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Antibacterial activity of the *Piper aduncum* oil and dillapiole, its main constituent, against multidrug-resistant strains

[Actividad antibacteriana del aceite de *Piper aduncum* y dillapiole, su componente principal, frente a cepas resistentes a múltiples fármacos]

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Abstract: The study aimed to evaluate the bactericidal activity of oil essential and dillapiole from *P. aduncum* against standard and multidrug-resistant strains of *Staphylococcus spp.* The oil showed antimicrobial action against these strains, but better results were obtained for the standards strains of *S. epidermidis* and *S. aureus*, with MIC of 250 and 500 µg/mL, respectively. Dillapiolle was less effective than the oil against the same standard and multi-drug resistant strains (MIC =1000 µg/mL). However, when dillapiolle was tested in combination with myristicin, another component of the oil, it increased its bactericidal activity and showed a synergistic action.

Keywords: *Piper aduncum*, *Piperaceae*, dillapiole; myristicin; piperitone; antimicrobial activity; multidrug-resistant strains

Resumen: El objetivo del estudio fue evaluar la actividad bactericida de los aceites esenciales y dillapiole de *P. aduncum* contra cepas estándar y multiresistentes de *Staphylococcus spp.* El aceite mostró acción antimicrobiana frente a estas cepas, pero se obtuvo mejores resultados para las cepas de *S. epidermidis* y *S. aureus*, con MIC de 250 y 500 µg/ml, respectivamente. Dillapiolle fue menos eficaz que el aceite contra cepas estándar y multiresistentes (MIC = 1000 µg/ml). Sin embargo, cuando dillapiolle fue probado en combinación con la miristicina, otro componente del aceite, que aumentó su actividad bactericida y mostró una acción sinérgica.

Palabras clave: *Piper aduncum*, *Piperaceae*, dillapiole, miristicina, piperitona, actividad antimicrobiana, las cepas multiresistente

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INTRODUCTION

Piper is the largest genus in the Piperaceae with about 1,000 species and among them there are about 170 species occurring in Brazil (Yuncker, 1972). *Piper aduncum* L. is a widespread shrub growing wild in the Amazon, known as “pimento-de-macaco” [syn. *Artanthe adunca* (L.) Miq., *A. elongata* (Vahl) Miq., *Piper aduncifolium* Trel., *P. angustifolium* Ruiz & Pav., *P. elongatum* Vahl, *Steffensia adunca* (L.) Kunth, *S. elongata* (Vahl) Kunth, among many other]. With respect the popular use, the leaf tea of *P. aduncum* is indicated in the treatment of pyelitis, cystitis, erysipelas, and for wound healing (Vieira, 1991; Vandenberg, 1993; Coimbra 1994).

Previously, from the leaves of *P. aduncum*, with occurrence in the Brazilian Amazon, was seen a significant essential oil yield (1.5% to 3.5%) and a high content of dillapiole (31.5% to 97.3%) (Gottlieb et al., 1981; Maia et al., 1998), a phenylpropene derivative. Dillapiole was also the main constituent in the oil of *P. aduncum* existing in Cuba (82.2%), Malaysia (64.5%), Costa Rica (61.8%) and Eastern Ecuador (45.92%) (Jantan et al., 1994; Ciccio & Ballestero, 1997; Pino et al., 2004; Guerrini et al., 2009). On the other hand, specimens of *P. aduncum* occurring in the Brazilian Atlantic Forest are rich in terpene compounds as linalool and (*E*)-nerolidol, as well as, 1,8-cineole, (*E*)-caryophyllene and aromadendrene in specimens existing in Bolivia and Panamá (Pino et al., 2004; Vila et al., 2005; Oliveira et al., 2006; Navickiene et al., 2006; Guerrini et al., 2009). In this respect, the constituents of volatile oils can vary in accordance with the climate, type and management of soil, sunlight, temperature, and the humidity of different ecosystems (Almeida et al., 2009).

Antimicrobial, molluscicidal and cytotoxic properties of extracts and essential oil from *Piper aduncum* have been reported. Prenylated p-hydroxybenzoic acid derivatives, dihydrochalcones and chromenes isolated from its leaf alcoholic extract were active against protozoa parasites and diverse microorganisms, including pathogenic bacteria and fungi (Nair & Burke, 1990; Orjala et al., 1993; Orjala et al., 1994; Okunade et al., 1997; Lentz et al., 1998; Kloucek et al., 2005; Guerrini et al., 2009). The ethanol extract from aerial part of *P. aduncum* were more active against Gram-positive than against Gram-negative bacteria (Kloucek et al., 2005).

The essential oil of *P. aduncum* proved to be toxic and insecticide for some insect pests, especially against *Anopheles marajoara* and *Aedes aegypti*, the mosquitoes that transmit malaria and dengue, as well as against *Solenopsis saevissima*, the fire ant which has caused serious problems in Northern Brazil. The biological effects observed for the oil of *P. aduncum* were attributed to dillapiole, a phenylpropene derivative and its main constituent (Bernard et al., 1995; Almeida et al., 2009; Souto et al., 2012). Dillapiole was also reported as a synergist of various natural insecticides, including carbamates, organochlorides, pyrethrum, tenulin, and azadirachtin. Furthermore, it was speculated that dillapiole exhibits synergistic action with other volatiles occurring in the oil of the *P. aduncum*, increasing its stability and insecticide effect (Hand & Dewan, 1974; Tomar et al., 1979a; Tomar et al., 1979b; Bernard et al., 1990). The oil of *P. aduncum* and dillapiole showed also fungicidal activity against *Crinipellis pernicioso* and *Fusarium solani* f. sp. *Piperis*, two phytopathogenic fungi, which infects the cocoa and pepper crops in the Brazilian Amazon (Bastos, 1997; Benchimol et al., 2001). The toxicological evaluation for the oil of *P. aduncum* showed low toxicity in mice (LD₅₀ 2.400 ± 191.7 mg/kg) (Sousa et al., 2008).

In the surveillance studies have been seen an increase in the resistance for Gram positive pathogens, which are dangerous nosocomial infection agents. About 60% of all strains are methicillin-resistant *Staphylococcus aureus* (MRSA) and *Staphylococcus coagulase negative* (SCN). These strains are resistant to most beta-lactam antibiotics, causing an increase in mortality of patients and high health-care costs (Rice, 2006; Martins & Cunha, 2007; Fessler et al., 2010). Moreover, it has been reported that bacteria resistant to beta-lactam antibiotics are more sensitive to oils and extracts of plants, as well as their isolated compounds (Ríos & Recio, 2005).

Above, it was seen that *P. aduncum* extracts have antimicrobial, molluscicidal and cytotoxic properties while its essential oil and dillapiole showed insecticide and fungicide effects. The aim of this study was to evaluate the antibacterial activity of the oil of *P. aduncum* and dillapiole against multi-resistant isolates, in order to analyze their potential use as inhibitors of hospital infection.

MATERIAL AND METHODS

Plant Material and processing

The aerial parts (leaves and thin stems) of *P. aduncum* have been obtained from an experimental station located in the municipality of Santo Antonio do Tauá, Pará state, Brazil. Vouchers were deposited in the herbarium of Emilio Goeldi Museum, city of Belém, state of Pará, Brazil. The plant was dried in an air circulating oven (24 h, 35 °C) to reduce the moisture to 15% and then subjected to hydrodistillation (300g, 3 h) using a Clevenger-type apparatus. The resulting oil was dried over anhydrous sodium sulfate, and its percentage content was calculated on the basis of the plant dry weight. The moisture amount of the sample was calculated after phase separation in a Dean-Stark trap (5 g, 60 min), using toluene.

Oil-composition analysis

The analysis of the oil was carried out on a THERMO DSQ II GC-MS instrument, under the following conditions: DB-5ms (30 m x 0.25 mm; 0.25 µm film thickness) fused-silica capillary column; programmed temperature, 60-240 °C (3 °C/min); injector temperature, 250 °C; carrier gas, was helium adjusted to a linear velocity of 32 cm/s (measured at 100 °C); injection type, splitless (2 µL of a 1:1000 hexane solution); split flow was adjusted to yield a 20:1 ratio; septum sweep was a constant 10 ml/min; EIMS, electron energy, 70 eV; temperature of ion source and connection parts, 200 °C. The quantitative data regarding the volatile constituents were obtained by peak-area normalization using a FOCUS GC/FID operated under conditions similar to those in GC-MS, except for the carrier gas, which was nitrogen. The retention index was calculated for all the volatiles constituents using an *n*-alkane (C₈-C₂₀, Sigma-Aldrich) homologous series.

Individual components were identified by comparison of both mass spectrum and GC retention data with authentic compounds, which were previously analyzed and stored in the data system, as well as with the aid of commercial libraries containing retention indices and mass spectra of

volatile compounds commonly found in essential oils (NIST, 2005; Adams, 2007).

Oil-fractionation

The oil (5 g) was submitted to column chromatography (CC, 80 x 3cm) over silica gel (SiO₂, 70 g, 230-400 mesh), with hexane as solvent, and the separated fractions were monitored by TLC (visualization with vanillin/H₂SO₄, 110 °C). The content of dillapiole in the oil and in the purified fractions was determined by GC/FID.

Determination of antibacterial activity

Test organisms

Antibacterial activity was evaluated for the standard strains of *Staphylococcus aureus* ATCC 25923 and *Staphylococcus epidermidis* ATCC 12228, which were obtained from the INCQS/FIOCRUZ (Instituto Nacional de Controle da Qualidade da Saúde, Fundação Oswaldo Cruz, Rio de Janeiro, Brazil). Furthermore, two multi-drug resistance (MDR) clinic isolates (*S. epidermidis* and methicillin-resistant *Staphylococcus aureus*, MRSA) were also applied as test organisms and obtained from cultures of patient samples existing in the Public Hospital (Bacteriological Laboratory) of Belém city, Pará, Brazil. These isolates were identified at species level, using conventional microbiological methods and *in vitro* susceptibility, when tested by disk diffusion in the automated system Vitek 2 (BioMérieux, France). MDR isolates were defined according to an international expert proposal in view to establish standard definitions for acquired resistance, supported by the European Centre for Disease Prevention and Control (ECDC, Stockholm, Sweden) and the US Centers for Disease Control and Prevention (CDC, Atlanta, GA, USA). The drug resistance profiles of these isolates were described in Table 1. According to this definition, a MDR isolate should have acquired resistance (non-sensitivity) to more than one agent in three or more antimicrobial classes (Magiorakos *et al.*, 2012).

Table 1
Bacterial source and antibiotic resistance profile.

Bacteria	Source	Antibiotic resistance
Methicilin-resistant <i>Staphylococcus aureus</i> (MRSA)	Surgical wound	Pen, Oxa, Met, Gen, Cip, Nor, Eri, Clin, Rif, TMP/SMX
MDR <i>Staphylococcus epidermidis</i>	Surgical wound	Pen, Oxa, Met, Gen, Cip, Mox, Nor, Eri, Clin, TMP/SMX
MDR <i>Staphylococcus lentus</i>	Surgical wound	Pen, Oxa, Met, Gen, Cip, Mox, Nor, Eri, Clin

Pen, Penicillin; Oxa, Oxacillin; Met, Methicillin; Gen, Gentamicin; Cip, Ciprofloxacin; Mor, Moxifloxacin; Nor, Norfloxacin; Eri, Erythromycin; Clin, Clindamycin; Rif, Rifampicin; TMP/SMX = trimethoprim/sulfamethoxazole; MDR - Multidrug-resistant

Broth micro-dilution assay for minimum inhibitory concentration (MIC)

For bacterial inocula preparation, strains were grown to exponential phase in Mueller–Hinton broth (Merck, German) at 37 °C, for 18 h, and adjusted by diluting fresh cultures to turbidity, equivalent to 0.5 McFarland scale (approximately of 2×10^8 CFU/mL) as described by Clinical and Laboratory Standards Institute (CLSI, 2012). MIC assay was performed by using the broth microdilution method in Mueller-Hinton broth (MHA) as described by CLSI (2012). Separately, the oil and dillapiolle were dissolved in tween 20 to the highest concentration (2000 µg/mL) to be tested and, then, a serial two-fold dilution was made in a concentration range from 100 to 1000 µg/mL in 1 mL sterile test tubes containing MHA. The inoculum (100 µL) containing 5×10^8 CFU/mL was added to each well and 100 µL from their serial dilutions were transferred into continuous wells. The final volume in each well was 200 µL. The last well containing MHA (100 µL) in Tween 20 without the oil and inoculum (100 µL) was used as negative control.

Chloramphenicol (50 µg/mL) served as the positive control in the parallel experiments. The MIC was defined as the lowest concentration of the oil and dillapiolle at which the microorganism does not demonstrate visible growth. The microorganism growth was indicated by the turbidity as described by Quadros *et al.* (2011). Each concentration reading

was repeated three times. All experiments were repeated at least twice.

Statistical analysis

Results were expressed as mean (SEM). Statistically significant differences between groups were determined by one-way analysis of variance (ANOVA) followed by Tukey's test ($p \leq 0.05$).

RESULTS AND DISCUSSION

Oil-analysis and purified fractions

The dried aerial part (leaves and thin stems) of *Piper aduncum* were subjected to hydrodistillation, and the yield of oil was 3.0%. The volatile constituents of the oil and its column chromatography purified fractions were analyzed by GC and GC-MS. The identified constituents were listed in Table 2, totaling 95.6%. The main constituent was dillapiolle comprising 76.5% of the oil. Taking into account the presence of myristicin (2.1%), apiolle (1.2%) and elemicin (0.8%), three other constituents structurally related to dillapiolle, the final content of phenylpropanoids reached 80.5% of the oil. The oil was subjected to column chromatography with a view to purifying dillapiolle. Between the purified fractions, the higher fraction (2.8 g) showed dillapiolle with a percentage of 94.6%, which then it was used in the antibacterial assays. It is also remarkable the high content of piperitone (6.1%) in the oil.

Table 2
Constituents identified in the oil (%) of *P. aduncum*.

Constituents	Retention Index*	Oil %
α -Pinene	934	0.7
β -Pinene	978	0.5
Limonene	1026	0.8
(Z)- β -Ocimene	1035	0.2
(E)- β -Ocimene	1045	0.4
γ -Terpinene	1056	1.3
Terpinen-4-ol	1174	2.3
Piperitone	1251	6.1
(E)-Caryophyllene	1416	1.5
Germacrene D	1484	1.2
Myristicin	1519	2.1
Elemicin	1555	0.8
Dillapiole	1621	76.5
Apiole	1678	1.2
Sesquiterpenes, both hydrocarbons and oxygenated, not identified		3,6
Total		99.2

*on column DB-5ms.

Antibacterial bioassays

The antibacterial activity of the oil of *P. aduncum* and dillapiole against ATCC strains and MDR isolates is showed in Figure 1. The oil was effective against *Staphylococcus aureus* ATCC strain at concentrations of 500 μ g/mL, 750 μ g/mL and 1000 μ g/mL, inhibiting the bacterial growth in 50%, 90% and 100%, respectively (Figure 1, panel A). However, the oil only was able to inhibit significantly the growth of MRSA isolate at the concentrations of 750 μ g/mL and 1000 μ g/mL, corresponding to 10% and 90%, respectively (Figure 1, panel B). With respect to dillapiole, it was able to inhibit 100% the

growth of *S. aureus* ATCC strain at concentration of 1000 μ g/mL, while it was not effective against the MRSA isolate at the same concentration (Figure 1, panel A and B). Similarly, the oil also inhibited the growth of *S. epidermidis* ATCC strain at concentrations between 250 to 1000 μ g/mL, while it was only effective against the MDR *S. epidermidis* isolate at concentrations of 750 to 1000 μ g/mL (Figure 1, panel C and D, respectively). With respect to dillapiole, it showed a inhibition of 25% in growth of *S. epidermidis* ATCC strain and MDR *S. epidermidis* isolate, at concentration of 1000 μ g/mL (Figure 1, panel C and D, respectively).

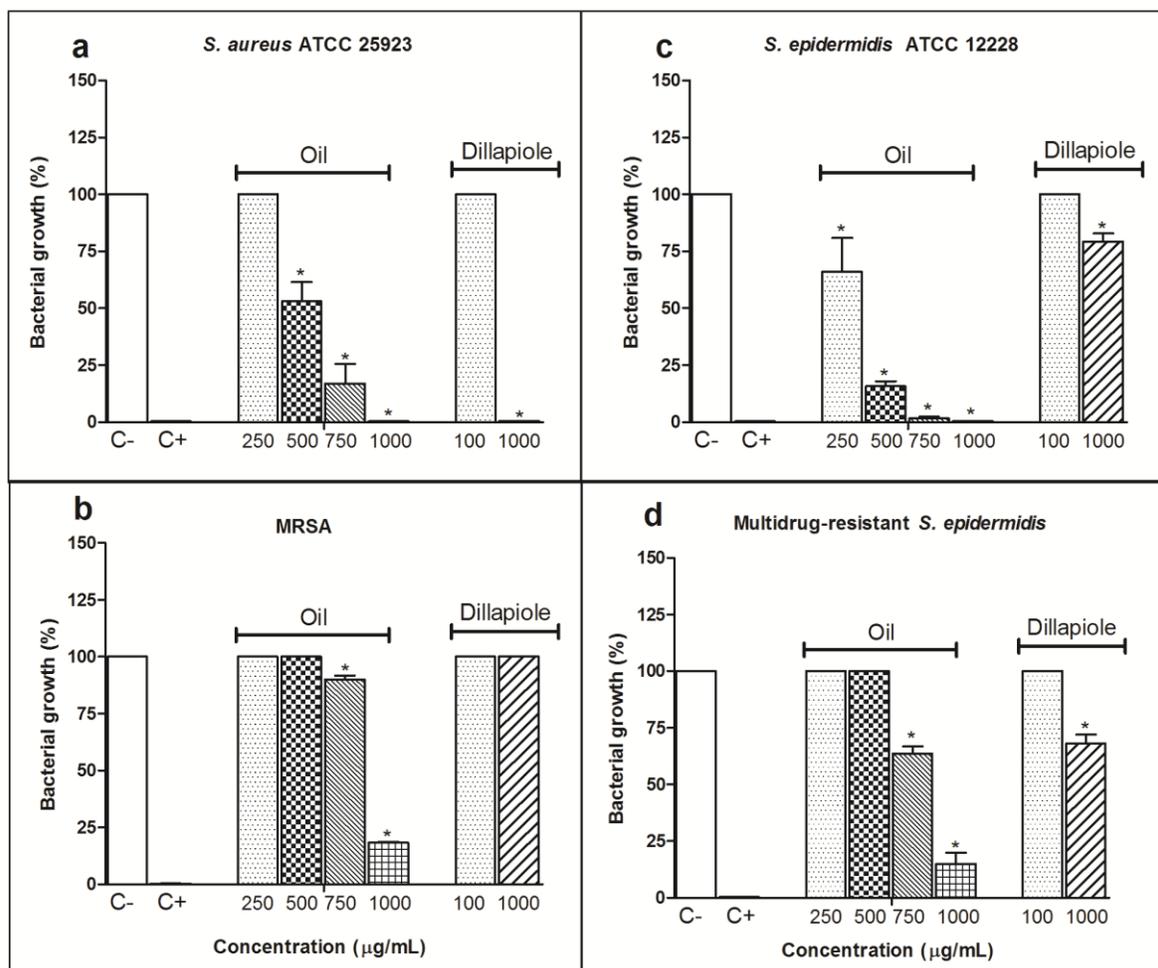


Figure 1

Antibacterial activity of the oil and dillapiole from *P. aduncum* against standard strains and multi-drug resistant isolates. (A) *S. aureus* ATCC 25923 strain; (B) methicillin-resistant *S. aureus* (MRSA) isolate; (C) *S. epidermidis* ATCC 12228 strain; and (D) MDR *S. epidermidis* isolate. *S. aureus* and *S. epidermidis* were incubated at different concentrations of oil and dillapiole, during 24 h and 37 °C. As negative control (C-) was used tween 20 and positive control (C+) was used chloramphenicol. Bacterial growth were expressed as mean (SEM) percentage (n = 3). *p < 0.001 compared with the negative control

The MIC data for the oil and dillapiole of *P. aduncum* tested against ATCC strains and MDR isolates, and compared with literature data, were summarized in Table 3. These data showed that the oil was able to inhibit the standard strains of *S. epidermidis* and *S. aureus* ATCC with MIC values of 250 and 500 µg/mL, respectively. Even with respect to oil, it was effective to inhibition the growth of MRSA *S. aureus* and MDR *S. epidermidis* with MIC values of 750 µg/mL, while for MDR *S. lentus* it was active only with values >1000 µg/mL. Previously, the oil of *P. aduncum* had indicated a MIC value of 5240

µg/mL for the inhibition of *S. aureus* ATCC 25923 (see Table 3) (Guerrini *et al.*, 2009).

In comparison with the oil, the dillapiole was less effective against the ATCC strains and MDR isolates, showing MIC values higher than 750 µg/mL (see Table 3). The fact that the oil was more effective than dillapiole might be interpreted by a synergistic action existing in the oil. It is likely that the presence of other volatile constituents in the oil was contributing to its greater bacterial effect. The co-occurrence of myristicin and dillapiole in essential oils is frequent because dillapiole results from

enzymatic methoxylation of myristicin. From the seeds of *Myristica fragrans* (Myristicaceae), it has been seen that myristicin exhibits high antimicrobial activity against gram-positive (*S. aureus*, MIC = 0.75 µg/mL; *Micrococcus luteus*, MIC = 0.625 µg/mL) and gram-negative bacteria (*Pseudomonas aeruginosa*, MIC = 0.60 µg/mL; *Escherichia coli*, MIC = 1.25 µg/mL) (Narasimhan & Dhake, 2006). On the other hand, others studies have shown that the myristicin was ineffective against *Staphylococcus aureus* ATCC 25923, *Staphylococcus epidermidis* ATCC 12228, *Escherichia coli* ATCC 8739, and *Pseudomonas aeruginosa* ATCC 9027 (Stefano *et al.*, 2011; Torbati *et al.*, 2013), showing that the antibacterial action of myristicin is still controversial.

Based on the facts above, the dilapiole when tested in combination with the myristicin (Fluka standard), under the same working conditions and using percentages of 1 to 2% of myristicin, showed antibacterial activity with compatible values to that previously observed for the oil and dilapiol alone, that was MIC values between 500 and 750 µg/mL (Table 3). Other important component from oil of *P. aduncum*, is the Piperitone, which it can help in bactericidal action of dilapiol and/or myristicin. Although in this study, the piperitone has not been tested with dillapiole because it was not possible to obtain a sample of this compound. However, most studies have reported that this component has a high bactericidal action against gram-positive and gram-negative bacteria. In this regards, the essential oil of *Mentha pulegium* L. rich in piperitone (38%) showed powerful antimicrobial activity against *Staphylococcus aureus* ATCC 25923 (MIC = 0.5 µg/mL), *Staphylococcus epidermidis* ATCC 12228 (MIC = 1 µg/mL), *Bacillus cereus* (MIC = 1 µg/mL), *Escherichia coli* (MIC = 2 µg/mL) (Mahboubi & Haghi, 2008). Similarly, the oil of *Tagetes patula* L. (Asteraceae) rich that also is in piperitone (33.8%) showed exhibited highly bactericidal effect against *S. aureus* ATCC 25923 (MIC = 30 µg/mL), *P. aeruginosa* (MIC = 130 µg/mL and *E. coli* (MIC = 60 µg/mL) (Rondón *et al.*, 2006). Others researches also have reported that the essential oil of aerial parts of *Ziziphora persica*) that also was detected piperitone

was active against several Gram-positive and Gram-negative bacteria with MIC in the range of 7.81–250 µg/ml (Meral *et al.*, 2002; Ozturk & Ercisli, 2006). Also, the oil of *Satureja parvifolia* (Lamiaceae) rich in piperitone (34.9%) was found to have moderate activity against *S. aureus* methicillin sensitive and *S. aureus* clinic isolate (MIC = 1630 µg/mL) (Luna *et al.*, 2008). These data support our finding that several compounds, including myristicin and piperitone, may act synergistically in the antimicrobial activity.

Concerning to the alcoholic extract of *P. aduncum* the antimicrobial properties observed were attributed to their isolated compounds, such as the p-hydroxybenzoic acid derivatives, dihydrochalcones and chromenes (Nair & Burke, 1990; Orjala *et al.*, 1993; Orjala *et al.*, 1994; Okunade *et al.*, 1997; Lentz *et al.*, 1998; Kloucek *et al.*, 2005). However, as it is crude extract obtained with polar solvents, it is very likely that the essential oil components have been extracted also and, to some extent, may have contributed to the antimicrobial properties observed for the plant. To corroborate this hypothesis, a previous ethanolic extract of *P. aduncum* showed smaller inhibition than the oil tested in the present work. The inhibition values for the strains of *S. aureus* ATCC 25923 and *S. epidermidis* 12228 were 1000 µg/mL and 2000 µg/mL in the extract while, for the oil the values were 500 µg/mL and 250 µg/mL, respectively.

CONCLUSION

The oil and extracts from aerial parts of *Piper aduncum* have showed numerous biological properties. In this study was seen that the oil has significant bactericidal activity against resistant strains of *Staphylococcus aureus*, *S. epidermidis* and *S. lentus*, which are dangerous nosocomial infection agents. Dillapiole, its main constituent, was less effective against these bacteria. However, when it was tested in combination with myristicin, other constituent of the oil, it had increased its bactericidal activity. Therefore, the bactericidal action of the oil is more significant due to synergistic action of its main constituents, as myristicin and piperitone.

Table 3
Antibacterial activity of the oil and dillapiole from *Piper aduncum* against standard strains and multi-drug resistant isolates (MRSA and MDR), in comparison with literature data.

Bacteria	Antibacterial activity (µg/mL)						
	<i>P. aduncum</i> Oil		Dillapiol e	Dillapiole + Myristicin	Myristicin-rich Oil	Piperitone-rich Oil	Ethanol Extract
	MIC	MIC _{Lit} ⁽¹⁾	MIC	MIC	MIC _{Lit(2)}	MIC _{Lit(3)}	MIC _{Lit(4)}
<i>S. aureus</i> ATCC 25923	500	5240	500	500	NA	30- 0.5	1000
<i>S. epidermidis</i> ATCC 12228	250		>750	750	NA	1	2000
<i>S. aureus</i> isolate Methicilin-resistant	>750		>1000	>750	0.75 NA	1630 >2000	
<i>S. aureus</i> (MRSA)							
MDR <i>S. epidermidis</i>	750		>750	>750			
MDR <i>S. lentus</i>	>1000		>1000	>1000			

Lit = literature data: (1) Guerrini et al., 2009; (2) Narasimhan & Dhake, 2006; (3) Rondón et al., 2006; Luna et al., 2008; (4) Kloucek et al., 2005. NA, Not Active.

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