Chapter

Comparative Analysis of the Chemical Composition, Antimicrobial and Antioxidant Activity of Essential Oils of Spices Used in the Food Industry in Brazil

Amanda Mara Teles, Adenilde Nascimento Mouchreck, Gustavo Oliveira Everton, Ana Lucia Abreu-Silva, Kátia da Silva Calabrese and Fernando Almeida-Souza

Abstract

There are many food-borne pathogens in the wild and they are considered the cause of serious public health problems in both developed and developing countries. The use of natural products, such as antimicrobial compounds, has been increasing, in an attempt to control bacteria present in foods, mainly pathogens resistant to conventional antibiotics. This chapter is intended to provide the antimicrobial and antioxidant activity of essential oils of *Cinnamomum zeylanicum* (cinnamon), *Origanum vulgare* (oregano), *Zingiber officinale* (ginger), *Rosmarinus officinalis* (rosemary), *Citrus latifolia* (tahiti lemon) and *Curcuma longa* (saffron) as well as to determinate its chemical composition. The oils had been extracted by hydrodistillation with a Clevenger type apparatus and the antimicrobial activity was performed against standard strains *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. The antioxidant activity was carried out using the ABTS [2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)] method. The essential oils presented a mixture of mono- and sesquiterpenes. The best minimum inhibitory concentration was determined to *C. zeylanicum* against *S. aureus*. *O. vulgare* antioxidant activity presented inhibition of 90.74% and EC_{50} of 14 μg mL^{-1}. These results demonstrate that the essential oils analyzed presented efficient antibacterial activity and antioxidant action being able to satisfy the demand of use as control of microorganisms in the food.

Keywords: essential oils, biological properties, antimicrobial activity, antioxidant activity, chemical composition

1. Introduction

Brazil has an extensive diversity of species in its flora, and great tradition in the use of medicinal plants linked to the popular medicine [1]. Medicinal plants are characterized by common sense within communities as an alternative for

nutritional and therapeutic purposes in the prevention and cure of diseases since ancient times. Their therapeutic use has aroused scientific interest, awakening new ways to control several diseases [2].

These species are commonly employed in the commercial sector, such as the food industry. Condiments or spices are used in the preparation of food in order to improve sensory characteristics and as a preservative agent due to its antioxidant and antimicrobial attributes [3]. These types of preservatives are more accepted by the population, mainly due to the search of the industries for healthier products [4].

The antimicrobial and antioxidant activities of various spices, such as *Rosmarinus officinalis* (rosemary) [5, 6], *Cinnamomum verum* (cinnamon) [7]*Curcuma longa* (saffron) [8], *Ocimum basilicum* (basil) [9, 10], *Zingiber officinale* (ginger) [11] and *Origanum vulgare* (oregano) [12, 13] that are widely used in the food industry have such proven biological properties.

The chemical constituents responsible for the antibacterial power of these condiments are named as phenolic compounds, such as carvacrol, linalool, thymol, menthol, limonene and eugenol [14], also including terpene derivatives, such as mono- and sesquiterpenes and phenylpropanoids [15].

These spices are mainly used through the essential oils obtained from these plants. Many of these oils are composed of substances such as those mentioned above and these are related to the permeability of the bacterial cell membrane and through this can act in the control of microbiological growth [16].

A very important factor is the yield of these oils, which are based on the method and extraction time [17] and thus add a higher commercial value associated with cost-benefit. Usually, they are synthesized by extraction techniques, such as distillation [18, 19] that separate it from the water by differences in density and polarity.

Essential oils are composed of a complex mixture of volatile chemicals present in various parts of medicinal plants. They provide the essence of the plant, being responsible for the flavor and aroma of spices [20]. They act in protection against pathogens, in the attraction of pollinators and can be found in leaves, flowers, fruits and even in roots of aromatic plants [21]. These compounds have specific odoriferous and lipophilic characteristics [22] and have received much attention in the last decades due to the antimicrobial activity that they present [23].

These natural products have proven antioxidant and antimicrobial potential and several studies describe the application of these products to prolong the shelf life of food products without risks to the consumer or interference in the natural characteristics of the food [19, 24].

The search for decrease in the use of antioxidants and synthetic antimicrobial agents intensifies studies to demonstrate the promising potential of these compounds [19, 25, 26]. These searches are based on the great risk of contamination through food, and the great resistance of bacteria to antibiotics, appearing the interest of adding natural antimicrobial agents in food as a way to mitigate cases of foodborne diseases [27].

Foodborne diseases can be identified when one or more individuals exhibit similar symptoms after ingestion of food contaminated with pathogenic microorganisms, their toxins, toxic chemicals or objects which constitute a common source. In the case of highly virulent pathogens, such as *Clostridium (C.) botulinum* and *Escherichia (E.) coli* O157: H7, only one case can be considered an outbreak [28]. Bacteria like *Staphylococcus aureus*, *Salmonella*, *Campylobacter* and *Escherichia coli* are important food pathogens, and are among the biggest cause of outbreaks in the word [29].

A polymerase chain reaction (PCR) analysis with samples of beef, sheep and processed chicken showed the presence of *Clostridium perfringens*, *Enterococcus faecalis* and *S. aureus* in 79, 86 and 94%, respectively. In meat samples, *E. coli* and enteric *Salmonella* were also found in respective concentrations of 90 and 91% [30].

Food-borne illness is a real problem in the present scenario as the consumerism of packaged food. Pathogens entering the packaged foods may survive longer. Therefore, antimicrobial agents either alone or in combination are added to the food or packaging materials to eliminate these agents [31].

Treatment in these cases leads to the indiscriminate use of antibiotics. These have provided a growing multidrug resistance of microorganisms, generating public health problems due to the residues in foods [2]. The antibiotics act as an important selective pressure for the emergence and persistence of resistant strains [32].

Exploiting the antimicrobial property, essential oils are considered as a "natural" remedy to this problem. Alternatives to the use of synthetic antimicrobial agents have been proposed in recent years, and some approaches include herbal products [28]. This promising determination of the action of these essential oils on microorganisms using Gram-positive and Gram-negative bacteria should be performed due to its low cost of acquisition, use and therapeutic action, such as the viability of medicinal potential and its use in the food industry, cosmetics and pharmaceuticals, whereas bacterial resistance is one of the most significant challenges to human health [33].

Thus, the objective of this chapter was to provide the antimicrobial and antioxidant activity of *Cinnamomum zeylanicum* (cinnamon), *O. vulgare* (oregano), *Z. officinale* (ginger), *R. officinalis* (rosemary), *C. longa L.* (saffron) and *C. latifolia* (tahiti lemon) essential oils as well as to determine its chemical composition.

2. Essential oils chemical profile

C. zeylanicum leaves, *C. latifolia* barks, *O. vulgare* and *R. officinalis* aerial parts and *Z. officinale* and *C. longa L.* rhizome were collected in the city of São Luis Maranhão, Brazil (latitude: −2.53073, longitude: −44.3068 2° 31′ 51″ South, 44° 18′ 24″ West). The taxonomic identification was performed by Ana Zelia Silva in the Seabra Attic Herbarium of the Department of Botany of the Federal University of Maranhão. All five plants were dried for 48 h and sprayed in an electric knife mill at the Food and Water Quality Control Laboratory of the Federal University of Maranhão.

The essential oil was extracted by hydrodistillation using Clevenger system. A quantity of 300 g of dry plant material diluted in water at a ratio of 1:10 was boiled at 100°C for 3 h. The oil was dried with anhydrous sodium sulfate and kept in an amber bottle under refrigeration. For in vitro biological assay, the essential oils and reference drugs were dissolved in dimethylsulfoxide (DMSO) at 100 times the highest concentration of use, and subsequently diluted in an appropriate medium to a final concentration of DMSO less than 1%.

Chemical characterization of the essential oils was performed by gas chromatography coupled to mass spectrometry (GC-MS). The essential oils under study were dissolved in 1 mg/mL ethyl acetate and analyzed on Shimadzu QP 5000 gas chromatograph with ZB-5 ms capillary column (5% phenyl arylene 95% dimethylpolysiloxane) coupled at 70 eV (40–500 Da) electronic impact detector HP 5MS with a transfer temperature of 280°C. The chromatographic conditions were injection of 0.3 μL of ethyl acetate; helium carrier gas (99.99%); injector temperature: 280°C; split mode (1:10); then an initial temperature of 40°C and a final temperature of 300°C; initial time of 5 min and final time of 7.58min. The results obtained for *C. zeylanicum* leaves are shown in **Table 1**.

A total of 15 compounds were identified and their main constituents such as cinnamic aldehyde (46.30%), α-copaene (16.35%) and trans-β-caryophyllene (8.26%) were identified and quantified. Various researchers have identified and quantified different chemical compounds of *C. zeylanicum* essential oil. A study identified nine

Peak	*C. zeylanicum* E.O.	
	Compounds	**(%)**
1	α-Pinene	1.47
2	Benzaldehyde	4.16
3	3-Phenylpropionaldehyde	2.95
4	Borneol	1.06
5	α-Terpineol	0.87
6	Cinnamic aldehyde	**46.30**
7	3-Phenyl-1-propanol	1.46
8	α-Copaene	16.35
9	trans-β-Caryophyllene	**8.26**
10	(e)-Cinnamyl acetate	7.54
11	α-Humulene	2.16
12	delta-Cadienene	1.42
13	(−)-Spathulenol	2.09
14	Caryophyllene oxide	2.80
15	Benzyl benzoate	1.12

Table 1.
C. zeylanicum (cinnamon) essential oil chemical composition.

compounds [34] with (E)-cinnamaldehyde as its major component [35, 36]. The essential oils of this plant generally have cinnamaldehyde [37], which corroborates the results obtained in this study. We already presented similar results to chemical composition of *C. zeylanicum* essential oil [38].

The chemical profile obtained for the aerial parts such as *R. officinalis* and *O. vulgare* is shown in **Table 2**. Its total composition presented 17 components with the major constituents being camphor (37.00%), 1,8-cineol (11.32%) and α-terpineol (7.12%). In *O. vulgare* essential oil, 20 compounds were found, represented by the main constituents cis-ρ-menth-2-en-1-ol (33.88%), linalyl acetate (13.90%) and p-cymene (8.29%). Probst also identified camphor as the major component of R. officinalis essential oil [39], being possible to observe similarity with the essential oil composition of this study, while other study obtained 1,8-cineol in a higher percentage, but camphor was present in the second place among the major components [40].

With respect to *O. vulgare* essential oil, while there is a description of similar chemical composition to our study [38, 41], another study found three different chemotypes in 25 samples of this essential oil: linalool/linalyl acetate chemotypes with predominant linalyl acetate; the second major chemotypes rich in carvacrol and c-terpinene; and a third rich chemotype in thymol [42].

The chemical composition of the essential oils of *C. longa* (saffron) and *Z. officinale* rhizomes is shown in **Table 3**. For essential oils obtained from *C. longa* rhizomes, 17 compounds were identified and the major chemical composition is represented by turmerone (55.43%), β-turmerone (12.02%) and γ-curcumene (6.96%). Similar results were described to *C. longa* essential oil [38, 43–45], with the main compounds turmerone and β-turmerone presenting the highest percentages.

In the essential oil of *Z. officinale*, 18 components were identified, constituting α-zingiberene (27.14%), geranial (14.06%) and nerolidol (13.51%) in greater percentage. Diemer studing essential oil of Z. officinale quantified the chemical profile in 12 constituents and concluded that α-zingiberene was the predominant

Peak	***R. officinalis* (rosemary) E.O.**		***O. vulgare* (oregano) E.O.**	
	Compounds	**(%)**	**Compounds**	**(%)**
1	β-Pineno	2.29	α-Pinene	0.80
2	β-Mirceno	4.36	Bicyclo[3.1.0]hexane	1.73
3	ρ-Cimeno	1.41	(+)-4-Carene	3.08
4	Limoneno	2.02	**p-Cymene**	**8.29**
5	**1,8-Cineol**	**11.32**	Cyclohexene	1.23
6	γ-Terpineno	1.61	β-Phellandrene	2.73
7	Linalol	2.99	p-Menth-2-en-1-ol	4.62
8	**Cânfora**	**37.00**	1,4-Cyclohexadiene	1.21
9	Pinocarvona	217	cis-Sabinene hydrate	1.29
10	Borneol	3.24	Terpinolene	3.11
11	Terpinen-4-ol	4.79	1,6-Octadien-3-ol	5.69
12	**α-Terpineol**	**7.12**	trans-Sabinene hydrate	1.59
13	Verbenona	5.85	**cis-p-Menth-2-en-1-ol**	**33.88**
14	Acetato de bornila	4.28	3-Cyclohexen-1-ol	5.26
15	β-Cariofileno	6.43	(+)-α-Terpineol	2.61
16	α-Humuleno	1.47	Carvacrol methyl ether	0.94
17	α-Bisabolol	1.65	**Linalyl acetate**	**13.90**
18	—		Thymol	2.41
19	—		trans-β-Caryophyllene	2.46
20	—		1H-Cycloprop(E)azulen-7-ol	3.16

Table 2.
Chemical composition of the essential oils of Rosmarinus officinalis (rosemary) and Origanum vulgare (oregano).

Peak	***C. longa* (saffron) E.O.**		***Z. officinale* (ginger) E.O.**	
	Compounds	**(%)**	**Compounds**	**(%)**
1	α-Pinene	1.15	α-Pineno	1.46
2	Myrcene	0.37	Canfeno	5.02
3	Vinyl propionate	0.20	β-Mirceno	1.29
4	ρ-Cymene	1.01	Sabineno	5.23
5	Bisabolone	0.55	1,8-Cineol	4.35
6	**β-Turmerone**	**12.02**	Linalol	0.50
7	1,8-Cineole	1.01	4,4-Dimetil-2-pentinal	0.80
8	Camphor	1.24	terc-Dodeciltiol	0.71
9	α-Terpineol	4.13	Neral	9.64
10	Terpinolene	0.43	Nerol	1.07
11	α-Zingiberene	0.29	**Geranial**	**14.06**
12	β-Sesquiphellandrene	2.67	2-Undecanona	0.63
13	β-Caryophyllene	1.00	Farnesol	1.27
14	**γ-Curcumene**	**6.96**	1,1-Diciclopropiletileno	0.55

Peak	*C. longa* (saffron) E.O.		*Z. officinale* (ginger) E.O.	
	Compounds	**(%)**	**Compounds**	**(%)**
15	ar-Curcumene	1.58	ar-Curcumeno	3.33
16	**Turmerone**	**55.43**	**α-Zingibereno**	**27.14**
17	β-Sesquiphellandrene	1.10	**Nerolidol**	**13.51**
18	—	-	β-Sesquifelandreno	9.45

Table 3.
Chemical composition of Curcuma longa (saffron) and Zingiber officinale (ginger) essential oils.

Peak	*Citrus latifolia* (tahiti lemon) E.O.	
	Compounds	**(%)**
1	ρ-Cymene	**10.86**
2	D-Limonene	8.85
3	Cyclooctanone	1.54
4	ρ-Mentha-E-2,8(9)-dien-1-ol	2.47
5	trans-Pinocarveol	3.23
6	14.70 Pinocarvone	2.02
7	ρ-Cymen-8-ol	3.02
8	Bicyclo(3.1.1)hept-2-ene-2-carboxaldehyde,6,6-dimethyl-	5.34
9	Myrtenol	6.31
10	trans-Carveol	1.58
11	cis-Carveol	**11.59**
12	Carvone	1.68
13	19.02 Carvone oxide	3.69
14	Limonene dioxide	**25.92**
15	1,2-Cyclohexanediol 1-methyl-4-(1-methyleth)	8.10
16	7-Oxabicyclo[4.1.0]heptane,1-methyl-4-1-(1-methylethyl)	1.24
17	2,7-Octadiene-1,6-diol,2,6-dimethyl	2.56

Table 4.
Chemical composition of lemon tahiti essential oil.

component [46]. Same results were observed by us in the present study. However, there are also descriptions of geranial as its major constituent in this oil [47].

The chemical composition obtained from *C. latifolia* leaves is presented in **Table 4**. The essential oil obtained presented from 17 components with the main constituents being limonene dioxide (25.92%), cis-carveol (11.59%) and ρ-cymene (10.86%). Similarly, it was found in the researches carried out in *C. latifolia* tanaka, identifying 17 compounds and limonene as the major compound with 46.3% [48] and 58.43% [49].

3. Antimicrobial activity

Escherichia coli (ATCC 25922), *Staphylococcus aureus* (ATCC 12600) and *Pseudomonas aeruginosa* (ATCC 27853) strains were cultured in brain heart infusion

broth for 24 h at 37°C and then diluted to 10^8 UFC/mL following the MacFarland scale, recommended by the Clinical and Laboratory Standards Institute [50].

The inoculum (100 μL) of each bacterium was seeded in Mueller-Hinton agar, with filter paper impregnated with 50 μL of essential oil placed on the surface. The plates were incubated at 35°C and after 24 h, the inhibition halo was measured with a millimeter ruler [51]. The minimum inhibitory concentration (MIC) was determined using the broth dilution methodology [52] and performed in triplicates with the same bacterium used in solid media diffusion techniques. Initially, an aliquot of the essential oil prepared in DMSO was transferred to a test tube containing BHI broth. Serial dilutions were then performed resulting in concentrations of 5–2000 μg/mL. Microbial suspensions containing 1.5×10^8 CFU/mL of the bacteria were added at each concentration and incubated at 35°C for 24 h. Tubes without bacteria were reserved for control of broth sterility and bacterial growth. After the incubation period, the minimum essential oil inhibitory concentration was defined as the lowest concentration which visibly inhibited bacterial growth observed by the absence of visible turbidity. To confirm growth inhibition, the BHI broth was subjected to the inoculum microbial seeding test on the surface of the plate-count agar.

The disc diffusion method evaluated the antibacterial activity of *C. zeylanicum*, *O. vulgare*, *Z. officinale*, *R. officinalis*, *C. longa* and *C. latifolia* essential oils to form inhibition halos against the growth of Gram-positive (*S. aureus*) and Gram-negative (*E. coli* and *P. aeruginosa*) bacteria strains. The diameters of the inhibition halos developed by the essential oils are shown in **Table 5**. The halos ranged from 7.67 to 15.33 mm. The largest inhibition halo against Gram-negative *E. coli* bacteria was quantified at 21 mm by *C. latifolia* essential oil. The best bactericidal activity for *S. aureus* was quantified at 15.66 mm by *C. longa*, while the Gram-positive *P. aeruginosa* was strongly inhibited by *C. longa* essential oil of, quantifying a halo of 12 mm.

The minimum inhibitory concentration (MIC) in μg mL^{-1}, the lowest visible concentration that prevents visible microbial growth in the culture medium by the action of the natural product, is being reported in **Table 5**.

The bactericidal activity of *C. zeylanicum* essential oil was demonstrated by larger halos against the Gram-positive bacteria. Similar results were found in *C. zeylanicum* essential oil [34, 38, 53] and the authors reported cinnamaldehyde as responsible for the antimicrobial action. However, lower results were also described when evaluating the antimicrobial activity of this oil against *Salmonella typhimurium* and *E. coli*, being its better inhibition against *S. aureus* [54].

The MIC's of *C. zeylanicum* essential oil were quantified using *S. aureus* strain and obtained a similar inhibitory concentration to that in this research, however *E. coli* and *Salmonella typhi* concentrations were far superior to that described in our study [55]. In another research conducted by Trajano et al. [4], concentrations are relatively lower than those observed in this study.

To the antimicrobial potential of *R. officinalis* essential oil, Cordeiro [56] also obtained inhibition halos for *S. aureus*, as well as Ribeiro [57] for *E. coli*, both using this same essential oil as antimicrobial. The antimicrobial activity of this oil for the strains tested in broth dilution showed MIC's similar to the experiment performed by Silva et al. [58]. However, values for such concentrations have also been reported in smaller units by Thanh et al. [59].

On the other hand, *O. vulgare* essential oil has demonstrated efficiencies for both Gram-positive and Gram-negative strains which can be observed by Stefanakis et al. [60] and Sankar et al. [61] who reported antimicrobial activity of this essential oil similar to this research against the same bacteria tested.

Soković et al. [62] obtained MIC's for *O. vulgare* essential oil smaller than those described in the results of this study for *S. aureus*, *E. coli*, *Salmonella enteritidis*

	E. coli (ATCC 25922)		*S. aureus* (ATCC 12600)		*P. aeruginosa* (ATCC 27853)	
	IH (mm)	**MIC ($\mu g\ mL^{-1}$)**	**IH (mm)**	**MIC ($\mu g\ mL^{-1}$)**	**IH (mm)**	**MIC ($\mu g\ mL^{-1}$)**
C zeylanicum	12.67 (±1.00)	216.67 (±14.43)	15.33 (±0.58)	**83.33** (±28.87)	9.33 (±0.58)	383.33 (±0.01)
O. vulgare	15.33 (±0.58)	**133.33** (±28.87)	14.67 (±0.58)	216.67 (±28.87)	10.33 (±0.58)	550.00 (±28.87)
C. longa	14.33 (±0.58)	266.67 (±28.87)	**15.66** (±0.58)	166.67 (±14.43)	12.00 (±0.58)	483.33 (±57.74)
Z. officinale	10.70 (±0.58)	1000.00	9.70 (±0.58)	200.00	8.67 (±0.58)	1500.0
R. officinalis	9.70 (±0.58)	1700.00	10.70 (±0.58)	1500.00	7.67 (±0.58)	1700.0
C. latifolia	21	250	10	500	11	1000

Table 5.
Diameters of inhibition halos (IH) and minimum inhibitory concentrations (MIC) for the essential oils activity against bacterial strains.

and *Salmonella typhimurium*. Sarikurkcu et al. [38, 63], also performed an assay to determine the MIC against *S. aureus* and *E. coli*, obtaining results similar to those observed.

For *C. longa* essential oil, the largest halos were quantified for Gram-positive bacteria, similar to results found by Gupta et al. [64], Teles et al. [38] and Mishra et al. [65] who reported the formation of halos against the same bacteria in this study submitted to antimicrobial activity assays. Singh et al. [66] also observed satisfactory MIC values for the control of the microorganisms tested in this study.

In relation to the bactericidal effect of the *Z. officinale* essential oil, the values obtained in our disc diffusion test are superior to those obtained in the study by Singh et al. [67], where the authors did not obtain inhibition halos for *E. coli* and *S. aureus*, and the same were reported by Grégio et al. [68]. However, MIC values were similar to those found by Sasidharan and Menon [69].

4. Antioxidant activity

The antioxidant activity by the ABTS method [2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)] was adapted according to the methodology suggested by [70]. The $ABTS^{\cdot}+$ radical was prepared by the reaction of 5.0 mL of a 3840 $\mu g\ mL^{-1}$ of ABTS solution with 88 μL of the 37,840 $\mu g\ mL^{-1}$ potassium persulfate solution. The mixture was left in the dark for 16 h. After formation of the radical, the mixture was diluted in ethanol (approximately 1:30 v/v) and absorbance was obtained at 734 nm. From the extracts and essential oils concentrations (5–150 $\mu g\ mL^{-1}$), the reaction mixture was prepared with the ABTS radical cation. In a dark environment, a 30 μL aliquot of each extract and essential oil concentration was transferred into 23 test tubes containing 3.0 mL of the ABTS radical cation and homogenized on a tube shaker. After 6 min, absorbance of the reaction mixture was obtained in a spectrophotometer at 734 nm. The analyzes were performed in triplicate and the capture of the free radical was expressed as percent inhibition (% I) of the ABTS radical cation.

The ABTS method allowed the calculation of the 50% effective concentration of the essential oils, which express the minimum concentration required to reduce the initial concentration of ABTS by 50%, and these are expressed in **Table 6**. The lowest concentration and consequently the best antioxidant activity was observed to oregano, with an EC_{50} quantified in 14 μg mL^{-1} and consequently also the highest percentage of ABTS inhibition.

The antioxidant effect of *C. zeylanicum* essential oil differs from that observed by [71] using the ABTS technique, where these authors verified a lower EC_{50}. This difference is explained by the authors due to variation in the chemical composition of the essential oils studied, which depends on factors such as the geographic location and the time of collection of the plant.

The result for *R. officinalis* essential oil exhibited by [57] shows a fairly high effective concentration comparing that obtained in this article. Also [72], when evaluating the antioxidant activity of this essential oil from five different crop fields, found a lower EC_{50} than this study. According to [73], the main responsible for the free radical stabilization capacity of this species is 1,8-cineol. In this way, it is possible to relate the lower antioxidant potential of the rosemary essential oil obtained in this research with the low content of 1,8-cineol.

On the other hand [72], while evaluating the antioxidant capacity of rosemary essential oil using DPPH, it had a relatively higher concentration than this study *Salmonella thyphimurium*. Also highlighting the difference of methods used, since its concentration, it presented higher concentrations at levels of approximately 700 more units.

Regarding the antioxidant potential of oregano essential oil, the author [74] obtained a higher value of efficient concentration than presented in our study, which highlights the data obtained satisfactory in this research. However [75], while still evaluating the antioxidant activity of *O. vulgare* essential oil, using the ABTS radical discoloration technique, a lower EC_{50} is observed than that observed in this study. According to these authors, the antioxidant potential of this oil is related to the presence of phenolic compounds, but it can also be attributed to a possible synergy between the various constituents.

When checking the antioxidant activity of *C. longa* [76], it is found that concentrations are much higher than those quantified for the essential oil using the DPPH assay, whereas, when using the ABTS assay, we exposed satisfactorily lower concentrations.

When studying the anti-inflammatory and anti-inflammatory activity of ginger essential oil [77], a much higher EC_{50} value is obtained which was presented in this study. These results are lower than that obtained in this study, and the authors attribute to this fact that the low concentration of phenolic compounds is mainly responsible for the antioxidant activity.

Essential oil	Effective concentration 50% EC_{50} (μg mL^{-1})	% ABTS inhibition (50 μg mL^{-1})
C. zeylanicum	215.93	11.11
O. vulgare	**14.00**	**90.74**
Z. officinale	308.16	25.9
R. officinalis	153.7	25.7
C. longa	173.43	14.8
C. latifolia	250	24.89

Table 6.
ABTS free radical sequestering activity by essential oils.

A relatively lower EC_{50} value was found for *Z. officinale* essential oil by the β-carotene/linoleic acid system [78]. The author attributes the antioxidant activity of the oil to the geranium and neral aldehydes, which were found in their essential oil at concentrations much higher than in this work.

5. Conclusions

These studies have shown that the essential oils of *C. zeylanicum* (cinnamon), *O. vulgare* (oregano), *Z. officinale* (ginger), *R. officinalis* (rosemary), *C. longa* L. (saffron) and *C. latifolia* (Tahiti lemon), in the chemical composition, presented a mixture of mono- and sesquiterpenes, with the major constituents being cinnamic aldehyde (46.30%), cis-p-menth-2-en-1-ol (33.8%), α-zingiberene (27.14%), camphor (37%), turmerone (55.43%) and limonene dioxide (25.92%), respectively. Results of disc diffusion showed the essential oil of *C. longa* as the oil with the highest bactericidal action independent of the bacteria strain; however, the lowest bactericidal concentration observed was the lowest concentration of *C. zeylanicum* essential oil (83.33 μg mL^{-1}) in *S. aureus* strains. The antioxidant activity of *O. vulgare* presented the percentage of inhibition of the 90.74% radical by 50 μg mL^{-1} having the EC_{50} of 14 μg mL^{-1}. These results indicate that bioactive molecules present in the essential oils of the species tested presented antimicrobial activity and antioxidant action. These characteristics contribute to the control of microorganisms and help increase the shelf life of foods.

Acknowledgements

The present study was funded by Coordenacão de Aperfeiçoamento de Pessoal de Nível Superior, Brazil (CAPES) [Finance Code 001]; Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (E-26/111.252/2014), for Kátia da Silva Calabrese; by the Fundação de Amparo à Pesquisa e Desenvolvimento Científico do Maranhão (APP-00844/09 and Pronex-241709/2014); Conselho Nacional de Desenvolvimento Científico e Tecnológico, (407831/2012.6 and 309885/2017-5) for Ana Lucia Abreu-Silva and by CNPq/SECTI/FAPEMA (DCR03438/16) for Fernando Almeida-Souza; as well as the IOC (article processing charges).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Author details

Amanda Mara Teles[1], Adenilde Nascimento Mouchreck[1], Gustavo Oliveira Everton[1], Ana Lucia Abreu-Silva[2], Kátia da Silva Calabrese[3] and Fernando Almeida-Souza[3]*

1 Federal University of Maranhão, São Luís, Brazil

2 State University of Maranhão, São Luís, Brazil

3 Oswaldo Cruz Institute, Rio de Janeiro, Brazil

*Address all correspondence to: fernandoalsouza@gmail.com

References

[1] Silva NCC, Fernandes Júnior A. Biological properties of medical plants: A review of their antimicrobial activity. Journal of Venomous Animals and Toxins Including Tropical Diseases. 2010;**16**:402-413

[2] Souza CN, De Almeida AC, Xavier MTR, Costa JPR, Da Silva LMV, Martins ER. Atividade antimicrobiana de plantas medicinais do cerrado mineiro frente a bacterias isoladas de ovinos com mastite. Unimontes Científica. 2017;**19**:51-61

[3] Teixeira-Loyola ABA, Siqueira FC, Paiva LF, Schreiber AZ. Análise microbiológica de especiarias comercializadas em Pouso Alegre, Minas Gerais. Revista Eletrônica Acervo Saúde. 2014;**6**:515-529

[4] Trajano VN, Lima EDO, Souza ELD, Travassos AER. Propriedade antibacteriana de óleos essenciais de especiarias sobre bactérias contaminantes de alimentos. Ciência e Tecnologia de Alimentos. 2009;**29**:542-545

[5] Morais AM, Centurião LN, De Oliveira LG, De Oliveira Aragão DM. Atividade antioxidante de especiarias in natura e desidratadas no consumo alimentar. Revista de APS—Atenção Primária à Saúde. 2018;**21**:156-157

[6] Silva AC, Iacuzio R, Da Silva Cândido TJ, Rodrigues MX, Silva NCC. Resistência antimicrobiana de *Salmonella* spp., *Staphylococcus aureus* e *Escherichia coli* isolados de carcaças de frangos: Resistência a antibióticos e óleos essenciais. Revista Brasileira de Agropecuária Sustentável. 2018;**8**:95-103

[7] Gomes EMC, Firmino AV, Pena RDCM. Efeito inibitório in vitro de extratos de *Cinnamomum zeylanicum* blume no controle de *Cylindrocladium candelabrum*. Ciência Florestal. 2018;**28**:1559-1567

[8] Oliveira TFVD. Características químicas e microbiológicas do açafrão-da-terra (*Curcuma longa*). Trabalho de Conclusão de Curso. Universidade Tecnológica Federal do Paraná; 2017

[9] Koroch AR, Simon JE, Juliani HR. Essential oil composition of purple basils, their reverted green varieties (*Ocimum basilicum*) and their associated biological activity. Industrial Crops and Products. 2017;**107**:526-530

[10] Lourenço M, Bernardi ACA, Lunardi N, Neto RJB, Bernardi PSM, Boeck EM. In vitro evaluation of the antimicrobial activity of basil (*Ocimum baslicum* L.) and coriander (*Coriandrum satirum* L.) oil extracts on *Streptococus* mutans. Journal of Research in Dentistry. 2018;**5**:40-45

[11] Silva FT. Ação do óleo essencial de gengibre (*Zingiber officinale*) encapsulado em fibras ultrafinas de proteína isolada de soja, poli (óxido de etileno) e zeína no controle antimicrobiano in situ [Dissertação de Mestrado]. Universidade Federal de Pelotas; 2018

[12] Porto LL, LRVD R. Avaliação do Potencial Antimicrobiano de Óleos Essenciais de Coentro (*Coriandrum sativum* L.) e Orégano (*Origanum vulgare* L.). Trabalho de Conclusão de Curso. Universidade Tecnológica Federal do Paraná; 2018

[13] Dutra TV, Castro JC, Menezes JL, Ramos TR, Do Prado IN, Júnior MM, et al. Bioatividade do óleo Essencial de Orégano (*Origanum vulgare*) Contra *Alicyclobacillus* spp. Culturas e Produtos Industriais. Vol. 129. 2019. pp. 345-349

[14] Santos G, Oliveira MC, Silva MM, Castro AA. Estudo comparativo

do coentro (*Coriandum sativum* L.) seco obtido em diferentes métodos de secagem. Revista Geintec-Gestão, Inovação e Tecnologias. 2012;**3**:236-244

[15] Calo JR, Crandall PG, O'bryan CA, Ricke SC. Essential oils as antimicrobials in food systems—A review. Food Control. 2015;**54**:111-119

[16] Santurio DF, Da Costa MM, Maboni G, Cavalheiro CP, De Sá MF, Dal Pozzo M, et al. Atividade antimicrobiana de óleos essenciais de condimentos frente a amostras de *Escherichia coli* isoladas de aves e bovinos. Ciência Rural. 2011;**41**:1051-1056

[17] Oliveira AR, Jezler CN, Oliveira RA, Mielke MS, Costa LC. Determinação do tempo de hidrodestilação e do horário de colheita no óleo essencial de menta. Horticultura Brasileira. 2012;**30**:155-159

[18] Milillo SR, Martin E, Muthaiyan A, Ricke SC. Immediate reduction of salmonella enterica serotype typhimurium viability via membrane destabilization following exposure to multiple-hurdle treatments with heated, acidified organic acid salt solutions. Applied and Environmental Microbiology. 2011;**77**:3765-3772

[19] Solórzano-Santos F, Miranda-Novales MG. Essential oils from aromatic herbs as antimicrobial agents. Current Opinion in Biotechnology. 2012;**23**:136-141

[20] Hintz T, Matthews KK, Rong D. The use of plant antimicrobial compounds for food preservation. BioMed Research International. 2015;ID 246264:1-12

[21] Jorge SSA. Plantas Medicinais: Coletânea de Saberes; 2017

[22] Pereira AIS. Atividade Antibacteriana e Caracterização Físico-Química de Óleos Essenciais Extraídos das Plantas Medicinais Comumente Utilizadas pela População de São Luís do Maranhão; 2017

[23] Bassanetti I, Carcelli M, Buschini A, Montalbano S, Leonardi G, Pelagatti P, et al. Investigation of antibacterial activity of new classes of essential oils derivatives. Food Control. 2017;**73**:606-612

[24] Tajkarimi MM, Ibrahim Salam A, Cliver DO. Antimicrobial herb and spice compounds in food. Food Control. 2010;**21**:1199-1218

[25] Andrade MA, Cardoso MDG, Batista LR, Mallet ACT, Machado SMF. Essential oils of *Cinnamomum zeylanicum*, *Cymbopogon nardus* and *Zingiber officinale*: Composition, antioxidant and antibacterial activities [Óleos essenciais de *Cymbopogon nardus*, *Cinnamomum zeylanicum* e *Zingiber officinale*]. Revista Ciência Agronômica. 2012;**43**:399-408

[26] Miranda CASF, Das Graças Cardoso M, Batista LR, Rodrigues LMA, Da Silva Figueiredo AC. Óleos essenciais de folhas de diversas espécies: Propriedades antioxidantes e antibacterianas no crescimento espécies patogênicas. Revista Ciência Agronômica. 2016;**47**:213-220

[27] Atarés L, Chiralt A. Essential oils as additives in biodegradable films and coatings for active food packaging. Trends in Food Science and Technology. 2016;**48**:51-62

[28] Oliveira ABAD, Paula CMDD, Capalonga R, Cardoso MRDI, Tondo EC. Doenças transmitidas por alimentos, principais agentes etiológicos e aspectos gerais: Uma revisão. Revista do Hospital de Clínicas de Porto Alegre. 2010;**30**:279-285

[29] World Health Organization (WHO). WHO Estimates of the Global Burden of Foodborne Diseases: Foodborne

Disease Burden Epidemiology Reference Group 2007-2015. 2015. p. 255. ISBN 978 92 4 156516 5

[30] Akyol I. Development and application of RTi-PCR method for common food pathogen presence and quantity in beef, sheep and chicken meat. Meat Science. 2018;**137**:9-15

[31] Vergis J, Gokulakrishnan P, Agarwal RK, Kumar A. Essential oils as natural food antimicrobial agents: A review. Critical Reviews in Food Science and Nutrition. 2015;**55**(10):1320-1323.

[32] Gebreyes WA, Wittum T, Habing G, et al. Spread of antibiotic resistance in food animal production systems. In: Dodd C, Aldsworth T, Stein RA, et al., editors. Foodborne Diseases. 3rd ed. Cambridge: Academic Press; 2017. pp. 105-130

[33] Yap PSX, Yiap BC, Ping HC. Essential oils, a new horizon in combating bacterial antibiotic resistance. The Open Microbiology Journal. 2004;**8**:6-14

[34] Unlu M, Ergene E, Unlu GV, Zeytinoglu HS, Vural N. Composition, antimicrobial activity and in vitro cytotoxicity of essential oil from *Cinnamomum zeylanicum* Blume (Lauraceae). Food and Chemical Toxicology. 2010;**48**:3274-3280

[35] Procopio FR, Oriani VB, Paulino BN, do Prado-Silva L, Pastore GM, Sant'Ana AS, et al. Solid lipid microparticles loaded with cinnamon oleoresin: Characterization, stability and antimicrobial activity. Food Research International. 2018; **113**:351-361

[36] Kačániová M, Terentjeva M, Vukovic N, Puchalski C, Roychoudhury S, Kunová S, et al. The antioxidant and antimicrobial activity of essential oils against pseudomonas spp. isolated from fish. Saudi Pharmaceutical Journal. 2017;**25**:1108-1116

[37] Echegoyen Y, Nerin C. Performance of an active paper based on cinnamon essential oil in mushrooms quality. Food Chemistry. 2015;**170**:30-36

[38] Teles AM, Rosa TDS, Mouchrek AN, Abreu-Silva AL, Calabrese KS, Almeida-Souza F. *Cinnamomum zeylanicum*, *Origanum vulgare*, and *Curcuma longa* essential oils: Chemical composition, antimicrobial and antileishmanial activity. Evidence-based Complementary and Alternative Medicine. 2019;ID 2421695:1-12

[39] Probst IS. Dissertação de Mestrado. Universidade Estadual Paulista; 2012

[40] Maia AJ, Schwan-Estrada KRF, Faria CMDR, Oliveira JSB, Jardinetti VA, Batista BN. Óleo essencial de alecrim no controle de doenças e na indução e resistência em videira. Pesquisa Agropecuária Brasileira. 2014;**49**:330

[41] Morshedloo MR, Salami SA, Nazeri V, Maggi F, Craker L. Essential oil profile of oregano (*Origanum vulgare* L.) populations grown under similar soil and climate conditions. Industrial Crops and Products. 2018;**119**:183-190

[42] Mastro G, Tarraf W, Verdini L, Brunetti G, Ruta C. Essential oil diversity of *Origanum vulgare* L. populations from southern Italy. Food Chemistry. 2017;**235**:1-6

[43] Martinez-Correa HA, Paula JT, Kayano ACA, Queiroga CL, Magalhães PM, Costa FT, et al. Composition and antimalarial activity of extracts of *Curcuma longa* L. obtained by a combination of extraction processes using supercritical CO_2, ethanol and water as solvents. The Journal of Supercritical Fluids. 2017;**119**:122-129

[44] Gopalan B, Goto M, Kodama A, Hirose T. Supercritical carbon dioxide extraction of turmeric (*Curcuma longa*). Journal of Agricultural and Food Chemistry. 2000;**48**:2189-2192

[45] Angel GR, Menon N, Vimala B, Nambisan B. Essential oil composition of eight starchy curcuma species. Industrial Crops and Products. 2014;**60**:233-238

[46] Diemer AW. Ação antimicrobiana de *Rosmarinus officinalis* e *Zingiber officinale* frente a *Escherichia coli* e *Staphylococcus aureus* em carne mecanicamente separada de frango [Dissertação de Mestrado]; 2016

[47] Andrade MA, Cardoso MG, Batista LR, Mallet ACT, Machado SMF. Óleos essenciais de *Cymbopogon nardus*, *Cinnamomum zeylanicum* e *Zingiber officinale*: Composição, atividades antioxidante e antibacteriana. Revista Ciência Agronômica. 2012;**43**:399-408

[48] Estevam E, Miranda M, Alves J, Egea M, Pereira P, Martins C, et al. Revista Virtual de Química. Composição Química e Atividades Biológicas dos Óleos Essenciais das Folhas Frescas de Citrus limonia Osbeck e Citrus latifolia Tanaka (Rutaceae). Revista Virtual Química. 2016;**8**:1842-1854

[49] Gargano AC. Dissertação de Mestrado. Brasil: Universidade Estadual Paulista; 2007

[50] Clinical and Laboratory Standards Institute. Performance Standards for Antimicrobial Disk Susceptibility Tests. 8a ed. 2003

[51] Bauer AW. Antibiotic susceptibility testing by a standardized single disk method. American Journal of Clinical Microbiology. 1966;**40**:2413-2415

[52] National Committee for Clinical Laboratory Standard. Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria that Grow Aerobically. 6a ed. 2003

[53] Chao SC, Yong DG, Oberg CJ. Secrening for inibitory activity of essential oils on selected bactéria. Fungi and viroses. Journal of Essential Oil Research. 2000;**12**:639-649

[54] Silveira SMD, Cunha Júnior A, Scheuermann GN, Secchi FL, Vieira CRW. Chemical composition and antimicrobial activity of essential oils from selected herbs cultivated in the south of Brazil against food spoilage and foodborne pathogens. Ciência Rural. 2012;**42**:1300-1306

[55] Boniface Y, Philippe S, de Lima HR, Pierre NJ, Alain AG, Fatiou T, et al. Chemical composition and antimicrobial activities of *Cinnamomum zeylanicum* Blume dry leaves essential oil against food-borne pathogens and adulterated microorganisms. Research Journal of Biological Sciences. 2012;**1**:18-25

[56] Cordeiro TS. Monografia. Universidade do Extremo Sul Catarinense; 2012

[57] Ribeiro DS. Dissertação de Mestrado. Universidade Federal da Bahia; 2011

[58] Silva AA, dos Anjos MM, Ruiz SP, Panice LB, Mikcha JMG, Junior MM, et al. Avaliação da atividade óleos essenciais de *Thimus vulgaris* (tomilho), *Syzygium aromaticum* (cravo-da-india) e *Rosmarinus officinalis* (alecrim) e dos conservantes benzoato de sódio e sorbato de potássio em *Escherichia coli* e *Staphylococcus aureus*. Boletim do Centro de Pesquisa de Processamento de Alimentos. 2015. p. 33

[59] Thanh TT, Lan LX, Thu H, Tam NKM. Isolation by different processes and in vitro bioactivities of rosemary (*Rosmarinus officinalis* L.) essential oil. In: AIP Conference Proceedings. AIP Publishing; 2017. p. 020040

[60] Stefanakis MK, Touloupakis E, Anastasopoulos E, Ghanotakis D, Katerinopoulos HE, Makridis P.

Antibacterial activity of essential oils from plants of the genus Origanum. Food Control. 2013;**34**:539-546

[61] Sankar R, Karthik A, Prabu A, Karthik S, Shivashangari KS, Ravikumar V. Origanum vulgare mediated biosynthesis of silver nanoparticles for its antibacterial and anticancer activity. Colloids and Surfaces, B: Biointerfaces. 2013;**108**:80-84

[62] Soković M, Glamočlija J, Marin PD, Brkić D, Van Griensven LJ. Antibacterial effects of the essential oils of commonly consumed medicinal herbs using an in vitro model. Molecules. 2010;**15**:7532-7546

[63] Sarikurkcu C, Zengin G, Oskay M, Uysal S, Ceylan R, Aktumsek A. Composition, antioxidant, antimicrobial and enzyme inhibition activities of two Origanum vulgare subspecies (subsp. vulgare and subsp. hirtum) essential oils. Industrial Crops and Products. 2015;**70**:178-184

[64] Gupta A, Mahajan S, Sharma R. Evaluation of antimicrobial activity of Curcuma longa rhizome extract against Staphylococcus aureus. Biotechnology Reports. 2015;**6**:51-55

[65] Mishra R, Gupta AK, Kumar A, Lal RK, Saikia D, Chanotiya CS. Genetic diversity, essential oil composition, and in vitro antioxidant and antimicrobial activity of *Curcuma longa* L. germplasm collections. Journal of Applied Research on Medicinal and Aromatic Plants. 2018;**10**:75-84

[66] Singh S, Sankar B, Rajesh S, Sahoo K, Subudhi E, Nayak S. Chemical composition of turmeric oil (*Curcuma longa* L. cv. Roma) and its antimicrobial activity against eye infecting pathogens. Journal of Essential Oil Research. 2011;**23**:11-18

[67] Singh G, Kapoor IPS, Singh P, Heluani CS, Lampasona MP, Catalan CAN. Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of *Zingiber officinale*. Food and Chemical Toxicology. 2008;**46**:3295

[68] Grégio AMT, Fortes ESM, Rosa EAR, Simeoni RB, Rosa RT. Ação antimicrobiana do *Zingiber officinale* frente à microbiota bucal. Estudos de Biologia. 2006;**28**:61

[69] Sasidharan I, Menon AN. Comparative chemical composition and antimicrobial activity fresh & dry ginger oils (*Zingiber officinale* roscoe). International Journal of Current Pharmaceutical Research. 2010;**2**:40-43

[70] Re R, Pellegrini N, Proteggente A, Pannala A, Yang M, Rice-Evans C. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radical Biology & Medicine. 1999;**26**:1231-1237

[71] Wang HF. Comparative study of the antioxidant activity of forty-five commonly used essential oils and their potential active components. Journal of Food and Drug Analysis. 2010;**18**:24-33

[72] Proestos C, Lytoudi K, Mavromelanidou OK, Zoumpoulakis P, Sinanoglou VJ. Antioxidant capacity of selected plant extracts and their essential oils. Antioxidants. 2013;2:11

[73] Ramos RS. Dissertação de Mestrado. Universidade Federal do Amapá; 2014

[74] Alarcon MET. Evaluación de la actividad antioxidante del aceite esencial foliar extraido de especies de oregano (*Origanum vulgare*), oregano "borde blanco" (*Origanum vulgare* ssp.) y oreganito (*Lippia alba*) cultivado en la zona norte del departamento de bolívar (colombia). Dissertação (Mestrado). Universidade Nacional da Colômbia; 2014. p. 131

[75] Babili FE, Bouajila J, Souchard JP, Bertrand C, Bellvert F, Fouraste I, et al. Oregano: Chemical analysis and evaluation of its antimalarial, antioxidant, and cytotoxic activities. Journal of Food Science. 2011;**76**:C512-C518

[76] Stanojević JS, Stanojević LP, Cvetković DJ, Danilović BR. Chemical composition, antioxidant and antimicrobial activity of the turmeric essential oil (*Curcuma longa* L.). Advanced Technologies. 2015;**4**:19-25

[77] Jeena K, Liju VB, Kuttan R. Antioxidant, anti-inflammatory and antinociceptive activities of essential oil from ginger. Indian Journal of Physiology and Pharmacology. 2013;**57**:51

[78] Andrade MA. Dissertação de Mestrado. Lavras: Universidade Federal de Lavras; 2010