against fungi and bacteria [19]. Among these, terpineol is the main antifungal  
47 constituent [20]. In the control of phytopathogens its use has shown promising results in the control of fungi *Cercospora*  
48 *beticola* [21], *Aspergillus niger*, *M. phaseolina*, *Penicillium* sp. and *Sclerotinia sclerotiorum* [22], demonstrating a strong  
49 antimicrobial activity.  
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51 The antifungal action of oils is related to their ability to dissolve in lipid media, causing modifications in the cell membrane  
52 structure [23]. Due to their low toxicity and rapid degradation in the environment, the use of essential oils to combat  
53 phytopathogens may be a good alternative to synthetic pesticides [24]. Thus, this work aimed to evaluate the fungitoxic  
54 potential of melaleuca essential oil on the mycelial growth of *Alternaria alternata* under *in vitro* conditions and in the  
55 treatment of cowpea seeds.  
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## 57 2. MATERIAL AND METHODS

  
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### 59 2.1 Place of experiments

  
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61 The work was conducted at the Center of Science and Technology Agrifood (CCTA) of the Federal University of Campina  
62 Grande (UFCG), Campus of Pombal. The experiments were carried out in the Phytopathology laboratory, between  
63 february 2018 to february 2019.  
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### 65 2.2 Sampling

  
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67 We used the fungal strain of *Alternaria alternata* 0878 yielded by the collection of phytopathogenic fungi Prof. Maria  
68 Menezes of the Federal Rural University of Pernambuco (UFRPE). The fungi were preserved in sterile distilled water by  
69 the Castellani method until the assay [25].  
70

71 The pure essential oil of Melaleuca (*Melaleuca alternifolia*) was purchased at a local store specialized in natural products.  
72 The cowpea bean seeds (*Vigna unguiculata* L. Walp) were purchased at a commercial house in the city of Patos, Paraíba.  
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### 74 2.3 Screening of the antifungal activity of Melaleuca essential oil in vitro

  
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76 Eleven treatments were used, 9 oil concentrations (0.0125, 0.025, 0.1, 0.2, 0.5, 0.25, 0.50, 0.75 and 1.0%), a negative  
77 control (without essential oil supplementation=0.0%) and a positive control (supplemented with 1 mL L<sup>-1</sup> of the fungicide  
78 Thiram, which is the dosage indicated by the manufacture's). Five replicates of each treatment were arranged in  
79 completely randomized design (CRD).  
80

81 The treatments were incorporated into PDA (Potato Dextrose Agar) culture medium just before pouring in sterilized Petri  
82 dishes. After solidification, one-centimeter mycelial disks were taken from the margins of 7days old culture and transferred  
83 to the center of each plate containing the treatments. The plates were then wrapped in plastic film and incubated in a BOD  
84 (Biochemical Oxygen Demand) at a temperature of 27±2°C.  
85

86 The concentrations were chosen from an initial concentration based on the literature [26,27] and then gradually reduced  
87 until the addition of oil to the medium was no longer able to prevent the fungal growth. To obtain the final concentrations,  
88 the direct dilution procedure in a culture medium [28] was used.  
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90 Colony growth was measured daily until the colony took the entire surface of the culture medium in one of the plates or in  
91 a maximum period of 7 days. Mycelial growth evaluation consisted of daily measurements of the diameter of the colonies  
92 obtained through the average of two perpendicular measurements, using a digital caliper, resulting in the average daily  
93 growth for each repetition of each treatment.  
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95 The percentage of mycelial growth inhibition (PGI; [29]) and mycelial growth rate index (IMGS; [30]) were calculated  
96 according to formulas (1) and (2):  
97

$$98 \quad PGI = \frac{[(negative\ control\ growth - treatment\ growth)] \times 100}{negative\ control\ growth} \quad (1)$$

$$100 \quad IMGS = \sum \frac{current\ mycelial\ growth - previous\ mycelial\ growth}{number\ of\ days\ of\ incubation} \quad (2)$$

102 The minimum inhibitory concentration was considered the lowest oil concentration capable of totally inhibiting *Alternaria*  
103 *alternata* mycelial growth.  
104

#### 105 **2.4 Screening of the antifungal activity of Melaleuca essential oil *in vivo* (on cowpea bean seeds)**

106 The experiment consisted of a completely randomized desing. The treatments consisted of sterilized distilled water  
107 solutions supplemented with 4 oil concentrations (0.2, 0.5, 1.0 and 5.0%), a negative control (without essential oil  
108 supplementation=0.0%) and and a positive control (supplemented with 1 ml L<sup>-1</sup> of the fungicide Thiram, which is the  
109 dosage indicated by the manufacture's). The concentrations used were determined based on the *in vitro* test. To emulsify  
110 the oin in the water Tween 80 (1 mL L<sup>-1</sup>) was used [31].  
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113 The cowpea bean seeds were desinfected in 2.0% sodium hypochlorite solution for five minutes, washed with sterile  
114 distilled water twice and dried at room temperature. Afterwards they were immersed for five minutes in different solutions  
115 (treatments). After drying at room temperature, the artificial inoculation was performed.  
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118 The inoculation was done depositing the seeds on colonies of *A. alternata* with 7 days of age. The seeds and the fungal  
119 colonies stayed for 48 hours in a BOD 27±2°C, with a 12-hour photoperiod [32].  
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121 After the treatment and inoculation, the samples were submitted to the sanity test, which was performed by the filter paper  
122 method with freezing [33]. Six hundred of cowpea bean seeds (100 per treatment) were used, distributed in Petri dishes  
123 (Ø=14 cm). In this method, ten seeds were placed at equal distances on each plate on triple layer of filter paper previously  
124 moistened in sterile distilled water and incubated initially for 24 hours on BOD at 27±2°C, with a 12-hour photoperiod.  
125 After this period, they were subjected to freezing (-20°C) for 24 hours, and then returned to the incubator for another five  
126 days.  
127

128 After incubation, the seed were examined individually, using a stereoscopic microscope, for the quantification of seeds  
129 infected by *Alternaria alternata*. The results were expressed as percentage of infected seeds.  
130

#### 131 **2.5 Statistical analysis**

132 The effect of oil concentration on fungal growth was analyzed using regressions in quadratic plateau model for *in vitro*  
133 experiment and in linear model for *in vivo* experiment.  
134

135 To test the difference between treatments with the essential oil and the treatment containing the fungicide (positive  
136 control), Mann-Whitney (Tukey nonparametric) multiple comparisons were applied. Non-parametric tests were used  
137 because of the lack of variance in the results of some treatments. Differences with a probability values below 5% were  
138 considered significant. The regressions were performed in the program R CoreTeam 3.5.1[34].  
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### 141 **3. RESULTS AND DISCUSSION**

#### 142 **3.1 *In vitro* antifungal assay**

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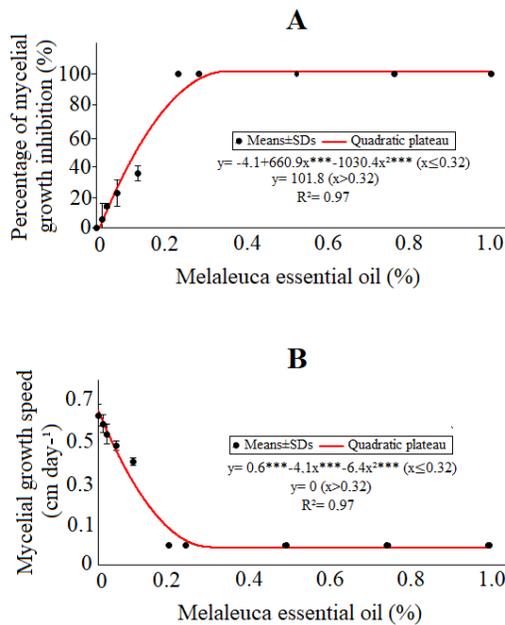
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### 3.1.1 Effects of Melaleuca essential oil on *Alternaria alternata*

All tested concentrations of melaleuca essential oil reduced the mycelial growth and growth speed of *Alternaria alternata*. The inhibition percentages increased significantly with the concentrations ( $P < .001$ )—reaching the maximum value (PGI=100%) the 0.2% concentration of the oil (Fig 1A), which is the minimum inhibitory concentration (MIC). On the other hand, applying the regression equation in a quadratic plateau model, the estimated minimum concentration (MCest) was 0.33%.

The mycelial growth rate is a variable inversely proportional to the inhibition percentage. For this reason, it presented opposite behavior, with significant reduction with the tested oil concentrations ( $P < .001$ ). The mycelial growth rate was more effectively reduced from the 0.2% concentration, in which growth paralyzed (IMGS=0.00 cm day<sup>-1</sup>) (Fig 1B), differing from the negative control, which presented the highest growth speed (0.63 cm day<sup>-1</sup>).



**Figure 1.** Inhibition percentage and mycelial growth speed of melaleuca essential oil against *Alternaria alternata*.

\*\*\*Level of significance below 0.1% ( $P < .001$ )

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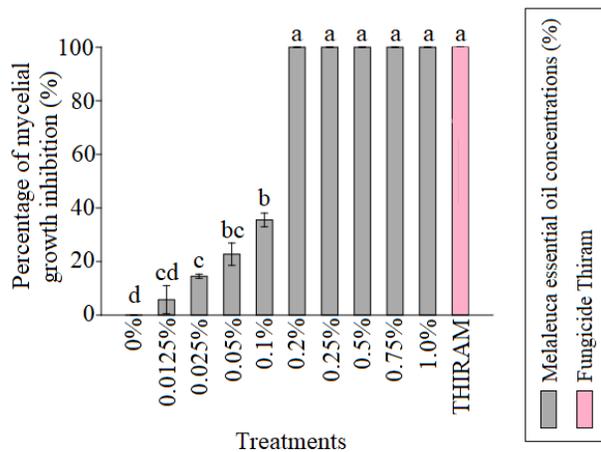
According to the literature, terpinenol (terpinen-4-ol) is the major constituent of the melaleuca essential oil, which is associated with your high fungitoxic potential [35]. One of the antifungal mechanisms of action of melaleuca essential oil is the change in the permeability and fluidity of the cell membranes of the microorganisms. As these organisms are permeable to oil, the main effects found are inhibition of cell respiration and alteration in membrane structure and integrity, as well as leakage of essential intracellular materials. These events cause growth inhibition or even cell death [36,37].

Using tea tree oil at concentrations close to or greater than ours, other authors obtained similar inhibition results. For example, Martins et al. [22] obtained total inhibition of *Macrophomina phaseolina* and *Sclerotinia sclerotiorum* at concentration 0.2%. While in the control of *Alternaria radicina* and *A. dauci*, Rlcioni and Orzali [38] reached the maximum inhibition from the concentration 0.5%.

Using the essential oil of the other plant species on control of *A. alternata*, other authors obtained similar results as superior or inferior to ours. For example, the total inhibition was achieved by Chutia et al. [39], Guimarães et al. [40] and Barboza [41] using mandarin orange (*Citrus reticulata*), lemongrass (*Cymbopogon citratus*) and alecrim-da-chapada (*Lippia gracilis*) essential oil at concentrations of 0,2 mL/100mL (0,2%), 14,49 µg mL<sup>-1</sup> (0,0014%) e 750 µL L<sup>-1</sup> (0,075%),

179 respectively. On the other hand, using peppermint essential oil (*Mentha piperita*), França et al. [42] obtained a maximum  
 180 inhibition of 41.6% at a concentration of 0.8%. Thus, both the fungitoxic potential of essential oils on *A. alternata*, as well  
 181 as their minimum inhibitory concentrations will vary depending on the plant species from which the essential oil was  
 182 extracted [43]. In addition, increasing inhibitory power as a function of increased concentration can either potentiate the  
 183 effect or generate product waste.

184  
 185 To understand the potential of melaleuca essential oil as a fungicide on *A. alternata*, we compared its fungitoxic effect with  
 186 that obtained by the fungicide Thiram (commercial synthetic fungicide). We observed strong inhibition effect of the oil  
 187 concerning the fungicide from the concentration of 0.2% (Fig 2). This result suggests that under *in vitro* conditions the oil  
 188 could replace the use of this agrochemical.



212 **Figure 2.** Effect of different treatments (melaleuca essential oil and the control treatments) on the mycelial growth  
 213 inhibition of *Alternaria alternata*.

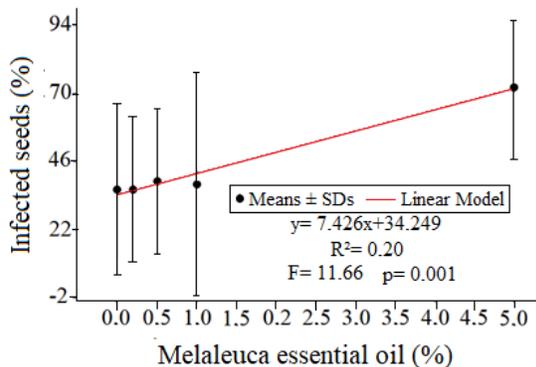
214 Superscript concentrations with the same letter were not significantly different from each other by the MannWhitney test ( $P > .05$ )

215  
 216 Due to the chemical complexity, the antifungal control promoted by essential oils is associated with their different  
 217 constituents [44] through different mechanisms of action that act simultaneously on different targets [15]. These peculiar  
 218 characteristics guarantee the advantage over synthetic fungicide, since they reduce the possibility of resistance by  
 219 phytopathogens [45].

### 221 3.2 *In vivo* antifungal assay

#### 223 3.2.1 Effects of Melaleuca essential oil on cowpea beans seed infected with *Alternaria alternata*

224  
 225 Contrary to that observed on the *in vitro* test, in cowpea bean seed treatment, the melaleuca essential oil was ineffective  
 226 in combating the incidence of *A. alternata*. Increasing concentrations did not reduce the number of seeds infected by the  
 227 phytopathogen ( $P < .001$ ; Fig 3).



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**Figure 3.** Effect of concentrations of melaleuca essential oil in the incidence of infected cowpea bean seeds by *Alternaria alternata*.

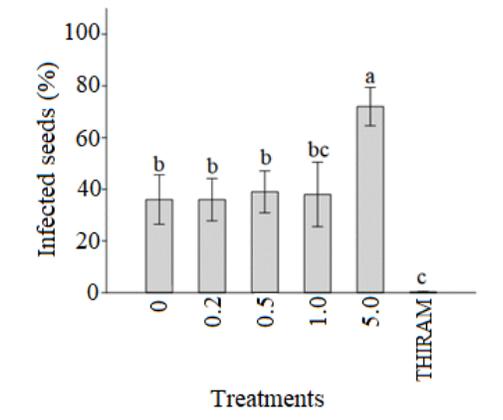
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The incidence of infected seeds at all oil concentrations was higher than the negative control (treatment without the addition of oil). One of the hypotheses raised by the authors is that the essential oil did not adhere to the seed surface due to the high volatilization of its constituents. Thus, during the incubation period some constituents may have evaporated and reduced to their antimicrobial capacity.

Khalili et al. [46] emphasize that the formation of oils by volatile compounds and their subsequent degradation may be influenced by ambient temperature. And according to Simões and Spitezer [47] and Rozwalka et al. [48], the volatilization of oil constituents as well as their instability in the presence of light, heat and humidity, modify the atmosphere inside the Petri dishes, leading to the loss of the effectiveness of an oil that, under other conditions, inhibited fungal growth.

The effect of melaleuca essential oil on the incidence of infected seeds was lower than Thiram fungicide at all concentrations tested (Fig 4). Between 0.2 and 1%, the oil did not differ significantly from the negative control ( $P>.05$ ), while at the 5% concentration, the oil promoted an increased incidence of phytopathogen in relation to the control. On the other hand, the treatment containing the Thiram fungicide prevented the development of phytopathogen in the seeds.

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**Figure 4.** Percentage of infected cowpea bean seeds by *Alternaria alternata* after the treatment with different concentrations of melaleuca essential oil and the control treatments.

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In the present study, although the melaleuca essential oil did not provide satisfactory results in the *in vivo* experiment, against other phytopathogens the use of essential oils in the treatment of bean seeds was successful. In the treatment of carioquinha bean seeds. Using carioquinha bean seeds treated with lemongrass (*Cymbopogon flexuosus* and *C. citratus*) and melaleuca (*Melaleuca* sp.) essential oils, Morais et al. [49] obtained a significant reduction in the incidence of seeds infected by *Aspergillus* sp. and *Penicillium* sp. Whereas, Wanderley et al. [50] proved the efficacy of citronella

(*Cymbopogon* sp.) fennel (*Pimpinella anisum*) and alfavaca (*Ocimum basilicum*) essential oils at a concentration of 1.5% over *Callosobruchus maculatus* in butterbean seeds.

Finally, despite the ineffectiveness of melaleuca essential oil in the treatment of cowpea bean seed, this oil may be useful in the treatment of other seeds and other pathogens. Essential oils present a low risk to the environment, producers and consumers, and hinder the development of pathogen resistance [51]. Thus, further studies on the use of these oils in the management of plant pathogens are needed to make them a viable alternative for farmers.

#### 4. CONCLUSIONS

Under *in vitro* conditions, melaleuca essential oil (*Melaleuca alternifolia*) totally inhibited the mycelial growth of *Alternaria alternata* from 0.2%, had an similar effect to the commercial fungicid Thiram. On the cowpea bean seed treatment, the essential oil had was not able to reduce the incidence of *A. alternata* using the adopted methodology.

#### REFERENCES

1. Neves AC. et al. Cultivo do feijão-caupi em sistema agrícola familiar. Teresina- PI: Embrapa Meio Norte, 2011:15. (Embrapa Meio Norte. Circular Técnica, 51). Portuguese.
2. CONAB - Companhia Nacional de Abastecimento. Perspectiva para a Agropecuária. Brasília. 2018;6:1-112. Portuguese.
3. Santos LAC, Silva DMP, Oliveira IA, Pereira CE, Campos MCC. Crescimento de cultivares de feijão-caupi em solo de terra firme e várzea. *Ambiência Guarapuava*. 2017;13(1):261-270. Portuguese.
4. Freire Filho FR. Feijão-caupi no Brasil: Produção, melhoramento genético, avanços e desafios. Embrapa Meio-Norte, Teresina. 2011:84. Portuguese.
5. Machado JC. Tratamento de sementes no controle de doenças. *Lavras: LAPS/UFLA/FAEPE*. 2000:13.
6. Athayde Sobrinho C, Viana FMP, Santos A. Doenças fúngicas e bacterianas. In: Freire Filho FR, Lima JAA, Ribeiro VQ. Feijão-caupi: avanços tecnológicos. (EDIÇÃO) Brasília, DF: Embrapa Informação Tecnológica, 2005, capítulo 12, p.461-484.
7. Rodrigues AAC, Menezes M. Detecção de fungos endofíticos em sementes de caupi provenientes de Serra Talhada e de Caruaru, estado de Pernambuco. *Fitopatologia Brasileira*. 2002;27(5):532-537. Portuguese.
8. Nechet KL, Halfeld-Vieira BA. Caracterização de isolados de *Rhizoctonia* spp., associados à mela do Feijão-Caupi (*Vigna unguiculata*), coletados em Roraima. *Fitopatologia Brasileira*. 2006;31:505-508.
9. Sinha A, Singh SK, Qaisar J. Seed mycoflora of French bean and its control by means of fungicides. *Tropenlandwirt. Witzenhousen*. 1999;11(1):59-67.
10. Marques RO, Alves VM, Lima MLP, Arruda GMT. Avaliação sanitária e fisiológica de feijão oriundos de Unaí – MG, Paracatu-MG e Cristalina-GO. *Summa Phytopathologica*. 2006;32(Suplemento). Portuguese.
11. Torres SB, Bringel JMM. Avaliação da qualidade sanitária e fisiológica de sementes de feijão macassar. *Caatinga*. 2005;18(2):88-92. Portuguese.
12. Candido e Silva EK, Melo LGL. Manejo de doenças de plantas: Um enfoque agroecológico. *Revista EDUCamazônia–Educação Sociedade e Meio Ambiente*. 2013;10(1):143-157. Portuguese.
13. Perina FJ. Óleos essenciais e frações majoritárias ativas no controle da mancha marrom de alternaria (*Alternaria alternata*) em tangerina ponkan. 2014. 112f. Tese (Doutorado em Agronomia). Universidade Federal de Lavras, Lavras, MG, 2014. Portuguese.
14. Hillen T, Schwan-Estrada KRF, Mesquinl RM, Cruz MES, Stangarlin JR, Nozaki M. Atividade antimicrobiana de óleos essenciais no controle de alguns fitopatógenos fúngicos *in vitro* e no tratamento de sementes. *Revista Brasileira de Plantas Mediciniais*. 2012;14(3):439-445. Portuguese.

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- 343 15. Abdel-Kader MM, El-Mougy NS, Lashin SM. Essential oils and *Trichoderma harzianum* as an integrated control  
344 measure against faba bean root rot pathogens. *Journal of Plant Protection Research*. 2011;51(3):306-311.
- 345
- 346 16. Silva M, Souza HRT, David HMSS, Santos LM, Silva RF, Amaro HTR. Qualidade fisiológica e armazenamento de  
347 sementes de feijão-comum produzidas no norte de Minas Gerais. *Revista Agro Ambiente*. 2014;8:97-103. Portuguese.
- 348
- 349 17. Santos MM, Peixoto AR, Pessoa ES, Nepa HBS, Paz CD; Souza AVV. Estudos dos constituintes químicos e  
350 atividade antibacteriana do óleo essencial de *Lippia gracilis* a *Xanthomonas campestris* pv. *viticola* "in vitro". *Summa*  
351 *Phytopathologica*, Botucatu. 2014;40(3):277-280. Portuguese.
- 352
- 353 18. Carson CF, Hammer KA, Riley TV. *Melaleuca alternifolia* (tea tree) oil: A review of antimicrobial and other medicinal  
354 properties. *Clinical Microbiology Reviews*. 2006;19(1):50-62.
- 355
- 356 19. Sagave L, Gressler LT, Flores FC, Silva CB, Vargas APC, Lovato M, Sangioni LA, Pötter L, Botton SA. Atividade de  
357 nanoformulações de *Melaleuca alternifolia* e terpinen-4-ol em isolados de *Rhodococcus equi*. *Arquivo Brasileiro de*  
358 *Medicina Veterinária e Zootecnia*. 2015;67(1):221-226. Portuguese.
- 359
- 360 20. Vieira TR, Barbosa LCA, Maltha CRA, Paula VF, Nascimento EA. Constituintes químicos de *Melaleuca alternifolia*  
361 (Myrtaceae). *Química Nova*. 2004;27(4):536-539. Portuguese.
- 362
- 363 21. Souza AD, Roggerio TU, Furlan MR, Aoyama EM. Óleo de melaleuca (*Melaleuca alternifolia* Maiden & Betche, Cheel)  
364 no controle de cercosporiose em beterraba. *Revista Brasileira de Plantas Mediciniais*. 2015;17(4):1078-1082. Portuguese.
- 365
- 366 22. Martins JAS, Sagata E, Santos VA, Juliantti FC. Avaliação do efeito do óleo de *Melaleuca alternifolia* sobre o  
367 crescimento micelial *in vitro* de fungos fitopatogênicos. *Bioscience Journal*. 2010;27(1):49-51a. Portuguese.
- 368
- 369 23. Brum RBCS, Cardon CH, Pereira AS, Cardoso DP, Dos Santos GR. Atividade antifúngica de óleos essenciais sobre  
370 fungos fitopatogênicos. *Magistra*. 2014;26(3):361-371. Portuguese.
- 371
- 372 24. Silva BVS, Paiva GF, Barbieri TPOM, Souza GHS, Gonçalves FJT. Efeito dos Óleos Essenciais Sobre o Crescimento  
373 Micelial *in vitro* de *Colletotrichum* spp. *Cadernos de Agroecologia*. 2018;13(2):1-9. Portuguese.
- 374
- 375 25. Castellani A. Maintenance and cultivation of common pathogenic fungi of man in sterile distilled water. Further  
376 Researches. *Journal of Tropical Medicine and Hygiene*. 1967;70:181-84.
- 377
- 378 26. Concha JM, Moore LS, Holloway WJ. Antifungal activity of *Melaleuca alternifolia* (tea-tree) oil against various  
379 pathogenic organisms. *Journal. American Podiatric Medical Association*. 1998;88(10):489-92.
- 380
- 381 27. Martins ESCS, Santos MS, Barros HMM, Farias MAA. Efeito dos óleos essenciais de citronela, alecrim e erva-cidreira  
382 no controle *in vitro* de *Ralstonia solanacearum* em pimentão. *Tecnologia & Ciência Agropecuária*. 2010;4(1):9-  
383 13b. Portuguese.
- 384
- 385 28. Pereira MC, Vilela GR, Costa LMAS, Silva RF, Fernandes AF, Fonseca EWNF, Picolli RH. Inibição do  
386 desenvolvimento fúngico através da utilização de óleos essenciais de condimentos. *Ciência e Agrotecnologia*, v. 30, n. 4,  
387 p. 731-738, 2006. Portuguese.
- 388
- 389 29. Bastos CN. Efeito do óleo de *Piper aduncum* sobre *Crinipellis pernicioso* e outros fungos fitopatogênicos. *Fitopatologia*  
390 *Brasileira*. 1997;22(3):441-443. Portuguese.
- 391
- 392 30. Oliveira JA. Efeito do tratamento fungicida em sementes no controle de tombamento de plântulas de pepino (*Cucumis*  
393 *sativus* L.) e pimentão (*Capsicum annum* L.). 1991. 111 f. Dissertação (Mestrado em Fitossanidade) – Escola Superior de  
394 Agricultura de Lavras, Lavras, 1991. Portuguese.
- 395
- 396 31. Santos PL. Manejo de *Macrophomina phaseolina* (Tassi) Goid. em sementes de feijoeiro (*Phaseolus vulgaris* L.) com  
397 óleos essenciais e antagonistas. 2018. 76f. Tese (Doutorado em Agronomia) – Universidade Estadual Paulista,  
398 Botucatu-SP. Portuguese.
- 399
- 400 32. Silva MAD, Silva WR. Comportamento de fungos e de sementes de feijoeiro durante o teste de envelhecimento  
401 artificial. *Pesquisa Agropecuária Brasileira*. 2000;35(3):599-608. Portuguese.
- 402
- 403 33. Limonard T. A modified blotter test for seed health. *Netherland Journal of Plant Pathology*. 1996;72(2):319-321.

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463

34. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria; 2018. Disponível em: <https://www.R-project.org/>.
35. Hammer KA, Carson CF, Riley TV. Effects of *Melaleuca alternifolia* (Tea Tree) essential oil and the major monoterpene component Terpinen-4-ol on the development of single and multistep antibiotic resistance and antimicrobial susceptibility. *Antimicrobial Agents and Chemotherapy*. 2012;52(2):909-915.
36. Hammer KA, Carson CF, Riley TV., Antifungal effects of *Melaleuca alternifolia* (Tea tree) oil and its components on *Candida albicans*, *Candida glabrata* and *Saccharomyces cerevisiae*. *Journal of Antimicrobial Chemotherapy*. 2004;53:1081-1085.
37. Azevedo FA, Polydoro DA, Bastianel M, Kupper KC, Stuart RM, Costa FP, Pio RM. Resposta de diferentes genótipos de tangerinas e seus híbridos à inoculação *in vitro* e *in vivo* de *Alternaria alternata*. *Revista Brasileira de Fruticultura*. 2010;32:1-8. Portuguese.
38. Riccioni L, Orzali L. Activity of tea tree (*Melaleuca alternifolia*, Cheel) and thyme (*Thymus vulgaris*, Linnaeus.) essential oils against some pathogenic seed borne fungi. *Journal of Essential Oil Research*. 2011;23(6):43-47.
39. Chutia M, Bhuyan PD, Pathak MG, Sharma TC, Boruah P. Antifungal activity and chemical composition of *Citrus reticulata* Blanco essential oil against phytopathogens from North East India. *LWT - Food Science and Technology*. 2009;42:777-780.
40. Guimarães LGL, Cardoso MG, Sousa PE, Andrade J, Vieira SS.— Atividades antioxidante e fungitóxica do óleo essencial de capim-limão e do citral. *Revista Ciência Agronômica*. 2011;42(2):464-472. Portuguese.
41. Barboza HS. Efeito fungitóxico do óleo essencial de alecrim-da-chapada em *Alternaria* sp. 2015. 31fls. Trabalho de Conclusão de Curso (Graduação em Agronomia) – Universidade Federal do SemiÁrido, Mossoró, RN, Brasil. 2015. Portuguese.
42. França KRS, Lima TS, Cardoso TAL, Ugulino ALN, Rodrigues APMS, Mendonça Júnior AF. *In vitro* Effect of essential oil of peppermint (*Mentha x piperita* L.) on the mycelial growth of *Alternaria alternata*. *Journal of Experimental Agriculture International*. 2018;26(5):1-7.
43. Antunes MDC, Cavacob A. The use of essential oils for postharvest decay control. A review. *Flavour Fragrance Journal*. 2010;25:351-366.
44. Russo M, Suraci F, Postorino S, Serra D, Roccotelli A, Agosteo GE. Essential oil chemical composition and antifungal effects on *Sclerotium cepivorum* of *Thymus capitatus* wild populations from Calabria, southern Italy. *Revista Brasileira de Farmacognosia*, v. 23, n. 2, p. 239-248, 2013.
45. Feng W, Zheng X. Essential oils to control *Alternaria alternata* *in vitro* and *in vivo*. *Food Control*. 2007;18:1126-1130.
46. Khalili ST, Mohsenifar A, Beyki M, Zhavah S, Rahmani-Cherati T, Abdollahi A, Bayat M, Tabatabaei M. Encapsulation of Thyme essential oil in chitosan-benzoic acid nanogel with enhanced antimicrobial activity against *Aspergillus flavus*. *Food Science and Technology*. 2015;60(1):502-508.
47. Simões CMO, Spitzer V. Óleos voláteis. In: Gosmann G, Mello JCP, Simões CMO, Schenkel EP. (Org.). *Farmacognosia: da planta ao medicamento*. 5th ed. Porto Alegre: UFRGS/UFSC, p.467-495. 2004. Portuguese.
48. Rozwalka LC. Extratos, decotos e óleos essenciais de plantas medicinais e aromáticas na inibição de *Glomerella cingulata* e *Colletotrichum gloeosporioides* de frutos de goiaba. *Ciência Rural*. 2008;58(2):301-307. Portuguese.
49. Moraes LAS, Ramos NP, Gonçalves GG, Betiol W, Chaves FCM. Atividade antifúngica dos óleos essenciais em sementes de feijão cv. Carioquinha. *Horticultura Brasileira*. 2008;26(2):6261-6266 Portuguese.
50. Wanderley MJA, Silva TMB, Arruda JD, Rocha RB, Cruz CSA, Wanderley PA. Efeito de óleos essenciais sobre *Callosobruchus maculatus* em feijão caupi *Vigna unguiculata* L. Walp. In: 6º Congresso Brasileiro de Plantas Oleaginosas, Óleos, Gorduras e Biodiesel. 2009. Minas Gerais, Montes Claros, 2009. Portuguese.

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464 51. Derbahlah AS, Hhamza AM, Gazzy AA. Efficacy and safety of some plant extracts as alternatives for *Sitophilus oryzae*  
465 control in rice grains. Journal of Entomology. 2012;9:57-67.  
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