Original Research Article

The importance of monoterpenes in the antibacterial activity of *Osteophloeum platyspermum* essential oils

Highlights

- The essential oils of *O. platyspermum* showed anti-*Staphylococcus aureus* activity
- The essential oils of *O. platyspermum* showed cytotoxicity against cancer cell lines
- Limonene, myrcene, elemol, β- and α-pinene, and terpinen-4-ol highlights biological activity
- The active terpenes are representative ~~in the Amazon~~ ~~rainy season~~

ABSTRACT

AIMS: To evaluate ~~essential oils' (EO's)~~ antibacterial and cytotoxic activities obtained from *Osteophloeum platyspermum* (*ucuuba-chico-de-assis*; Myristicaceae) fresh leaves against *Staphylococcus aureus*, MCF-7 breast, and PC-3 prostate cancer cell lines.

Study design: Thirteen EO's were submitted to antibacterial and cytotoxicity assays that included 18 compounds that commonly occurred in the EO's. Results were used to determine the relationship between the ~~EO's~~ biological activities and the dry (DS) or rainy ~~(RS)~~ seasonal ~~variation~~ using the relative percentage of the tepenes.

Place and duration of the study: the study was conducted at the Center for Research in Biodiversity (Microbiology Laboratory and Cell Culture Laboratory), Paulista University. Biological activity ~~evaluations occurred~~ between October/2016 and November 2019).

Methodology: Thirteen essential oils were obtained from the leaves of *O. platyspermum* and were previously chemically characterized. From the analyses, 18 terpenes were determined to

commonly occur in the 13 EO's. Microdilution broth and cytotoxicity assays were performed to obtain minimal bactericidal concentrations (MBCs) and 50% (EC50) effective concentrations for the cytotoxicity assays. Data from the 18 terpenes were submitted to two-way ANOVA, cluster (CA), principal component (PCA), and canonical correspondence analyses (CCA), and to a one-sample t-test. The relationship between the EO's biological activities and the dry (DS) or rainy (RS) seasonal variation was determined. One sample t-test was performed to verify the potency of the EO's cytotoxic effects.

Results: Previously, 18 terpenes were identified in all the 13 EO's. From those, α-terpineol, limonene, myrcene, linalool, and terpinen-4-ol were relevant to the ordination of the DS EO set, while spathulenol, α-pinene, β-pinene, isospathulenol, α-cadinene, ledol, cubenol-1-epi, neo-intermedeol, elemol, β-elemene, γ-elemene and viridiflorol were relevant to the ordination of the RS EO set. The biological activities were more related to the EO's collected in the RS than those in the DS. Also, biological activities showed to be related to the occurrence of limonene, myrcene, elemol, β-pinene, α-pinene, and terpinen-4-ol.

Conclusions: Although the presence of the 18 terpenes is relevant to the species, the occurrence of limonene, myrcene, elemol, β-pinene, α-pinene, and terpinen-4-ol had a significant role in the effectiveness of the biological activity expression of the EO's from *O. platyspermum*, particularly those occurring during the rainy season, in the Amazon rain forest.

KEYWORDS: Myristicaceae, terpenes, biological activity, breast cancer, prostate cancer, *Staphylococcus aureus*.

LIST OF ABBREVIATION

CCA-canonical correspondence analysis; CFU-colony forming units; DMSO-dimethylsulfoxide; DOXO-doxorubicin; DS-dry season; EO-essential oils; IBAMA- Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (Environmental Agency); MMA-Ministério do Meio Ambiente (Environmental Ministry); PCA-principal component analysis; RS-rainy season, Sau-*Staphylococcus aureus*; SRB-sulforhodamine B; TCA-trichloroacetic acid;

1. INTRODUCTION

Osteophloeum platyspermum (Spruce ex A. DC.) Warb. (Myristicaceae), popularly known as *ucuuba-chico-de-assis*, is the only representative of the genus occurring in the Amazon Rain Forest [1-3]. Reports on the hallucinogenic properties [4] and the description of compounds as (-)-kaur-16-en-19-oic, acid, sitosterol, stigmasterol, (±)-3-demethylhomopterocarpin, and (±)-maackiain [5], eperu-8(20),13-dien-3α, 15-diol, glyceryl laurodimyriaste, glyceryl 1,3-lauromyristate, dihydroguaiaretic acid, hydroxyotobain, hydroxyoxootobain, guaiacin, and otobaphenol [6] have been done, as was the evaluation of the essential oils (EO's) collected from the leaves and the pericarp of the species [7].

The ~~essential oil~~ composition was previously determined [7]. Briefly, the leaves of ~~one~~ individual tree of *O. platyspermum* [*M.B. Paciencia*, 846 (UNIP Herbarium)] ~~were 13 times collected in a spanning period comprehending~~ November/2009 to October/2010, under license IBAMA/MMA/Brazil #12A/08. ~~The~~ plant ~~was~~ accessed in a *terra firme* forest near Manaus, AM, Brazil, spanning from November 2009 to October 2011. A voucher of ~~the~~ species ~~was~~ deposited at UNIP Herbarium #UNIP5720. Leaves were collected during the dry season - characterized by a diminish in the accumulated precipitations - and during the rainy season, indicated by an increase in rainfalls. Dry season is commonly known as "summer" and ~~rain~~ season as "winter", in the Amazon Forest. Each collection was subsequentially numbered, from collection # 2 to collection # 14.

~~At~~ each collection, the leaves of the same specimen were taken and subjected to steam distillation in the Clevenger apparatus for four h. EO's ~~were~~ collected using pentane,

then the pentane was removed by air evaporation, and sodium sulfate anhydrous was added to remove the remaining water. After that, EO's were kept in amber flasks under -10^{o}C until use. Essential oils (EO's) were diluted to concentrations of 10%, 5%, 2.5%, and 1.25% in dimethylsulfoxide (DMSO, Synth) before being tested in the biological assay; GC-MS analyzed each essential oil according to procedures described elsewhere [7].

According to the previous work [7], the yields of the essential oils were 408OE2 (0.236%), 408OE3 (0.7343%), 408OE4 (0.4202%), 408OE5 (0.5958%), 408OE6 (0.3025%), 408OE7 (0.3587%), 408OE8 (0.3587%), 408OE9 (0.6873%), 408OE10 (0.2916%), 408OE11 (0.5706%), 408OE12 (0.2276%), 408OE13 (0.2432%) and 408OE14 (0.2904%). From the oils, 50 terpenes have been previously identified in the species, and the 18 terpenes that occurred in all the 13 essential oils were used in the statistical analyses, in the present work: are α-pinene (9.8 %), β-pinene (34.6 %), myrcene (7.4 %), limonene (21.0 %), linalool (1.3 %), terpinen-4-ol (1.0 %), α-terpineol (5.5 %), β-elemene (0.8 %), γ-elemene (0.7 %), δ-amorphene (0.5 %), elemol (0.3 %), spathulenol (2.8 %), viridiflorol (1.2 %), ledol (0.7 %), cubenol-1-epi (0.7 %), isospathulenol (1.3 %), α-cadinol (1.8 %), neo-intermedeol (0.6 %).

Some information regarding *O. platyspermum* has been reported, although the EO's biological activity information remains unfulfilled. The present report aims at filling that gap by considering the biological activities of 13 essential oils obtained from the leaves collected from the wild plant against *Staphylococcus aureus* and breast and prostate human cancer cell lines, predicated by the light of multivariate analysis.

2. MATERIAL AND METHODS

2.1 Microdilution broth assay and determination of minimal bactericidal concentrations

EO's were tested using the microdilution broth assay (MBA), in sterile conditions [8,9]. Briefly, 190-µL aliquot of the bacterial suspension of *Staphylococcus aureus* (ATCC 29213; Thermo Oxoid, USA) adjusted to 1.5×10^{8} colony-forming units per mL (CFU/mL) in Müller-Hinton broth was dispensed into 96-well microplates. A 10µL aliquot of each EO at the adequate concentration was added to the correspondent wells. Microplates were incubated at

36°C for 24 h. The inhibition of bacterial growth was visually assessed, and bacterial suspensions from all test wells were sub-cultured in sterile Müller-Hinton agar to evaluate the effectiveness of treatments [8]. Minimal bactericidal concentrations (MBCs) against *S. aureus* were obtained for the EO's, using the pre-determined EO concentrations as previously described. EO's final test concentrations (20 times fold dilution) for the antibacterial assay were achieved to end up with 0.5%, 0.25%, 0.125%, and 0.0625%, and a 400 times fold dilution was performed to each of the oils used in the cytotoxic assay, resulting in a final concentration of 0.025%. Percentages are given in v/v.

2.2 Cytotoxicity assay

Breast adenocarcinoma (MCF-7) and prostate carcinoma (PC-3) cancer cell lines were obtained from the National Cancer Institute (NCI/NIH/USA), and were kept cryopreserved up the use. They were weekly cultivated in cell culture flasks with RMPI-1640 supplemented with 5% fetal bovine serum, 1% glutamine, and 1% gentamycin. Flasks were kept in an incubator at 37° C, with 5% CO_2 and 100% relative humidity. Similar conditions were maintained during the assay. Cells were seeded in 96 microplates at densities of 10,000/well (MCF-7) and 7,500/well (PC-3). Cultures were incubated for 24h before the essential oils were added. The oils remained in contact with the cells for 48h in the microculture assay. After that, percentages of cell growth were obtained by the sulforhodamine B (SRB, Sigma, USA) assay [9-12]. Doxorubicin (DOXO, Synth, Brazil) was used as a reference drug.

2.3 Sulforhodamine B (SRB) Assay

SRB is a tetrazolium derivative dye that binds to mitochondrial proteins of viable cells, was used in the assay. Viable cells were fixed to the microplates' wells by adding 50 µL of cold 50% trichloroacetic acid (TCA; Synth, Brazil) for one h under refrigeration. Microplates were washed with water for five times ~~up to the~~ complete removal of non-viable cells. Plates were left to air-dry for 24 h. An amount of 100 µL of SRB 0.4% in acetic acid was added to each well and kept in contact for 10 min in a plate shaker. After that, unbound SRB was removed from the

plate by washing the wells four times with 0.1% acetic acid with a plate washer. The remaining dye was then resuspended with the addition of 100 µL of Trizma Buffer (Merck, Germany) and shaken for 10 min. The total of viable cells was measured by the optical densities of the wells in a microplate spectrophotometer reader at 515 nm. The percentage of cell growth was obtained by the formula [(T-T0)/(C-T0)] * 100 = %CG, where T corresponds to treated cells, C corresponds to control or untreated cells, and T0 corresponds to cell growth in the first 24h of the assay, before treatment being added to the corresponding wells [11-14]. If the results are negative, cell lethality (CL) has occurred, meaning that the EO reduced the number of cells to a number lower than that registered in T0, and the expression of the results is given in %CL.

2.4 Statistical analyses

To analyze the relationship ~~among~~ the terpenes that commonly occurs in the 13 essential oils, ~~named as the variables~~, to the factors related to the seasonal ~~variation~~, ~~as the~~ dry season (DS), rainy season (RS), and ~~to the~~ biological activity, ~~the~~ use ~~of~~ cluster, principal component (PCA), and canonical correspondence analyses (CCA; MVSP statistical package) considering the 18 terpenes commonly occurring as the variables and the 13 essential oils as the cases. Season information (dry season, DS, or rain season, RS) and antibacterial/cytotoxicity results expressed as MBCs and %CLs were used in the analyses as factors to ordinate and to perform CCA [15]. Data ~~related to %~~ cell lethality from the cytotoxicity were analyzed by Shapiro-Wilk normality test and by one-sample t-test (GraphPad Prism 7.0 package) considering the percentage of growth inhibition obtained for doxorubicin, the standard drug, as the hypothetical value of -0.42 and -12.24 for breast and prostate cancer cell lines, respectively.

3. RESULTS AND DISCUSSION

Table 1 shows the biological activity observed for the EO's from the leaves of *O. platyspermum*. The 13 EO's were ~~considerably~~ active against *S. aureus*, ~~and~~ cytotoxic to MCF-7 and PC-3 cancer cells.

Table 1. Results obtained from the cytotoxic analysis against MCF-7 breast and PC-3 prostate cancer cell lines and minimal bactericidal concentrations obtained from antibacterial analysis against *Staphylococcus aureus* (Sau) ~~for~~ the 13 essential oils obtained from the leaves of *Osteophloeum platyspermum*, Myristicaceae, ~~assessed~~ by the SRB and microdilution broth assays, respectively. ~~Minimal bactericidal concentrations~~, MBCs, are expressed in µg/mL and % of growth inhibition, %CL's are expressed in percentage, concerning time zero growth. NT=not tested.

	MBC Sau	MCF-7 %CL	PC-3 %CL
408OE2 (DS)	0.25	-7.67	-32.56
408OE3 (RS)	0.25	-14.61	-37.71
408OE4 (RS)	0.5	-25.42	-57.08
408OE5 (RS)	0.06	-3.15	5.39
408OE6 (RS)	0.5	-30.37	-55.78
408OE7(DS)	0.5	-15.38	27.36
408OE8 (DS)	0.13	13.94	26.26
408OE9 (RS)	0.06	7.08	22.87
408OE10 (RS)	0.5	-15.79	-21.82
408OE11 (RS)	0.06	-32.34	-39.78
408OE12 (DS)	0.25	-7.11	-13.08
408OE13 (DS)	0.25	-20.66	-42.23
408OE14 (DS)	0.5	-13.88	-50.75
Doxorubicin	NT	-0.42	-12.24

DS=dry season; RS=rainy season; NT=not tested; CL=cell lethality compared to a T0 cell growth at 24 h.

Figure 1 reports the differences among terpene percentages concerning seasonal occurrence. Terpenes interfered with 97.4 % of the variance (*P*<.0001), the seasonality contributed with 0.0009 % of the variance (p>0.05), and the interaction corresponded to 0.4731 % of the variance (*P*<.0001). It was observed that β-pinene occurred more in the RS than in the DS (*P*=.0003), while limonene (*P*=.0326) and α-terpinene (*P*<.0001) occur in higher amounts during the DS.

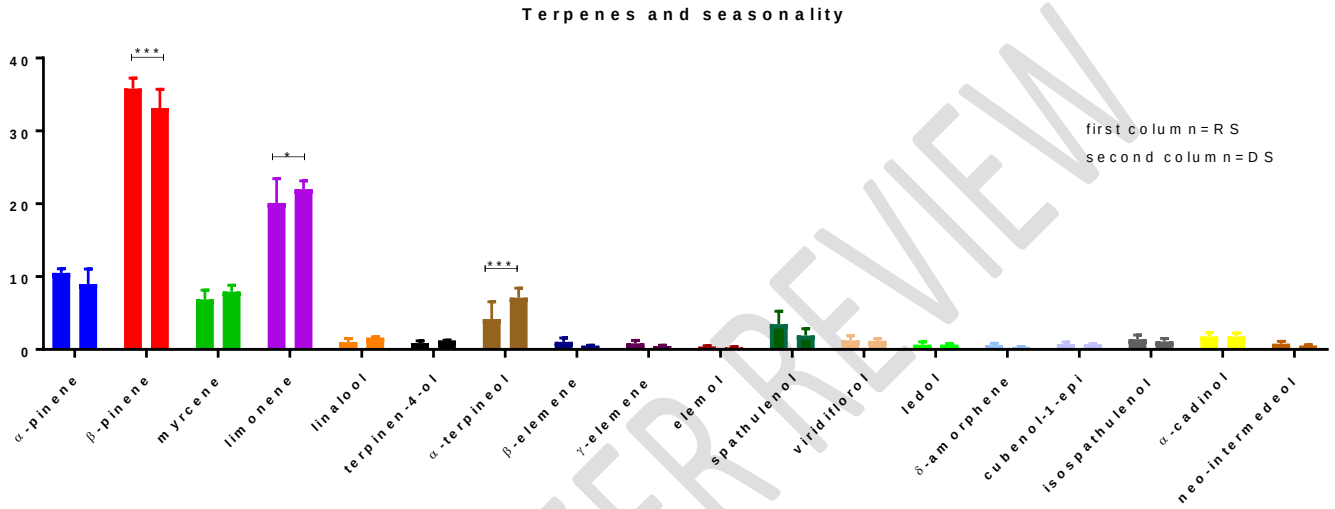


Figure 1. Differences in the terpene percentage in the essential oils obtained from ~~the~~ leaves of wild *Osteophloeum platyspermum* (Myristicaceae) in relation to the seasonal occurrence. Two-way ANOVA evaluation followed by Sidak's multicomparison post-test considering the seasonal factor to compare each terpene expression variation. *$P<.05$; ***$P<.0001$.

Multivariate analyses considered the 18 common terpenes as the variables and the 13 essential oils as the cases. Figure 2 shows the results obtained in the cluster analysis (UPGMA, Bray-Curtis). In the present work, cluster analysis (figure 2) was performed to explore the possibility of ordinating the 13 essential oils according to the dry and rainy seasons, using the variation in percentage within the 18 variables. The ordination was observed for the RS essential oils, which in figure 2 are highlighted in green, and for the DS essential oils, highlighted in blue. Three oils did not cluster, 408OE4, 408OE7, and 408OE11.

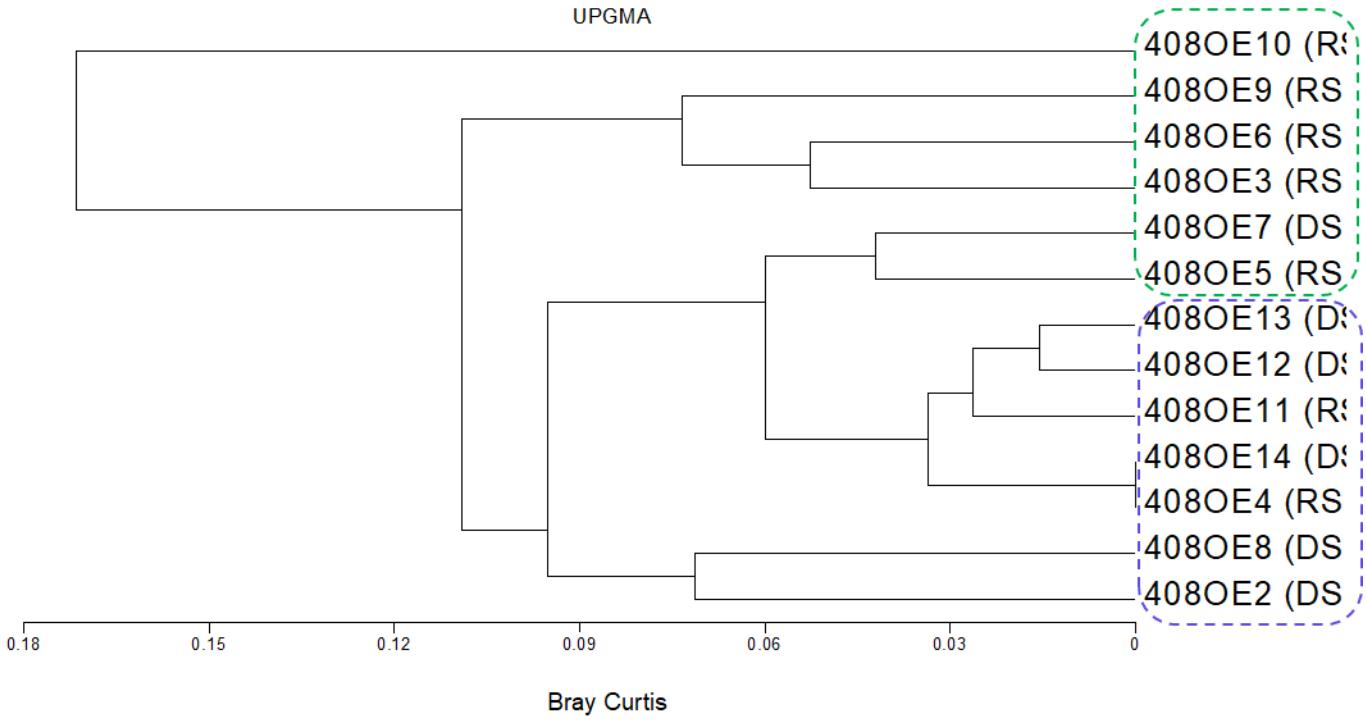


Figure 2. Results of cluster analysis considering 18 terpenes that concomitantly occur in the 13 essential oils obtained from the leaves of *Osteophloeum platyspermum* (Myristicaceae). Blue dots = dry season; green dots = rainy season.

Figure 3 shows the principal component analysis, as they are seasonally ordinated. The cumulative percentage in the first axis is 53.945, in the second axis is 84.140 and on the third axis is 95.113. The analysis resulted in the EO's ordination according to the seasonal variation related to the dry and rainy seasons. The EO's that composed the DS group were

408OE2, 408OE7, 408OE8, 408OE12, 408OE13, and 408OE14, which were influenced by the presence of α-terpineol, limonene, myrcene, linalool, and terpinen-4-ol. In contrast, the RS group, composed of EO's 408OE3, 408OE5, 408OE6, 408OE9 and 408OE10, were influenced by the presence of the other 13 terpenes, such as spathulenol, α-pinene, β-pinene, isospathulenol, α-cadinol, ledol, neo-intermedeol, δ-amorphene, cubenol-1-epi, elemol, β-elemene, γ-elemene, and viridiflorol. In both cluster analysis and PCA, EO's 408OE4 and 408OE11 did not group in the respective RS set, although 408OE7 was ordinated in its respective DS set in the PCA.

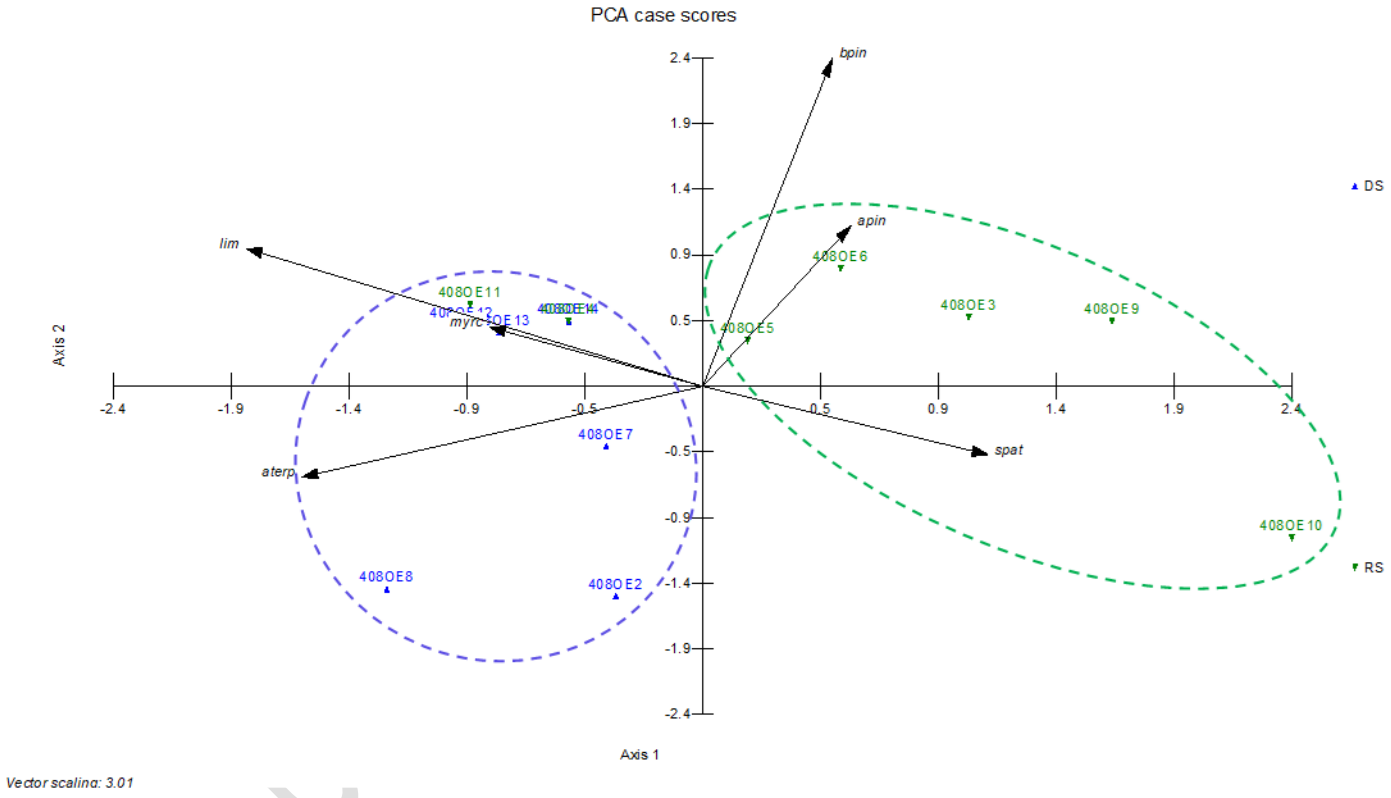
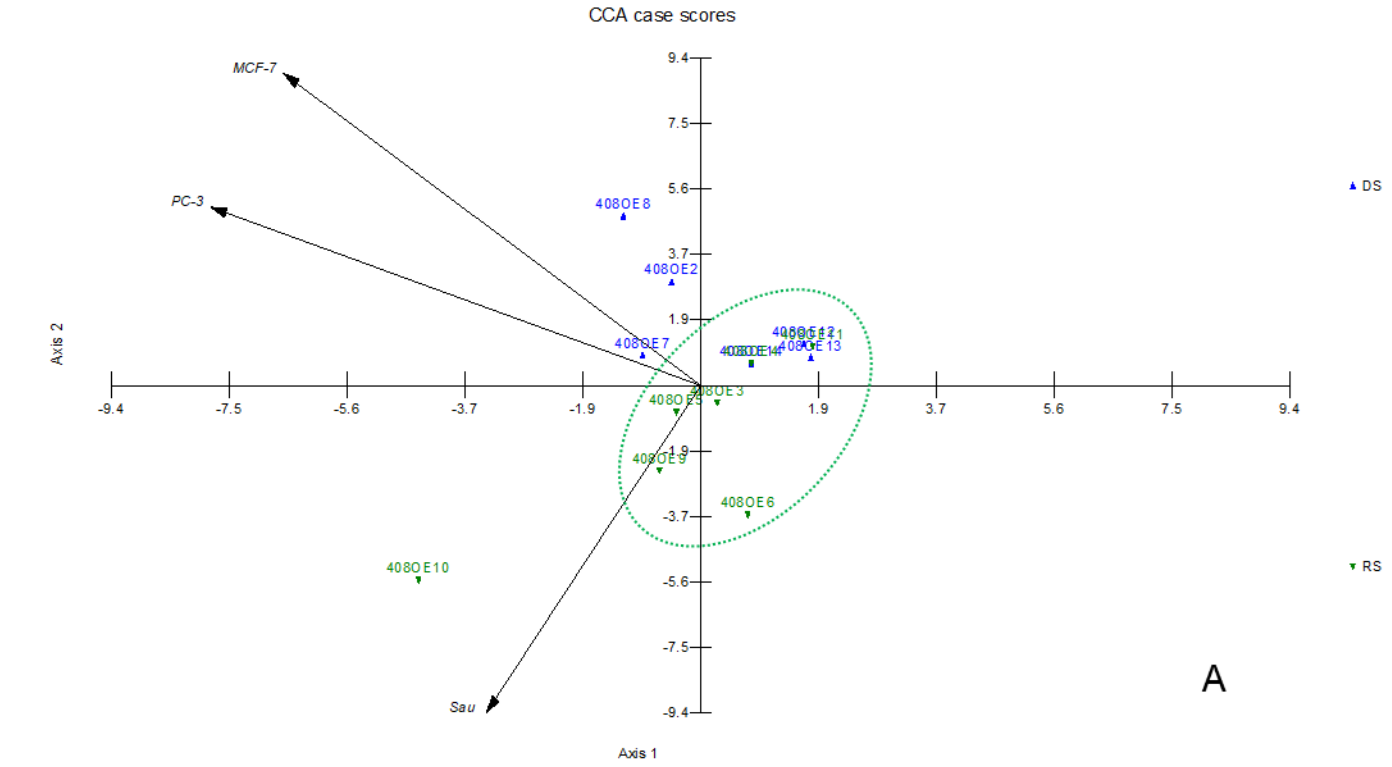


Figure 3. Results of principal component analysis considering 18 terpenes, expressed as the variables in ~~the~~ statistical analyses ~~and~~ that concomitantly occur in ~~the~~ 13 essential oils, defined as ~~the~~ cases, ~~and~~ obtained from ~~the~~ leaves of *Osteophloeum platyspermum* (Myristicaceae). Significance was considered as α <.05.

Essential oils ~~from~~ *O. platyspermum* were obtained from the leaves of ~~one individual~~ tree ~~in a period spanning~~ from November 2009 to October 2011. They were tested against Sau and against breast and prostate human cancer cell lines to evaluate possible correlations of the biological activity to both dry and rain seasons (table 1). Multivariate analyses are ~~being~~ regularly used to cope with the interpretation of data obtained from essential oil compounds and their relationship ~~with~~ factors ~~as~~ biological activities [16], seasonal expression, and analyzing the influence of climatic factors [15] ~~in the production of the essential oil~~ [17]. Cluster analysis and PCA were adopted as a tool to discriminate three Myrtaceae essential oils [14], while PCA was used to discriminate clones of *Juniperus communis* and wild *Juniperus* sp. [18]. ~~The variability~~ in essential oils of five wild populations of *Dorema aucheri* using cluster analysis, PCA and CCA ~~were~~ used to study the relationship of environmental parameters on the amount of some components as α-caryophyllene, thymol, cuparene, and caryophyllene oxide and β-gurjunene [19].

Figure 4 shows ~~the~~ CCA was obtained by considering the 18 terpenes as ~~the~~ variables and ~~the~~ 13 EO's as ~~the cases~~, added to the biological analysis factors ~~MBCs~~ and %CL's. The cumulative percentage in the first axis is 73.859 and in the second axis is 91.898. The smaller the values of MBC's and %CL's are, the better the essential oils' antibacterial and cytotoxic activities are [15,16]. In figure 4A, ~~the~~ vectors representing ~~the~~ biological activities oppose the active EO's location and ~~are~~ represented by the EO ~~set that is more~~ active against Sau (408OE5, 408OE8, 408OE9, and 408OE11). The same is observed for the more active ones against MCF-7 (408OE4, 408OE6, 408OE11, and 408OE13) and for those that were more active against PC-3 (408OE2, 408OE3, 408OE4, 408OE6, 408OE10, 408OE11, 408OE13, and 408OE14). It was observed that ~~the~~ prostate cancer cell line was more sensitive to the activity of the essential oils. Moreover, figure 4B shows that limonene, myrcene, and elemol strongly influence the ordination of 408OE4, 408OE11, 408OE12, 408OE13, and 408OE14, and consequently the biological activity. The presence of β-pinene, α-pinene, and terpinen-4-ol is also relevant for the biological activity of the *O. platyspermum* EO's.



A

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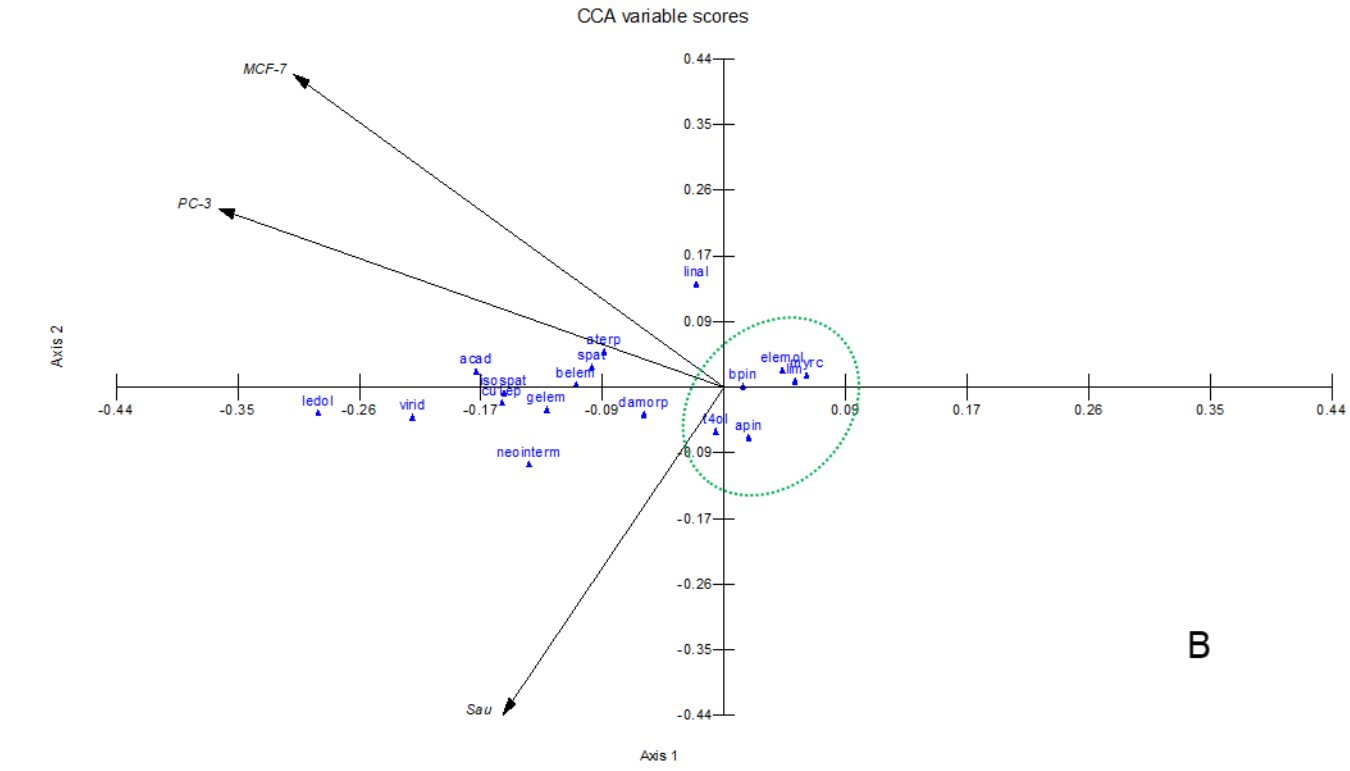

B

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Figure 4. Canonical correspondence analysis considering 18 terpenes, expressed as the variables in ~~the~~ statistical analyses and that concomitantly occur in the 13 essential oils, defined as the cases, obtained from ~~the~~ leaves of *Osteophloeum platyspermum* (Myristicaceae) and ~~the~~ results obtained from antibacterial and cytotoxic assays. **A.** Case scores **B.** Variable scores. Significance was considered as α<.05.

Figure 5 reports results ~~from the one~~-sample t-test performed ~~with~~ breast and prostate cancer cell lines. Shapiro-Wilk ~~normality~~ test was adopted to evaluate the normality of %CL values obtained from breast and prostate cancer cytotoxic assay (*P*=.7665 and *P*=.0716, respectively). One-sample t-test was ~~made to evaluate~~ the EO's cytotoxic activity compared to doxorubicin (DOXO), the drug used as a reference in the assay (reference %CL -0.42; actual mean=-12.72, discrepancy of -12.3, where t=3.283; df=12 and *P*=.0065). Also, one-sample t-test made with prostate cancer cells did not show significance (t=0.9683; df=12 and *P*=.3520; theoretical mean = -12.24, actual mean=-20.69, discrepancy of -8.445).

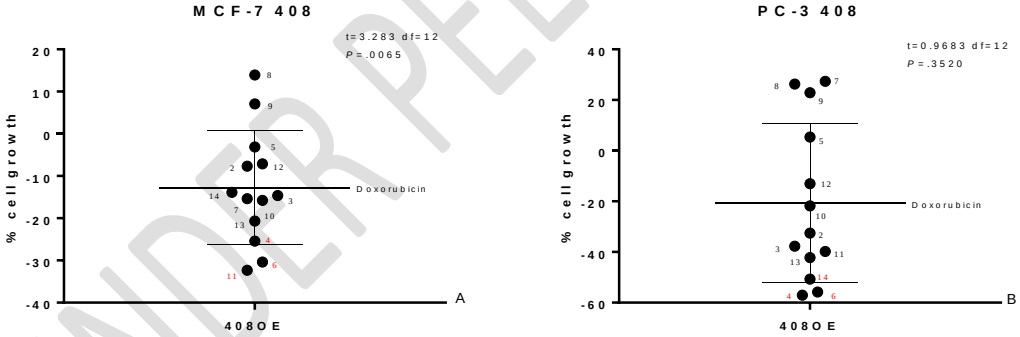


Figure 5. **A.** ~~One~~-sample t-test ~~made~~ with the percentage growth/lethality obtained in the cytotoxic assay ~~with~~ breast ~~human~~ cancer cell line MCF-7. **B.** ~~One~~ sample t-test ~~made~~ with ~~the~~ percentage growth/lethality obtained in the cytotoxic assay with ~~prostate~~ human cancer cell line PC-3. Theoretical means were defined as the value corresponding to the percentage of growth/lethality obtained for doxorubicin, the standard drug, determined as -0.41 and -12.24, respectively. Significance was considered as α<.05.

Although the essential oils 408OE4 and 408OE11 were made from the leaves collected in RS, they did not cluster or gather in their respective set. Nonetheless, they showed to be the most active EO's among the 13 that were tested, once 408OE4 was significantly cytotoxic against both breast and cancer cells, and 408OE11 was active against the bacteria and cytotoxic against the breast cancer cell.

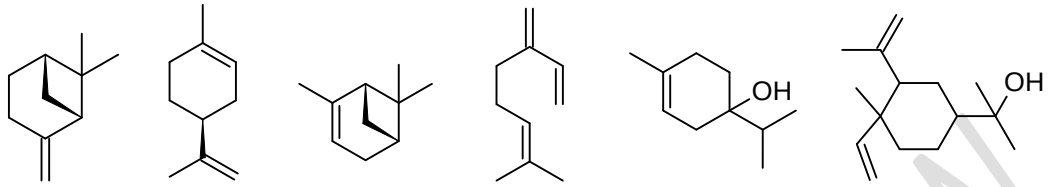
Table 1 shows results from the minimal bactericidal concentrations (MBCs) obtained against *Staphylococcus aureus* ATCC 29213 (Sau), tested in the microdilution broth assay and expressed as percentage (v/v). Table 1 also shows results obtained from the cytotoxicity analyses made with the EO's against human breast (MCF-7) and prostate (PC-3) cancer cell lines, expressed as %CL. According to our findings, EO's 408OE5, 408OE9, and 408OE11, in which MBCs were 1.25 µg/mL, showed the most activity against Sau, while 408OE4, 408OE6, 408OE7, 408OE10, and 408OE14 were less active against the bacteria. EO's 408OE4, 408OE6, and 408OE11 were significantly cytotoxic against the breast cancer cell, while 408OE4, 408OE6, and 408OE14 were more active against the prostate cancer cell line. Essential oils obtained from leaves collected in the rainy season showed to be more active against Sau (408OE5, 408OE9, and 408OE11), as well as they were more cytotoxic against the cancer cells (408OE4, 408OE6, 408OE11). Oils 408OE4 and 408OE6 were cytotoxic to both cell lines while less active against the bacteria.

Figure 5 represents the essential oils' breast and prostate cancer cytotoxicity statistics and corroborates findings for 408OE4, 408OE6, and 408OE11. According to our findings, March, April, and May are relevant months in which the occurrence of terpene composition in essential oils from *O. platyspermum* supports better biological activities.

4. CONCLUSIONS

The essential oils obtained from the leaves of *O. platyspermum* were ordinated into two sets related to the dry and the rainy seasons that are characteristics of the Amazon rain forest. The essential oils also have shown variation in antibacterial and cytotoxic activities. Although the constant presence of the 18 terpenes is relevant to the species, the occurrence of

limonene, myrcene, elemol, β-pinene, α-pinene, and terpinen-4-ol (figure 6) had a significant role in the effectiveness of the *O. platyspermum* EO biological activity, particularly those occurring during the rainy season, in the Amazon rain forest.



β-pinene (MH) limonene (MH) α-pinene (MH) myrcene (MH) terpinen-4-ol (OM) elemol (OS)

Figure 6. Relevant terpenes involved in the biological activity of the essential oils obtained from the leaves of *Osteophloeum platyspermum*.

REFERENCES

1. Joly AB. Botânica. Introdução à taxonomia vegetal. Cia Editora Nacional, São Paulo, Brazil. 1983. 777p.

2. Gentry AH. A Field guide to the families and genera of woody plants of Northwest South America (Colombia, Ecuador, Peru) with supplementary note on herbaceous taxa. The University of Chicago Press, Chicago, 1993, 895 p.

3. Steyermark JA, Berry PE, Yatskievych K, Holst BK. Flora of the Venezuelan Guayana. Missouri Botanical Garden Press, St. Louis, USA, 2001; 6: 740.

4. Bennet BC, Alarcón R. *Osteophloeum platyspermum* and *Virola duckei* (Myristicaceae): newly reported as hallucinogens from Amazonian Ecuador. Econ. Bot. 1994; 48: 152-158.

5. Braz Fo R, Gottlieb OR, de Moraes AA, Pedreira G, Pinho SLV, Magalhães MT, de S Ribeiro MN. The chemistry of Brazilian Myristicaceae. IX. Isoflavonoids from Amazonian species. Lloydia. 1977; 40: 236-238.

6. Braz Fo R, de Carvalho MG, Gottlieb OR. The chemistry of Brazilian Myristicaceae. Planta Med. 1984; 50: 53-55.

7. Suffredini IB, Sousa SRN, Frana SA, Diaz IEC, Suffredini HB, Paciencia MLB. Multivariate analysis of the terpene composition of *Iryanthera ulei* Warb. (Myristicaceae) and its relationship to seasonal variation over a two-year period. J. Essent. Oil-Bear. Plant., 2016; 19: 1380-1393.

8. Castilho AL, Saraceni CHC, Diaz IEC, Paciencia MLB, Suffredini IB. New trends in Dentistry: plant extracts against *Enterococcus faecalis*. The efficacy compared to chlorhexidine. Braz. Oral Res. 2013; 27: 109-115.

9. Silva JPC, Castilho AL, Saraceni CHC, Diaz IEC, Paciencia MLB, Varella AD, Younes RN, Suffredini IB. Anti-streptococcal activity of Brazilian Amazon rain forest plant extracts present discloses a potential to preventive strategies against dental caries. J. Appl. Oral Sci., 2014; 22: 91-97.

10. Monks A, Scudiero D, Skehan P, Shoemaker R, Paull K, Vistica D, Hose C, Langley J, Cronise P, Vaigro-Wolff A, Gray-Goodrich M, Campbell H, Mayo J, Boyd M. Feasibility of a high-flux anticancer drug screen using a diverse panel of cultured human tumor cell lines. J. Natl. Cancer Inst., 1991; 83: 757-766.

11. Suffredini IB, Paciencia MLB, Varella AD, Younes RN. *In vitro* prostate cancer cell growth inhibition by Brazilian plant extracts. Pharmazie, 2006; 61: 722-724.

12. Suffredini IB, Paciencia MLB, Frana SA, Varella AD, Younes RN. *In vitro* breast cancer cell lethality by Brazilian plant extracts. Pharmazie, 2007a; 62: 798-800.

13. Suffredini IB, Paciencia MLB, Varella AD, Younes RN. *In vitro* cytotoxic activity of Brazilian plant extracts against a human lung, colon and CNS solid cancers and leukemia. Fitoterapia, 2007b; 78: 223-226.

14. Sobeh M, Braun MS, Krstin S, Youssef FS, Ashour ML, Wink M. Chemical profiling of the essential oils of *Syzygium aqueum*, *Syzygium samarangense* and *Eugenia uniflora* and their discrimination using chemometric analysis. Chem. Biod., 2016; 13: 1537-1550.

15. Martins ER, Díaz IEC, Paciencia MLB, Frana SA, Marques MOM, de Morais DR, Eberlin MN, Suffredini IB. Amazon climatic factors driving terpene composition of *Iryanthera polyneura* Ducke in *terra-firme* forest: A statistical approach. PLoS One, 2019a; 10.1371/journal.pone.0224406.

16. Silva NH, Paciencia MLB, Frana AS, Diaz IEC, Suffredini IB. Antibacterial activity of essential oils from leaves of *Iryanthera ulei* Warb. (Myristicaceae): a temporal analysis perspective. J. Essent. Oil-Bear. Pl., 2020; 23: 890-901.

17. Martins ER, Díaz IEC, Paciencia MLB, Frana SA, Morais D, Eberlin MN, Silva JS, Silveira ER, Barros MP, Suffredini IB. Interference of Seasonal Variation on the Antimicrobial and Cytotoxic Activities of the Essential Oils from the Leaves of *Iryanthera polyneura* in the Amazon Rain Forest. Chem Biodivers., 2019b; 16:e1900374. doi: 10.1002/cbdv.201900374.

18. Maurya AK, Devi R, Kumar A, Koundal R, Thakur S, Sharma A, Kumar D, Kumar R, Padwad YS, Chand G, Singh B, Agnihotri VK. Chemical composition, cytotoxic and antibacterial activities of essential oils of cultivated clones of *Juniperus communis* and wild *Juniperus* Species. Chem. Biodivers., 2018; 15:e1800183. doi: 10.1002/cbdv.201800183.

19. Akbarian A, Rahimmalek M, Sabzalian MR. Variation in essential oil yield and composition of *Dorema aucheri* Boiss., an endemic medicinal plant collected from wild populations in natural habitats. Chem. Biodivers., 2016; 13:1756-1766. doi: 10.1002/cbdv.201600160.