

Essential Oils in postharvest management of 'Dancy' tangerine

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Abstract: Alternative post-harvest management of phytopathogens has proven to be efficient and sustainable. This research aimed to determine the action of essential oils on the behavior of the fungus *A. alternata* f. sp. *citri* and postharvest quality changes of 'Dancy' tangerine fruit. The experiment was conducted at the Phytopathology Laboratory of the Federal University of Paraíba. 'Dancy' mandarin fruits were harvested at the C2 ripening stage. The treatments used on the fruits were: essential oils of ginger, copaiba, mint, fennel, and citronella, diluted in sterile water at 1%. Additional controls were the fungicide Thiabendazole (400 mL 100 L⁻¹) and the control (untreated). The experiment was conducted in a controlled environment, the completely randomized design was used, each treatment consisted of 4 replicates of three fruits. It was evaluated: the percentage of *in vitro* growth inhibition of fungus; disease severity; and the physicochemical analysis: soluble solids content, titratable acidity, SS/AT ratio, pH, ascorbic acid, juice yield, firmness and mass loss. Once the data was available, statistical analysis was performed using the Scott-Knott test at 5% probability. The tested essential oils do not affect the postharvest quality of 'Dancy' tangerine fruits. The essential oils of mint, citronella and fennel at 1% are efficient in the *in vitro* control of *A. alternata* f. sp. *citri* presenting fungistatic action. The oils of copaiba, mint, and 1% fennel are efficient in reducing the severity of *A. alternata* f. sp. *citri* in 'Dancy' tangerine fruits. Thus, essential oils have potential in the management of phytopathogens.

Keywords: *Alternaria alternata* f. sp. *citri*, Alternative control, Fruit quality, Fungistatic activity, Severity.

Abbreviation: SDW: Sterilized distilled water; TA: Titratable acidity (g citric acid. 100 g⁻¹ pulp); B.O.D: Biochemical oxygen demand; CEAGESP: São Paulo warehouses and general stores company; cv: Cultivar; CRD: completely randomized design; EOs: Essential oils; f: Special form; FAO: Food and Agriculture Organization of the United Nations; FML: Fresh mass loss; IAC: Agronomic institute of Campinas; IAL: Adolfo Lutz Institute; IBGE: Brazilian Institute of Geography and Statistics; LAFIT: Phytopathology laboratory; N: firmness (N); PDA: Potato-dextrose-agar; PGI: Percentage of growth inhibition; pH: Hydrogen potential; ppm: parts per million; sp: Species; SS: Soluble solids (Percentage).

Introduction

Brazil is the world's largest producer of citrus and leads the ranking in the export of concentrated Orange (*Citrus sinensis*) juice. With emphasis on the citrus belt of São Paulo and Triângulo/Southwest of Minas Gerais, being the largest producers on the national scene, with 13 million tons in the 2024 harvest, equivalent to 29% of the world production, with a growth of 6% more compared to the previous harvest (IBGE, 2025). Among the fruits of the *Citrus* genus, the tangerine (*Citrus reticulata*) occupies the seventh position in the world ranking, producing approximately 1,052,000 tons in 2023 (FAO, 2025).

Production in the Northeast region in 2023/24 exceeded 40,000 tons of tangerines from an area of 4,300 hectares, corresponding to 3.85% of national production. The state of Paraíba contributed 15,037 tons of tangerines produced on 1,895 hectares (IBGE, 2025). However, this production is predominantly from family farming, a sector that still suffers from a lack of technology and adoption of good management practices, which leads to low productivity, phytosanitary problems, and a reduced shelf life of the fruits (Porcino et al., 2023).

In Paraíba, mainly tangerines of the cultivar 'Dancy' are produced, which has a medium-sized fruit, flattened shape and sweet taste. Its peel is smooth and semi-adherent, with an intense orange color, orange pulp, in addition to containing a large amount of fiber, mineral salts such as magnesium, potassium, calcium and phosphorus (Porcino et al., 2023). The

quality of citrus fruits is an important factor mainly aimed at industrial processing and fresh consumption. It is worth mentioning the importance of the internal and external characteristics of the fruits, since these aspects guarantee a good acceptance by the consumer and a better sensorial quality (Devite, 2023).

However, tangerines are affected by several pathogens, among them the fungus *Alternaria alternata* f. sp. *citri*, which causes alternaria brown spot, is a facultative saprophyte, which in contact with the host releases a specific toxin, which causes cell death at the site of attack. The symptoms are manifested in the form of brown spots surrounded by a yellow halo on tangerine fruits, but all the organs of the plant can be attacked by the pathogen. Depending on the degree of incidence and severity of the disease, fruit losses can reach 90% (Porcino et al., 2023), in addition to the low physical-chemical quality of the fruits.

Considering that the application of chemicals to control phytopathogens is a worldwide problem, the use of essential oils (EOs) has gained prominence due to their different biological actions on phytopathogens. EOs are a mixture of volatile compounds, extracted from flowers, leaves, roots, seeds and other parts of plants (Porcino et al., 2023). These compounds have been shown to be a viable option for the management of post-harvest diseases, in addition to acting in the control of fruit deterioration, by the presence of bioactive components, such as alkaloids, coumarins, flavonoids (Affes et al., 2022).

Several studies demonstrate that the higher the essential oil concentration, the greater the inhibition of mycelial growth of postharvest pathogens. However, a 10% concentration was considered phytotoxic to the fruits (Lopez-Reyes et al., 2010; Antonioli et al., 2020; Magri et al., 2023). Peppermint (*Mentha arvensis* 100 ppm) and ginger (*Zingiber officinale* 500 ppm) essential oils control *Penicillium italicum* in orange and lemon (*Citrus aurantiifolia* Swingle) (Lee et al., 2015). In addition to microbial efficiency, essential oils extend the shelf life of fruits, as observed by Tripathi et al. (2004), who reported that essential oils of mentha, ocimum, and zingiber effectively extended the shelf life of orange and lemon.

Within this context, this research aimed to determine the action of essential oils on the behavior of the fungus *A. alternata* f. sp. *citri* and changes in postharvest quality of 'Dancy' tangerine fruit.

Results

The results regarding the percentage of mycelial growth inhibition (PGI) of *Alternaria alternata* f. sp. *citri* *in vitro* and the severity of alternaria brown spot in 'Dancy' tangerine fruits showed statistical difference between the essential oil-based treatments for both variables (Table 1).

Table 1. Percent growth inhibition (PGI) of *Alternaria alternata* f. sp. *citri* *in vitro*, and Severity of alternaria brown spot in 'Dancy' tangerine fruits, submitted to 1% essential oils and Thiabendazole fungicide (400 mL/100L).

Treatments	PGI (%)	Severity (%)
Control	0.00 d	6.42 a
Copaiba oil	24.36 c	3.50 b
Ginger Oil	35.60 b	8.00 a
Mint oil	100 a	3.13 b
Citronella Oil	100 a	7.84 a
Fennel oil	100 a	3.85 b
Fungicide	100 a	2.80 b
CV =	4.44%	45.25%

Means followed by the same lowercase letter in the column are not differentiated by the Scott-Knott test up to 5% of significance.

For the variable percentage of growth inhibition (PGI) of *A. alternata* f. sp. *citri* *in vitro*, treatments with mint, citronella and fennel essential oils completely inhibited (100%) the mycelial growth of the fungus, presenting a similar action to the effect of the commercial fungicide thiabendazole®, used as a positive control. Among the essential oils used, mint (3.13%), fennel (3.85%) and copaiba (3.50%) provided the lowest severity of the disease in tangerine fruits cv. 'Dancy'.

The results of variables, total soluble solids content (° Brix) and titratable acidity and G/L in fruit of 'dancy' submitted to different essential oils indicate that there was no significant difference between treatments and control. However, it is possible to note that for the content of total soluble solids (° Brix), there was a significant increase ($p < 0.01$) over the storage days for the analyzed treatments (Table 2).

For the titratable acidity content, a significant effect ($p < 0.01$) was observed between treatments and storage period. The titratable acidity presented an average value of 1.75% citric acid, ranging between 1.75 and 2.65%. The control showed the lowest values of titratable acidity, with a significant difference only in the last storage period, where there was an increase (Table 2).

For the SS/AT ratio, it was found that there was a significant interaction between treatments as a function of storage periods ($p < 0.01$). However, between the evaluated periods, it can be seen that periods 2 and 3 differed ($p < 0.01$) statistically in relation to the others, with maximum values of 4.40 and 4.47 g L⁻¹ (Table 3). The control showed the highest value of soluble solids and titratable acidity, also known as a ratio of 4.56 g L⁻¹.

Table 2. Contents of soluble solids (Brix) and titratable acidity g/L in 'Dancy' tangerine fruits treated with 1% essential oils and thiabendazole fungicide (400 mL/100L).

Treatments	Physico-chemical analyses/Periods*				
	Contents of soluble solids in fruits (Brix)				
	1	2	3	4	5
Control	8.28 aA	8.27 aA	8.75 bA	8.58 aA	9.45 aA
Copaiba oil	8.46 aA	8.81 aA	9.14 aA	8.72 aA	9.05 aA
Ginger Oil	8.10 aA	8.69 aA	8.90 aA	8.63 aA	8.95 aA
Mint oil	8.19 aA	8.56 aA	8.85 aA	8.23 bB	9.02 aA
Citronella Oil	7.95 aA	8.53 aA	9.00 aA	9.18 aA	9.22 aA
Fennel oil	8.22 aA	8.55 aA	9.09 aA	8.87 aA	9.19 aA
Fungicide	8.25 aA	8.62 aA	9.08 aA	8.28 bB	9.10 aA
CV= 8.19 %					
titratable acidity					
Control	2.06 bA	1.78 aA	1.75 bB	1.78 bB	2.49 aA
Copaiba oil	2.33 aA	2.14 aA	2.07 bB	2.20 aA	2.51 aA
Ginger Oil	2.40 aA	2.30 aA	2.08 bB	2.29 aA	2.13 bB
Mint oil	2.65 aA	2.08 aA	2.38 aA	2.15 bA	2.10 bB
Citronella Oil	2.35 aA	2.08 aA	2.11 bB	2.36 aA	2.35 aA
Fennel oil	2.40 aA	1.88 aA	2.35 aA	2.41 aA	2.04 bB
Fungicide	2.57 aA	2.05 aA	2.03 bB	2.13 bA	2.52 aA
CV= 23.56%					

*Assessment performed at three-day intervals. Means followed by the same lowercase letter in the column and uppercase in the row are not differentiated by the Scott-Knott test up to 5% of significance.

Table 3. Ratio of total soluble solids and titratable acidity g/L (SS/AT) ratio in 'Dancy' tangerine fruits treated with 1% essential oils and thiabendazole fungicide (400 mL/100L).

Treatments	Physico-chemical analyses/Periods*				
	Total soluble solids and titratable acidity g/L (SS/AT)				
	1	2	3	4	5
Control	4.05 bA	4.78 aA	5.20 aA	4.89 aA	3.85 bB
Copaiba oil	3.75 aA	4.22 aA	4.54 aA	4.01 aB	3.82 aB
Ginger Oil	3.55 aA	3.95 aA	4.41 aA	3.95 aB	4.26 aA
Mint oil	3.19 bA	4.37 aA	3.87 aA	4.01 aB	4.68 aA
Citronella Oil	3.49 aA	4.33 aA	4.47 aA	3.94 aB	4.13 aB
Fennel oil	3.50 bA	4.85 aA	4.11 bA	3.76 bA	4.60 aA
Fungicide	3.36 bA	4.29 aA	4.67 aA	3.99 bB	3.76 bB
CV= 22,15 %					

*Assessment performed at three-day intervals. Means followed by the same lowercase letter in the column and uppercase in the row are not differentiated by the Scott-Knott test up to 5% of significance.

For the variable pulp firmness, a significant effect ($p < 0.01$) was observed in the interaction between treatments and evaluation period. Most treatments showed a decrease in firmness in relation to the initial value, throughout the storage. The fruits were moderately firm, presenting a range of 4.13 to 7.63 N (Table 4).

Regarding pH, there was a significant difference ($p < 0.01$) in the interaction between essential oils and storage period (Table 4). In general, a variation of the hydrogenic potential of the fruits was observed with average values of 3.85 to 4.40, being verified that, on the last day of evaluation, the treatments presented a significant difference between them.

The 'Dancy' tangerine fruits had an average juice yield of 46.16%. There was a significant difference between treatments ($p < 0.01$) in all periods, except for the 1st storage period. All treatments showed higher juice yield in the 2nd evaluation period. The amount of ascorbic acid increased as a function of fruit maturation, with a higher amount on the 4th day of evaluation. A significant difference was observed between treatments versus periods ($p < 0.01$). The treatments that presented the highest means of ascorbic acid were ginger, fennel and fungicide, 17.62, 16.66 and 16.30 mg, respectively (Table 5).

Regarding the fresh mass loss (FML), it was observed that there was a significant difference ($p < 0.01$) between storage time and treatments, as well as in the interaction treatments versus storage time ($p < 0.01$). As seen in Table 6, there is a gradual increase in the PML of the fruits during storage.

The treatment with peppermint essential oil showed greater loss of fresh mass 94.44%, statistically differing from the other treatments at the end of the storage period (Table 6).

Table 4. Firmness (N) and hydrogenic potential (pH) in 'Dancy' tangerine fruits treated with 1% essential oils and thiabendazole fungicide (400 mL/100L).

Treatments	Physico-chemical analyses/Periods*				
	1	2	3	4	5
Firmness (N)					
Control	4.85 aA	4.44 aB	4.75 aA	4.81 aA	4.13 aB
Copaiba oil	4.58 aB	5.49 aA	5.93 aA	5.45 aB	4.40 aB
Ginger Oil	6.05 aA	5.74 aA	5.96 aA	6.59 aA	3.98 aB
Mint oil	6.11 bA	5.31 bB	7.63 aA	4.29 bB	5.19 bB
Citronella Oil	4.78 aB	6.23 aA	5.35 bB	6.18 aA	5.45 bB
Fennel oil	4.71 bC	6.31 aA	5.80 bB	5.03 aB	4.25 bC
Fungicide	4.66 bB	3.88 bB	6.10 aA	6.78 aA	4.96 bB
CV= 44.72 %					
Hydrogen potential (pH)					
Control	4.04 aB	4.45 aA	4.19 aB	4.03 aB	4.01 bB
Copaiba oil	3.92 bC	4.34 aA	4.14 aA	3.93 aB	4.03 bB
Ginger Oil	3.85 bA	4.33 aA	4.19 aA	3.95 aA	4.17 aB
Mint oil	3.88 bA	4.40 aA	4.11 aA	3.98 aA	4.13 aA
Citronella Oil	3.99 aA	4.36 aA	4.13 aB	3.92aB	4.07 bB
Fennel oil	3.92 bB	4.38 aA	4.08 aA	3.92 aB	4.10 aA
Fungicide	3.89 bA	4.36 aA	4.14 aB	3.99 aB	4.03 bB
CV= 2.64 %					

*Assessment performed at three-day intervals. Means followed by the same lowercase letter in the column and uppercase in the row are not differentiated by the Scott-Knott test up to 5% of significance.

Table 5. Yield of juice and ascorbic acid (mg) in 'Dancy' tangerine fruits treated with 1% essential oils and thiabendazole fungicide (400 mL/100L).

Treatments	Physico-chemical analyses/Periods*				
	1	2	3	4	5
Rendimento de suco					
Control	46.16 aA	33.33 bB	35.75 aB	34.50 aB	29.41 bB
Copaiba oil	42.08 aA	37.33 bB	27.91 bB	10.16 cC	33.50 aB
Ginger Oil	35.33 bB	40.38 aA	23.16 bC	36.00 aB	34.91 aB
Mint oil	35.00 bB	37.91 bA	24.75 bB	26.66 bB	37.16 aA
Citronella Oil	35.83 bB	42.25 aA	35.25 aB	36.08 aB	36.00 aB
Fennel oil	45.36 aA	42.00 aA	23.75 bC	36.50 aB	34.25 aB
Fungicida	39.16 bA	39.16 aA	31.75 aB	34.29 aB	29.66 bC
CV= 22.26 %					
Ascorbic acid in fruits					
Control	15.41 bB	14.30 bC	17.01 aA	17.03 bA	15.98 cB
Copaiba oil	15.01 cC	14.81 aC	15.66 cC	17.81 bA	16.99 bB
Ginger Oil	15.55 bC	14.79 aC	17.53 aB	18.62 aB	21.61 aA
Mint oil	15.87 bB	14.81 aC	15.77 cB	17.35 bA	15.42 cB
Citronella Oil	15.58 bC	14.72 aD	16.14 bB	18.15 aA	15.50 cC
Fennel oil	16.13 aB	14.74 aC	17.53 aA	18.04 aA	16.85 bB
Fungicide	15.46 bC	14.15 bD	16.92 bB	18.40 aA	16.58 bB
CV=9.61%					

*Assessment performed at three-day intervals. Means followed by the same lowercase letter in the column and uppercase in the row are not differentiated by the Scott-Knott test up to 5% of significance.

Discussion

In a study carried out by Rodrigues (2021), it was observed that treatments based on 1% and 1.5% citronella essential oil inhibited 79.01 and 93.09%, respectively, of the mycelial growth of *Alternaria* sp. *in vitro*. This effect on mycelial growth is due to the synergism between the compounds existing in the oil, with the major components being citronellal (47.12%), geraniol (18.56%) and citronellol (11.07%) (Soares et al., 2025). In view of the above, it is possible to observe that the essential oils of plants have great potential in the control and alternative management of post-harvest diseases.

In view of the above, it is possible to observe that the essential oils of plants have great potential in the control and alternative management of post-harvest diseases. However, it is still necessary to evaluate the applicability of these substances *in vivo* and to what extent these compounds can influence the physical chemistry characteristics of plants (Porcino et al., 2017).

According to CEAGESP standards (2011), the minimum content of soluble solids for tangerine is 9.0%, where the fruits of this work present values above this (Table 2). Silva et al. (2014), evaluating the fruits of tangerine trees cv 'Ponkan', found

Table 6. Fresh mass loss (FML) of 'Dancy' tangerine fruits treated with 1% essential oils and thiabendazole fungicide (400 mL/100L).

Storage periods (days)	Treatments-Oils						
	Control	Copaiba	Ginger	mint	Citronella	fennel	Fungicide
1	91.58 aA	96.08 aA	91.08 aA	105.00 aA	99.50 aA	100.42 aA	94.17 bA
2	89.83 aA	94.75 aA	89.67 aA	103.33 aA	98.00 aA	98.50 aA	90.08 bA
3	87.42 aA	93.08 aA	87.67 aA	100.33 aA	96.00 aA	96.08 aA	88.08 bA
4	86.00 aA	91.75 aA	85.92 aA	98.92 aA	94.00 aA	94.08 aA	86.25 bA
5	83.67 aA	90.50 aA	84.92 aA	97.58 aA	92.50 aA	92.67 aA	80.75 bA
6	82.17 aA	89.17 aA	83.25 aA	95.67 aA	91.17 aA	91.00 aA	79.75 bA
7	80.50 aA	88.00 aA	82.08 aA	94.33 aA	89.00 aA	88.58 aA	77.42 bA
8	77.00 aB	87.75 aB	81.25 aB	93.42 aB	86.17 aB	85.42 aB	77.33 bA
9	75.00 aA	86.83 aA	80.58 aA	92.75 aA	83.17 bA	84.67 aA	71.42 cA
10	71.33 aA	86.33 aA	79.92 aA	90.75 aA	79.92 bA	83.25 aA	67.42 cA
11	70.67 aA	85.00 aA	77.42 aA	89.00 aA	76.00 bA	80.00 aA	66.00 cA
12	70.17 aA	85.00 aA	77.42 aA	88.83 aA	74.83 bA	79.92 aA	64.33 cA
13	68.50 aA	83.83 aA	75.08 aA	86.58 aA	72.75 bA	79.08 aA	59.67 cA
14	68.08 aA	83.83 aA	75.08 aA	85.75 aA	72.25 bA	79.08 aA	62.50 cA
CV(%) =	28.90%						

Means followed by the same lowercase letter in the column and uppercase in the row are not differentiated by the Scott-Knott test up to 5% of significance.

mean values of SS of 9.5%, corroborating the results obtained in the present research. The soluble solids content is considered an important quality factor, because as the sugar levels accumulate in the fruit, the soluble solids content also increases (Chitarra and Chitarra, 2005).

The increase in the total soluble solids content is a natural process resulting from the progress of the ripening of the fruits, since when immature they have a high content of starch that is converted into glucose. As they mature, soluble sugar levels rise through respiratory augmentation (Kumar et al., 2024). According to Moura et al. (2019), evaluating clove tangerine fruits, obtained an average soluble solids content of 9.70%, a value similar to those found in this work.

According to Chaves Neto et al. (2019), titratable acidity values were found in 'Dancy' tangerine fruits, ranging from 0.5 to 1.0 citric acid. Citric acid is the main organic acid in tangerines, which are consumed when the acidity content is reduced to the point where its juice becomes pleasant to the taste of consumers. It should be noted that pH values are related to titratable acidity values, but they do not change in the same proportion (Kumar et al., 2021). The values presented in the present work are below the range of 6 to 20 g L⁻¹, classified as ideal for tangerine (Ceagesp, 2011), since the SST/AT ratio above 7 is considered adequate to consume the fruits in natura.

In studies carried out by Silva et al. (2014), the SS/AT ratio in 'Ponkan' tangerine fruits presented an average of 7.8 g L⁻¹, that is, values close to those found in the present work. Silva (2020), evaluating the industrial potential and for fresh consumption of fruits of different tangerine varieties, observed that the 'Dancy' variety presented SS/AT values in the range of 9.63 g L⁻¹. According to the results found, the essential oils used do not interfere with the post-harvest characteristics, maintaining the quality of the 'Dancy' tangerine fruits.

It can be affirmed that there was a correlation between the increase in the amount of ascorbic acid and the effect of the essential oils of ginger and fennel, knowing that the variations in the levels of vitamin C are due to the differences between the stages of maturation of the fruits. Vitamin C is present in fruits mainly in the form of ascorbic acid, it is a nutritional parameter of great importance, which tends to decrease when exposed to high temperatures in oxidative reactions (Bhandari et al., 2022). Second to Chitarra and Chitarra (2005), the increase in pH is directly related to the decrease in fruit acidity, which occurs with the advancement of maturation.

According to Detoni et al. (2009), the acceptable ascorbic acid concentration range for tangerines ranges from 20 to 50 mg 100 mL⁻¹. It was found that the ascorbic acid rates obtained in the present work are within the acceptable range for tangerines. Authors report that ascorbic acid has antioxidant and fruit protection characteristics, supporting the production of compounds such as vitamin C that can intercept free radicals, preserving their quality and maintaining cell integrity (Bhandari et al., 2022).

According to Ceagesp (2011) standards, the standard values for juice yield for "Rangpur", "Mexerica", "Ponkan" and Murcote tangerines are, respectively, 40, 35, 35 and 42%. Thus, 'Dancy' tangerine presents a juice yield considered standard, with similar values. Ribeiro (2020), evaluating the quality characteristics of tangerine hybrids ('Piemonte' tangerine, 'Murcott' tangor and 'Page' and 'Nova' tangerine-tangelos) grafted on 'Rangpur' lemon, reported juice yield values that ranged from 48.83 to 53.89% in the Brazilian coastal tablelands.

The loss of mass is related to the respiratory process of the fruits, which occurs as a result of the water eliminated in the transpiration process, caused by the difference in vapor pressure between the fruit and the air in the environment (25 °C). Or due to the synthesis of enzyme complexes that degrade the cellulose present in the fruits, resulting in the loss of integrity and a decrease in the cohesion of plant cells (Demartelaere et al., 2017). The use this oil may have induced greater fruit

respiration, causing greater water loss and consequent greater loss of fresh mass. Fruit mass is one of the main criteria adopted by consumers to analyze quality, especially when they are destined for the fresh market (Botelho et al., 2019). The oils used did not accelerate fruit metabolism, which in turn did not accelerate mass loss. However, the intensity of mass loss can result in wrinkling and wilting of the fruit, compromising organoleptic and nutritional qualities, leading to postharvest quality losses (Bhandari et al., 2022).

Therefore, this research highlights the importance and effectiveness of essential oils, with their antimicrobial properties, maintenance of postharvest quality of mandarin fruits, and ecological characteristics (high volatility and biodegradability). Furthermore, they can be applied to control spoilage and increase food safety. Like this, the essential oils tested do not alter the post-harvest physical-chemical quality of 'Dancy' tangerine fruits. The essential oils of mint, citronella and fennel at 1% are efficient in inhibiting the *in vitro* mycelial growth of *A. alternata* f. sp. *citri*. Copaiba, mint fennel oils and 1% are efficient in reducing the severity of *A. alternata* f. sp. *citri* on 'Dancy' tangerine fruits.

Materials and methods

Experiment location

The experiment was carried out at the Phytopathology Laboratory (LAFIT) belonging to the Phytotechnic department of the Agricultural Sciences Center, Federal University of Paraíba, Campus II, Areia, Paraíba.

Plant material

The tangerine fruits cv 'Dancy' were obtained in a commercial orchard in the municipality of Remígio-PB (6° 54' 10" S and 35° 50' 2" W), all the fruits were cultivated without chemical treatment, and were presented in the maturation stage C2 (yellow-orange skin color, with increased sugar content and reduced acidity).

The fruits were sanitized with 1% sodium hypochlorite for 5 min, followed by triple washing in sterilized distilled water (ADE), dried at a temperature of 25 ± 2 °C.

Essential oils of copaiba (*Copaifera* sp.), ginger (*Zingiber officinale* Roscoe), mint (*Mentha arvensis* L.), citronella (*Cymbopogon nardus* Rendle) and fennel (*Pimpinella anisum* L.) were used.

In vitro growth of *Alternaria alternata* f. sp. *citri*

The isolate was cultured in potato-dextrose-agar (PDA) culture medium, pH 6.0, incubated for five days at a temperature of 25 °C and a 12-hour photoperiod in a Biochemical Oxygen Demand (B.O.D.). After this period, the evaluation of the inhibition mycelial growth of the pathogen was performed.

To evaluate the *in vitro* effect of the treatments on the pathogen isolate, essential oils were added at a concentration of 1% diluted in a PDA culture medium with pH 6.0, poured into *Petri* dishes, where a 5 mm disk of diameter of the pure fungal colony. Additional controls were the fungicide Thiabendazole (400 mL/100L) and PDA culture medium (no treatment). The plates were kept at a temperature of 25 ± 2 °C and a photoperiod of 12 h. The percentage of colony growth inhibition (PGI) was evaluated using the formula:

$$PGI = \frac{\text{control growth} - \text{treatment growth}}{\text{control growth}} \times 100(1)$$

Application of essential oils in 'Dancy' tangerine fruits

The following essential oils (EOs) were used for the treatments: copaiba (*Copaifera* sp.), ginger (*Zingiber officinale* Roscoe), mint (*Mentha arvensis* L.), citronella (*Cymbopogon nardus* Rendle) and fennel (*Pimpinella anisum* L.) at a concentration of 1%, plus two drops of Tween 80 (dispersant), all the oils were diluted ADE and the additional controls were composed of the fungicide Thiabendazole 400 mL 100 L⁻¹ and ADE (without treatment - control). The fruits were immersed for 5 minutes in each treatment, composed of four repetitions of three fruits.

Inoculation of *A. alternata* f. sp. *citri* fruit

After application of the treatments, all fruits were organized in polypropylene trays, kept under temperature of 25 ± 2 °C and photoperiod of 12 h for two days. After this period, 1 mm deep lesions were made (through a sterilized pin) in the equatorial region on opposite and equidistant sides on the fruit peel by the prick method.

The spore suspension was obtained by adding 10 mL of ADE to *Petri* dishes containing pure colonies of the fungus and, with the aid of a sterile spatula, the conidia were removed, then filtered through a sterile gauze layer and quantified in a hemacytometer. Fruit inoculation was carried out by spraying spores at a concentration of 10⁵ conidia mL⁻¹ of *A. alternata* f. sp. *citri* to the point of runoff, spraying was performed with the aid of a manual sprayer. Then the fruits were incubated in a humid chamber, composed of polyethylene bags previously moistened with ADE, for 48 hours, at a temperature of 25 ± 2 °C and a photoperiod of 12 h.

Disease severity was measured after removal from the humid chamber, symptoms were quantified 15 days after inoculation of the pathogen, according to the methodology proposed by Renaud et al. (2008), the rating scale ranges from 0.1 to 25%.

Post-harvest evaluations

Post-harvest evaluations were carried out in periods, totaling five evaluations with three-day intervals between each one, with the exception of the variable mass loss with daily evaluations.

Physicochemical analysis

Mass loss (g): determined by gravimetry on a UX4200 – SHIMADZU semi-analytical balance; Juice yield (%): Due to the difference between the mass of fresh fruit, the mass of the rind and the albedo; Firmness (N): determined using a Fruit Hardness tested digital penetrometer, insertion region of 6 mm in diameter, taking two readings in the equatorial region of the intact fruit, on opposite sides; Soluble solids (SS) content (%): Determined by direct reading with benchtop refractometer according to IAL (2008). Titratable Acidity (AT) (g citric acid. 100 g⁻¹ pulp): Obtained by titration using 0.1M NaOH solution with phenolphthalein indicator, until the color changes to permanent light pink, using 5 g of the sample in 50 mL of distilled water according to IAL methodology (2008). SS/AT Ratio: Determined by dividing the SS indices by AT. pH: Using a digital potentiometer, according to the methodology of IAL (2008). Ascorbic acid: The quantification was determined from 5.0 mL of juice, to which 50 mL of 0.5% oxalic acid were added. Results were expressed in mg ascorbic acid (Strohecker and Henning, 1967).

Statistical analysis

The experiment was conducted in a completely randomized design, consisting of seven treatments. For the *in vitro* test, four replicates of three plates were used, and for the *in vivo* test and post-harvest, four replicates of three fruits were used. The data were subjected to analysis of variance (ANOVA) and comparison of means by Scott-Knott's test at 0.05 probability level. The statistical procedures were processed with using the ASISTAT® program.

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Conflicts of Interest

The authors declare no conflicts of interest

Authors' contributions

The authors' contributions to the study and preparation of this manuscript were: Mirelly Miguel Porcino was responsible for writing, developing the original idea, preparing and discussing the data; Valdeir de Souza Oliveira was responsible for project administration, data collection, and discussion of the results; Edcarlos Camilo da Silva contributed to statistical analysis and discussion of the results; Hilderlande Florêncio da Silva contributed to study validation and supervision; Robério de Oliveira was responsible for methodology and data collection; José Ayrton Moraes de Lima was responsible for methodology and data collection; Lucy Glaide da Silva was responsible for methodology and data collection; and Luciana Cordeiro do Nascimento was responsible for review, editing, supervision, and resource provision. All authors read and accepted the published version of the manuscript.

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