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BIOLOGICAL SCIENCES

Antineoplastic potential and chemical evaluation of essential oils from leaves and flowers of *Tagetes ostenii* Hicken

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Abstract: Breast and cervical cancer represent a major problem of women's global public health. Here, we investigated the chemical composition of essential oils from leaves and flowers of *T. ostenii* and the antineoplastic potential in a cervical cancer and breast cancer cell line, SiHa and MCF-7; and non-tumoral cells, HaCat. The chemical analysis revealed a predominance of oxygenated monoterpenes in both essential oils. The IC50 after 24 h of treatment was 72 ng/mL for EO 1 and 83 ng/mL for EO 2 in SiHa cells. For MCF-7 the IC50 was 174.3 ng/mL for EO 1. For HaCat cells it was 54.45 ng/mL for EO 1 and 20.83 ng/mL for EO 2. A synergistic effect with both essential oils and cisplatin was also verified. SiHa cells had their wound healing capacity reduced after 48 h of treatment with EO 2 and both essential oils were able to significantly inhibit the adhesion process and clonogenic ability after 24 h of treatment. Our results suggest a long-lasting inhibitory activity in SiHa cells because of the low recovery capacity of cells after treatment withdrawal. Flow cytometer with annexin V/propidium iodide demonstrated a majority cell death through late apoptosis after 24, 48 and 72 hours of treatment.

Key words: cervical cancer, cytotoxicity, essential oils, natural product(s).

INTRODUCTION

Cancer remains as a major problem of public health worldwide. According to the last estimates of International Agency for Research on Cancer (IARC), the increasing cancer burden is due to several factors including population growth and aging, as well as the changing prevalence of certain causes of cancer linked to social and economic development.

Cervical cancer ranks eighth for incidence of all cancers worldwide and fourth for both incidence (6.6%) and mortality (7.5%) in the women population (Ferlay et al. 2018). Nowadays, it is clearly known the association of human papillomavirus (HPV) as a principal cause of cervical intraepithelial neoplasia (CIN) and cervical cancer (Satterwhite et al. 2013). Papillomavirus type 16 and human papillomavirus type 18 infections are responsible for 70%–75% of all cervical cancers and 40%–60% of its precursors (Clifford et al. 2006). Furthermore, it is also well established that the presence of genetic and epigenetic alterations like DNA methylation, histone modifications, and noncoding RNAs are needed for the development of carcinogenesis (Fang et al. 2014), (Saavedra et al. 2012).

Meanwhile, breast cancer is the second most prevalent neoplasm in the world population, and it is the first cancer in incidence (24.2%) and mortality (15%) in women. In Brazil, breast cancer occupies the first place in incidence and

59.700 new cases are estimated for each year of 2018 and 2019 (Instituto Nacional de Cancer José Alencar Gomes da Silva 2017). Historically, breast cancer has been treated according to biomarkers such as the expression of estrogen receptor (ER), progesterone receptor (PgR) and the status of HER2 (Naito & Urasaki 2018).

Despite the efforts to improve conventional treatments such as radical surgery, radiotherapy, and chemotherapy, it is known that the adverse events of these methodologies affect the patients quality of life. Radiotherapy has been widely used in the treatment of several cancers, but this option suffers from a high frequency of acute and chronic complications (Gallagher et al. 1986). Patients most common adverse events with radiotherapy and chemotherapy treatment are abdominal pain, varying degrees of diarrhea, hemorrhage, intestinal obstruction, and granulocytopenia during the therapy, but some of these symptoms can occur months or years after the procedure like intermittent diarrhea; intolerance to certain foods; malabsorption of vitamins, lactose, and bile acids (Dang et al. 2018), (Lee et al. 2017).

The chemotherapeutic agent cisplatin has been recognized as the most active cytotoxic agent for treatment of cervical cancer and cisplatin combined with radiation had shown a 30%–50% improvement in survival in patients with locally advanced cervical cancer, but unfortunately with a high level of hematologic and non-hematologic toxicity (Keys et al. 1999), (Morris et al. 1999), (Peters III et al. 2000), (Rose et al. 1999), (Whitney et al. 1999). Moreover, platinum-based antineoplastic resistance is the main reason for the poor prognosis of recurrent or advanced cervical cancer, especially those previously treated with platinum-based chemotherapy or radiosensitizing cisplatin (Hisamatsu et al. 2012), (Moore et al. 2010). Besides that, it is estimated that approximately 30–35% of patients with invasive cervical cancer will develop recurrent disease after primary treatment (Torre et al. 2015).

Thus, there is an urgency in the search for new molecules and alternative strategies against cancer. In this context, natural products, especially those from the flora, represent a great source of molecules with biological activities and, also, antitumor potential. Many of the studies that explore plant potential were based on traditional medicine reports from communities and local population (Newman et al. 2003). Regarding cancer treatment, several important new commercialized drugs have been obtained from natural sources. Of the 92 drugs commercially available prior to 1983 in the United States, or approved worldwide between 1983 and 1994, approximately 62% can be related to a natural product origin (Brandão et al. 2010), (Newman et al. 2000).

Asteraceae is the largest family of angiosperms, comprising 25.000 species (Bremer & Anderberg 1994). In Brazil, the family is represented by approximately 196 genres and about 1.900 species (Barroso 1991). Its members are widely used in folk medicine due to its biological activity and chemical composition (Schiavon et al. 2015).

Tagetes ostenii Hicken is a South American native plant representative of the Asteraceae family, widely distributed in Uruguay and south of Brazil (Deble et al. 2005). In addition to being popularly known for medicinal indications, species of the genus Tagetes have been scientifically described as antibacterial, antifungal, larvicidal, insecticidal, antiparasitic, nematicidal, antihyperglycemic and antioxidant (Andreotti et al. 2013), (Romagnoli et al. 2005), (Salehi et al. 2018), (Schiavon et al. 2015), (Vasudevan et al. 1997). They are highly available due to their high germination rate and produce flowers and seeds all year round

(Barroso 1991). In addition, this genus includes different plants producing essential oils of commercial importance already known (Salehi et al. 2018). Essential oils are low molecular weight compounds derived from secondary plant metabolism and chemical composition characterized by pharmacological activities of great interest (Adams 2007). The species *T. ostenii* also produces essential oils, but very little studied about its biological effects (Deble et al. 2005).

Thus, in this study we evaluated the antineoplastic potential of essential oils from *T. ostenii* leaves and flowers in human cancer cells, as well as the possible toxicity in non-tumor cells.

MATERIALS AND METHODS

Materials

Gentamicin, fungizone (amphotericin B) and fetal bovine serum (FBS) were purchased from Gibco (Gibco BRL, Grand Island, NY). Dulbecco's modified Eagle's medium (DMEM), trypsin/EDTA solution, Trypan Blue dye and MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyl tetrazolium bromide) were purchased from Sigma Aldrich (St. Louis, MO, USA). Annexin V Apoptosis Detection Kit was purchased from QuatroG. Cisplatin chemotherapeutic was kindly donated by Dr. Guido Lenz. All other chemicals and solvents used were of analytical grade.

Plant Material and oil extraction

Flowers and leaves of *T. ostenii* were collected in Santo Antônio da Patrulha, Rio Grande do Sul, Brazil, in April 2015, and botanically identified by Sérgio Augusto de Loreto Bordignon. The voucher specimen was deposited in the Herbarium of the Institute of Natural Sciences of the Universidade Federal do Rio Grande do Sul under number 181985. Once at the laboratory, the plant material was washed with distilled water and the essential oils were obtained by hydrodistillation process for 3 h using a Clevenger type apparatus in accordance with the instructions in the Brazilian Pharmacopoeia (BRASIL 2010). For the cells treatment, the essential oils were solubilized in propylene glycol at 20% (v/v) and then diluted to obtain the final concentration tested with culture media. Essential oils and solvent solution were maintained in the refrigerator (~ 4°C) and protected from light exposure. The biological experiments were performed after one week of oil extraction.

Chemical analysis

The quantitative and qualitative analysis of the components present in both essential oils were performed in Gas Chromatograph coupled with Mass Spectrometer (GC-MS), Shimadzu QP5000-quadrupole MS system, operating at an ionization energy of 70 eV and an interface temperature of 250 °C. A DB-5 fused silica capillary column (30 m, 0.25 mm; film thickness 0.25 µm; Supelco) was used. Injector and detector temperatures were set at 220 °C and 250 °C, respectively; oven temperature was initially maintained at 60 °C for 3 min and then programmed to 60–300 °C at 3 °C/min (total of 88 min). Helium was used as carrier gas (1 mL/min). Percentages of compositions were obtained from electronic integration measurements by peak area normalization. Scan time and mass range were 1 s and m/z 40–550, respectively, and the injection volume was 1 µL. Four analyzes were performed with both essential oils, the first one at extraction time (0 h), 24 h, 48 h and one week after this procedure. The identification of the components was based in comparison of their retention indices and their mass spectral fragmentation pattern, with data taken from the literature (Adams 2007) and by comparison with mass spectra recorded

in the NIST 62 and NIST 12 (National Institute of Standards and Technology) library of mass spectra.

Cell lines

The human cell line derived from invasive cervical carcinoma, SiHa (HPV 16-positive) and the human breast adenocarcinoma cell line, MCF-7 were obtained from American Type Culture Collection (ATCC - Rock-Ville, MD). The immortalized human keratinocytes, HaCaT, were kindly donated by Dr. Silvya S. Maria-Engler (Faculdade de Ciências Farmacêuticas, Universidade de São Paulo). Cell lines were cultured in DMEM High Glucose (SiHa and HaCat cell line) and Low Glucose (MCF-7) supplemented with 10% of fetal bovine serum (FBS), 100 µg/mL Gentamicin and 0.5 µg/mL fungizone. Cell culture was maintained at 37 °C in 5% of CO_2 atmosphere.

Cell Viability Analysis

To verify SiHa, MCF7 and HaCat cell viability after treatment, the MTT (3-[4,5-dimethylthiazol-2-yl]-2,5-diphenyl tetrazolium bromide) assay was used (Mosmann 1983). The cells were seeded in a density of 3.0 ×10^3 cells/well in a 96-well plate and incubated for adhesion at 37 °C in 5% CO_2 atmosphere. After cell adhesion the supernatant was aspirated, and the cells were treated with the essential oils at different concentrations (0.01, 0.02, 0.03, 0.04, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5, 2.5, 5, 10, 15, 20, 25 and 30 µg/mL) for 24 hours. Controls were prepared using only culture medium, and vehicle control using propylene glycol and culture medium. After withdrawn treatment, MTT solution (0.5 mg/mL) was added to each well and plates were incubated in the dark for 3.5 hours at 37 °C. Formazan crystals formed by tetrazolium reduction were dissolved with Dimethyl Sulfoxide (DMSO) and quantified at 545 and 630 nm using an EnVision Multilabel Plate Reader (PerkinElmer). The results were expressed as percentage of control cells (only cells in culture medium), which was considered as 100% of cell viability. IC50 values were calculated from log dose-response curves using GraphPad Prism 5 software.

To evaluate synergistic effect, the chemotherapeutic agent cisplatin was used in combination with leaf or flower essential oil. SiHa cells were seeded in 96 well plates and incubated with IC50 value of essential oils and IC50 value of cisplatin (80 µM) (NG et al. 2011), alone or in combination. After 24, 48 and 72 hours of treatment, cell viability was assessed by the MTT assay described above. For all the assays (excluding the cell viability assay, where a vehicle control was used for each concentration tested) we used the concentration of propylene glycol present in the IC50 of the flower's oil as a vehicle control because it has the higher concentration of the solvent.

Wound Healing Assay

Wound Healing capacity was measured using the wound healing assay as described by Rodriguez et al. (2005). Briefly, SiHa cells were seeded in 24-well plates (2.8 x 10^4 cells/well) and incubated to grow to confluence. The confluent cell monolayer was carefully wounded using a pipette tip and then, the cellular debris was removed by washing with PBS. The wounds were photographed before and after treatment with essential oils at IC50 concentration of 83 ng/mL for the flower and 72 ng/mL for the leave. The scratched region was recorded using an Olympus CK40 microscopy system coupled to an UCMOS 03100 KPA digital camera before, 24 and 48 hours after treatment. The results were calculated by comparing the wound width before and after treatment in treated and control cells.

Adhesion Assay

To determine the ability of the essential oils to interfere in the adhesion cell's capacity, SiHa cells were plated (1×10^4 cells/well) in 96-well plates. Immediately the cells were treated with essential oils at IC50 concentration for 8 hours. After this time, the supernatant of each concentration was collected, and the cells were washed with PBS 1x and this solution was collected and mixed with the initial supernatant. Then, the total collected was centrifuged at 1000 rpm for 5 min and the pellet was mixed with trypan blue dye exclusion (1:1) for counting of viable cells using hemocytometer. Results were expressed as the number of viable treated cells which did not adhere in comparison with the control. We also quantified the adherent viable cells after treatment by fixing the cells with paraformaldehyde 4% and stained with crystal violet 0.5% (diluted in methanol 20%). After this, the cells were washed with distilled water to remove the excess of dye and eluted with acetic acid 10%. The cells were quantified at 570 nm using an EnVision Multilabel Plate Reader (PerkinElmer). The results were expressed as percentage of control cells, which was considered as 100% of cell adhesion.

Clonogenic assay

The clonogenic ability following treatment with essential oils of *T. ostenii* in cancer cells was performed by clonogenic assay as described by Franken et al. (2006). For this purpose, SiHa cells (2.8×10^4 cells/well) were seeded in a 24-well plate and after adhesion, subconfluent cultures were treated with essential oils at IC50 concentration for 24 hours. Then the cells were washed with PBS to remove the treatment, trypsinized, counted in a hemocytometer, and replated in 24-well plates (150 cells/well) and incubated at standard conditions for 5 days. After this period the colonies formed were fixed with paraformaldehyde 4% and stained with crystal violet 0.5% (w/v) (diluted in methanol 20%) for manually counting. Results were expressed as percentage of control cells, which was considered 100% of colony forming.

Washout Assay

The recovery of cell viability after withdrawal of treatment was determined by Washout Assay. SiHa cells (2.8×10^4 cells/well) were seeded in a 96-well plate and after adhesion, subconfluent cultures were treated with essential oils at IC50 concentration for 24 hours. Then, adherent cells were washed with PBS 1x to remove entire treatment, trypsinized, counted and replated in a 96-well plate (2.800 cells/well). After, the cells were incubated for 4 days at standard conditions, and the MTT assay was used to measure cell viability as described before (Cell Viability Analysis section).

Annexin V /propidium iodide staining

Phosphatidylserine externalization was determined by the annexin fluorescence signal of an annexin V–fluorescein isothiocyanate conjugate (QuatroG) according to the manufacturer's protocol. SiHa cells were treated for 24, 48 and 72 hours with essential oils at IC50 concentration of 83 ng/mL for the flower and 72 ng/mL for the leaf. After this time, the cells were washed, trypsinized and centrifuged at 1500 rpm for 5 min. The pellet was resuspended with annexin binding buffer 1x (0.1 M Hepes/NaOH pH 7.4, 1.4 M NaCl, 25 mM $CaCl_2$) and incubated with annexin V and PI at room temperature in the dark for 15 minutes. The cells were analyzed on a BD FACSVerse cytometer equipped with a 488 nm excitation laser and the software Facsuite was used for results analysis.

Statistical analysis

All values were expressed as averages and standard deviation (SD) from at least two independent experiments. Data were analyzed using one-way analysis of variance (ANOVA) followed by the Tukey test using the GraphPad Prism 5 (San Diego, USA, 2007). Statistical differences were considered significant when the value was $p < 0.05$.

RESULTS

Chemical analysis of essential oils from leaves and flowers of *T. ostenii*

The chemical analysis of essential oils was performed by Gas Chromatography coupled with Mass Spectrometer (GC-MS). The essential oils were analyzed at extraction time (0 h), 24, 48 h and one week after this procedure. For leaf's essential oil (EO 1), it was verified a predominance of oxygenated monoterpenes compounds (Table I), with dihydro-tagetone (64.2%) and (Z)-tagetone (15.9%) as majorities at 0 h. After one week from the extraction, both compounds remained as most abundant with a small variation in the percentage, demonstrating chemical stability.

In relation to flower's essential oil (EO 2), it was observed a predominance of both oxygenated and hydrocarbons monoterpenes. At 0 h of extraction, the compounds (E)-ocimenone (39.9%), (Z)-ocimenone (17.5%) and (Z)-β-ocimene (26.1%) were the majorities. After one week from the extraction these compounds also continuous as predominance but with a significant variation in their abundance. (E)-ocimenone (11.8%) showed a decrease in relation to 0 h while (Z)-ocimenone (26.8%) and (Z)-β-ocimene (56.3%) exhibited an increase in their percentage.

Cell viability analysis of tumoral and non-tumoral cell lines after treatment

For leaf and flower essential oil of *T. ostenii*, all tested concentration, from 0.01 to 30 µg/mL, were able to inhibit significantly the viability of cervical cancer cells (SiHa) when compared with control cells (containing only culture medium). While the vehicle (propylene glycol) did not markedly inhibit the viability of these cells in the lower concentrations analyzed (up to 2.5 µg/mL) for both essential oils, demonstrating that the vehicle used did not affect the viability of SiHa cell line (Figures 1a and b).

At 24 hours of treatment the inhibition of SiHa cells was between 31.3% (at 0.02 µg/mL concentration) to 95.6% (at 1 µg/mL concentration) for EO 1 and between 29.5% (at 0.01 µg/mL) to 93.3% (at 0.5 µg/mL) for EO 2. Based on the cell viability tests it was possible to obtain the half maximal inhibitory concentration (IC50) of 72 ng/mL for EO 1 and 83 ng/mL for EO 2 in the human cervical cancer cell line, SiHa, after 24 hours of treatment.

In order to analyze the viability of breast cancer cells (MCF-7) we tested only the essential oil of *T. ostenii* leaves (EO 1) at concentrations of 0.01 to 10 µg /mL for 24 hours of treatment. We observed a significantly inhibition of cells viability when compared with medium and vehicle treated cells in concentrations greater than 0.2 µg/mL. Also, the vehicle did not significantly inhibit the viability of these cells in all tested concentrations (Figure 1e).

The inhibition of MCF-7 cells viability after 24 hours of treatment with EO 1 was between 3.8% (at 0.03 µg/mL) to 92.8% (at 4 µg/mL). Based on the cell viability tests it was possible to obtain an IC50 of 174,3 ng/mL.

We also tested both essential oils of *T. ostenii* to verify cytotoxicity in the non-tumoral cell line HaCat with concentrations between 0.01 to 10 µg/mL. The results from the treatment with

Table I. Chemical composition of essential oil obtained from leaves and flowers of *Tagetes ostenii* by hydrodistillation and analyzed in four different days from the extraction moment.

		Leaves				Flowers			
RI	**Compound**	**0h**	**24h**	**48h**	**1 week**	**0h**	**24h**	**48h**	**1 week**
	Monoterpenes hydrocarbons								
1026	limonene	3.0	3.1	3.7	3.4	2.4	2.4	2.8	5.1
1036	(Z)-β-ocimene	4.1	4.1	4.4	3.4	26.1	26.1	28.1	56.3
	Oxygenated monoterpenes								
1051	dihydro-tagetone	64.2	64.2	62.8	65.3	4.2	4.3	7.4	-
1144	(E)-tagetone	3.9	3.5	4.5	4.2	1.5	1.5	1.9	-
1152	(Z)-tagetone	15.9	15.9	17.2	14.9	4.6	4.6	8.3	-
1230	(Z)-ocimenone	-	-	-	-	17.5	17.6	18.7	26.8
1239	(E)-ocimenone	-	-	-	-	39.9	39.9	31.6	11.8
	Sesquiterpenes hydrocarbons								
1478	biciclogermacrene	1.4	1.4	0.9	0.7	2.4	2.4	1.3	-
1504	δ-cadinene	1.3	1.3	1.2	1.3				-
1565	copaen-4-α-ol	0.3	0.3	0.5	0.3				-
	Oxygenated sesquiterpenes								
1572	Spathulenol	2.9			0.9				-
1581	epi-globulol	0.3	0.3	0.3					-
1631	epi-α-cubenol		2.4	1.7	1.2				-
1644	cubenol	3.6	3.6	2.7	3.5				-

RI, retention index; percentage of peak area relative to total peak area; Compounds are listed in the order of elution on DB5 column.

EO 1 demonstrated no significant inhibition of cell viability up to 0.05 µg/mL and up to 0.01 µg/mL for EO 2 in comparison to control cells. As shown for the tumor cells, the vehicle tested also did not cause significant inhibition on cell viability of the non-tumoral cell line HaCat in the lower concentrations (up to 1.5 µg/mL) (Figure 1c and d).

After 24 hours of treatment the inhibition of HaCat cell line was between 2% (at 0.01 µg/mL) to 95.4% (at 1.5 µg/mL) for EO 1 and 3.8% (at 0.01 µg/mL) to 96% (at 0.5 µg/mL) for EO 2. We also calculated the IC50 concentration for both oils in the HaCat cell line and obtained the value of 54.45 ng/mL for the leaf essential oil and 20.83 ng/mL for the flower.

When evaluated the IC50 concentration calculated for SiHa cell line (72 ng/mL for EO 1 and 83 ng/mL for EO 2) in both cell lines, the results for the treatment of SiHa cells with EO 1 showed an inhibition on cell viability of 53.9%, 25% and 64.5%, for 24, 48 and 72 h of treatment, respectively (Figure 2a). For treatment with EO 2, it was observed an inhibition of 47.5%, 68.1% and 92.6% for each time, respectively (Figure 2b). In relation to the non-tumoral cell line HaCat,

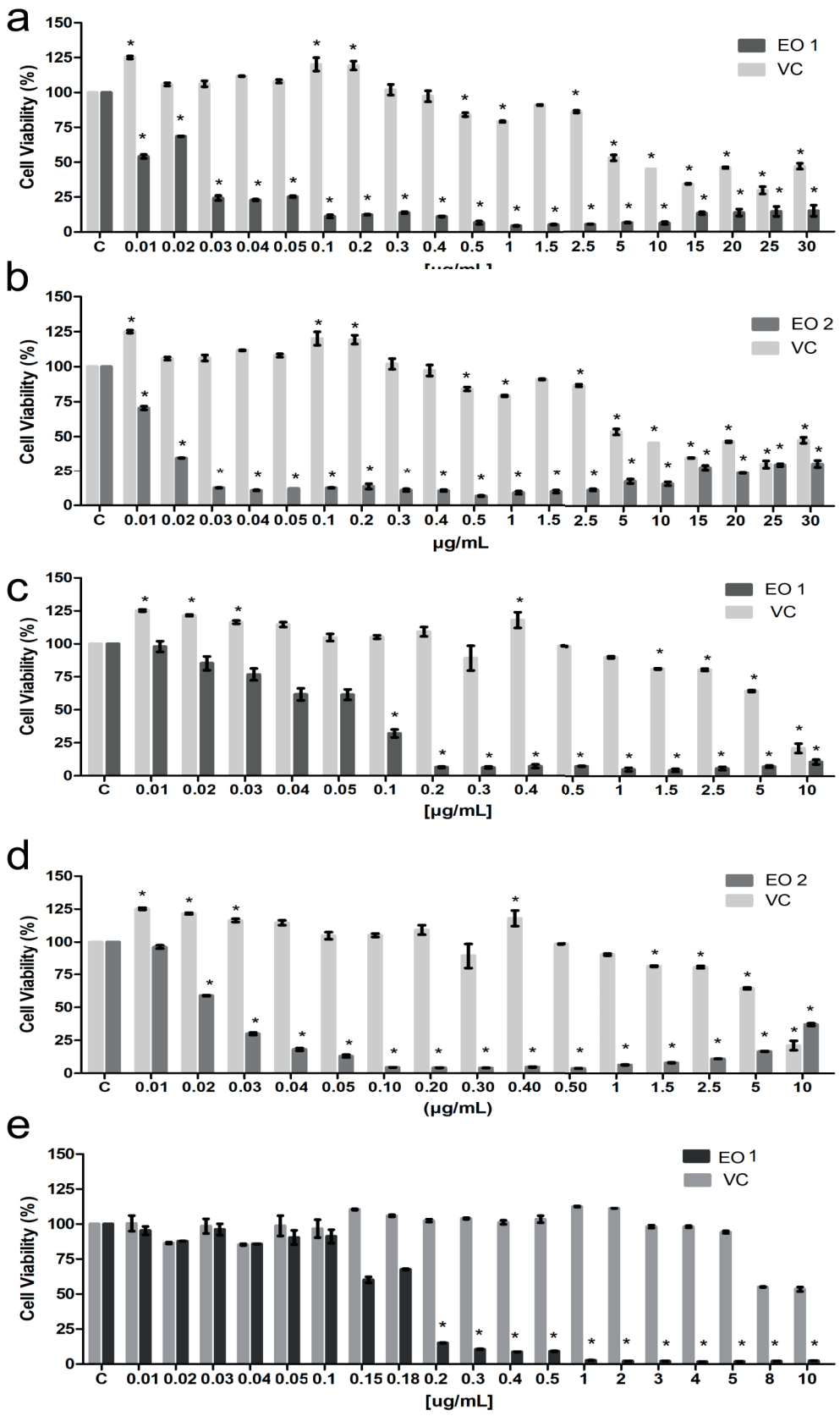

Figure 1. Effect of treatment with different concentrations of *T. ostenii's* leaves (EO 1) and flowers (EO 2) essentials oils. Cell viability of SiHa cell line after 24 h of treatment with EO 1 (a) and EO 2 (b) and vehicle control (VC). Cell viability of HaCat cell line after 24 h of treatment with EO 1 (c) and EO 2 (d) and vehicle control (VC). Cell viability of MCF-7 cell line after 24 h of treatment with OE 1 (e) and vehicle control (VC). Data show mean and standard deviation of three independent experiments performed in quadruplicate. * P <0.05 = significant in relation to control (C). (One-way ANOVA followed by Tukey's test).

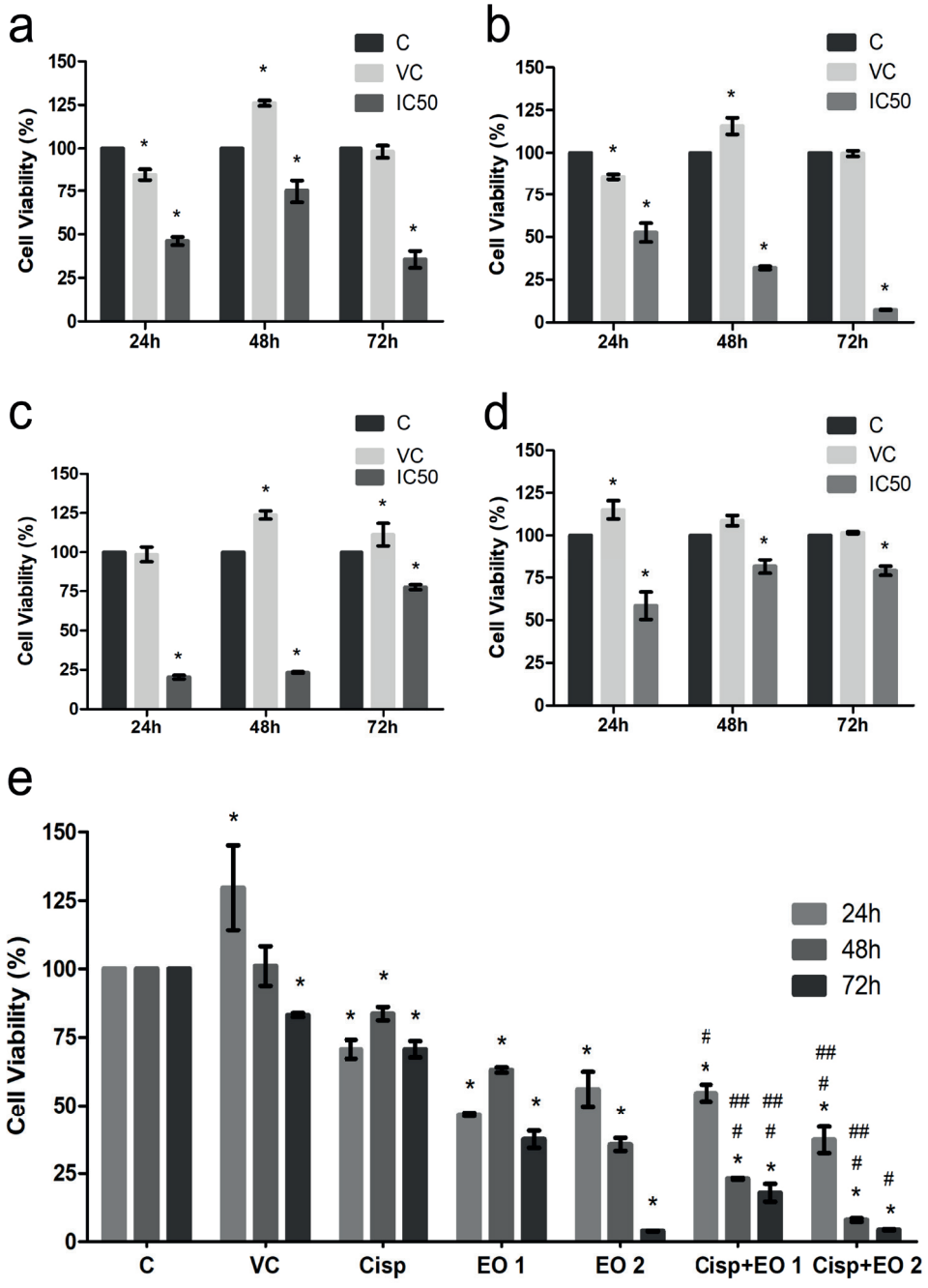

Figure 2. Effect of treatment with IC50 concentration of *T. ostenii's* leaves (EO 1) and flowers (EO 2) essentials oils. Cell viability of SiHa cell line after 24, 48 and 72 h of treatment with EO 1 (72 ng/mL) **(a)** and EO 2 (83 ng/mL) **(b)** and vehicle control (VC). Cell viability of HaCat cell line after 24, 48 and 72h of treatment with EO 1 (72 ng/mL) **(c)** and EO 2 (83 ng/mL) **(d)** and vehicle control (VC). Data show mean and standard deviation of two independent experiments performed in octuplicate. * P <0.05 = significant in relation to control (C). (One-way ANOVA followed by Tukey's test). **(e)** Cell viability of SiHa cell line after treatment with EO 1, EO 2, cisplatin (Cisp.) (80 µM) alone or in combination, and vehicle control (VC) after 24, 48 and 72 h. Data show mean and standard deviation of two independent experiments performed in quadruplicate. *P < 0.05: significant in relation to control. #P < 0.05: significant in relation to cisplatin alone (Cisp.). ## P < 0.05: significant in relation to essential oil alone (EO 1 or EO 2). (One-way ANOVA followed by Tukey's test).

the treatment with EO 1 and EO 2 inhibited cell viability in 79.6%, 76.7%, and 22.5%, and 41.5%, 18.4% and 21% for each oil respectively for the three times of treatment (Figures 2c and d).

The selective index (SI) was determined to evaluate the discrimination of treatments between tumoral and non-tumoral cells. The selectivity index was calculated as the ratio IC50 (non-tumoral cells)/IC50 (tumoral cell line). A selectivity index > 1 indicates that the cytotoxicity on tumoral cells surpassed the one on the non-tumoral cells (Callacondo-Riva et al. 2008). For the results obtained the SI estimated for *T. ostenii* in SiHa cells was 0.75 for EO 1 and 0.25 for EO 2. For MCF-7 cells the SI was 0.31.

Combined treatment with Cisplatin and essential oils of *T. ostenii* results in synergistic effects on cervical cancer cell viability

It is known that polychemotherapy is of proven efficacy and aims to reach cell populations at different stages of the cell cycle and with different phenotypes, to use the synergistic action of drugs, to decrease the development of drug resistance and to promote greater response per dose administered. For this reason, we analyzed the possible interaction between the essential oils studied and the chemotherapy drug cisplatin.

When Siha cells were treated with EO 1 at IC50 concentration and cisplatin simultaneously for 24 hours, the inhibition was 45.4%. After 48 hours, the combined treatment inhibited the cells viability in 77.1% and 82.2% after 72 hours. However, a synergistic effect was observed only at 48 and 72 hours of treatment (Figure 2e). In relation to the treatment with EO 2 at IC50 concentration and cisplatin, the inhibition was 62.8%, 92% and 95.6% after 24, 48 and 72 hours of incubation, respectively. A synergistic effect was observed at 24 and 48 hours of treatment.

Effects on cell migration and adhesion capacity after essential oils treatment

Apart from the observed inhibition on the cell viability, the investigation of the essential oils of *T. ostenii* effects in relevant indicators for human cervical cancer cells also demonstrated significant results. The Wound Healing method was performed to determine the rate of cell migration. This method is based on the observation that, upon creation of a "wound" on a confluent cell monolayer, the cells on the edge of this wound will move toward the opening until new cell-cell contacts are established again (Liang et al. 2007). The most common information derived from the wound healing assay is the rate of gap closure, which is a measure of the speed of the collective motion of the cells (Jonkman et al. 2014).

In Figure 3a, we can observe a picture of the wounds in the cell monolayer before (0 h) and after the treatment (24 and 48 h). The wound healing capacity was reduced after 48 h of treatment with EO 2 and we could observe an increase in the wound width in about 7.4% when compared with the initial width (Flower 0 h) (Figure 3b). After 48 h of treatment with leaf's essential oil, the wound healing capacity appears not to be affected and we observed a reduction in the wound width about 22% when compared with the initial width (Leaf 0 h). Meanwhile, the control and vehicle control cells had their wound healing process significantly reduced after 48 h of treatment, with a decrease of 22.5% and 19% when compared with the initial wound width (C 0 h and VC 0 h), respectively.

The tumor cell adhesion capacity was analyzed after 8 h of treatment and we quantified, simultaneously, the viable cells in the supernatant and the cells that were able to adhere to the plate. Both essential oils of *T. ostenii* were able to significantly inhibit the adhesion process by increasing the number of

viable cells in the supernatant about 2.8 times for leaf's oil and 7 times for the flower when compared to control cells (Figure 3c). It was also verified a decrease in adhered viable cells after treatment, with a reduction in cell viability of 84.3% for leaf's treatment and 72.9% for the flower when compared to control cells (Figure 3d).

Clonogenic ability and cell viability recovery after essential oils treatment

Another significant parameter to evaluate the effect of a treatment on cancer cells is the colony forming capacity. The clonogenic assay is a method used to determine the fraction of seeded cells that retain the capacity to produce colonies and for this reason is useful to determine the effectiveness of cytotoxic agents (Franken et al. 2006), (Mello et al. 2014).

Figure 4b shows that the treatment with both essential oils of *T. ostenii* at IC50 concentration reduced markedly the number of colonies formed in relation to control cells. These results were quantified and revealed that after 24 h of treatment with EO 1 and EO 2 the colony forming capacity was significantly reduced in 88.7% and 90%, respectively when compared to the control (Figure 4c).

To determine the persistence of the effects of treatment exposure in cancer cells we evaluated the cell viability after the removal of the essential oils. Therefore, the tumor cells were treated for 24 h with each essential oil at IC50 concentration and then the treatment was removed, and the cells were replated and incubated at standard conditions. As shown in Figure 4d only 6.4% of the treated cells with EO 1 and 22.1% with EO 2 were able to recover their viability even after the removal of the treatment in relation to control cells.

Cell death induced by *T. ostenii* essential oils

The data obtained through flow cytometry and double staining for annexin V/ propidium iodide showed that at 24 h of treatment with EO 1 the majority of the cells were marked for apoptosis (16.4%) and late apoptosis (35.9%) (Figure 5, Table II and Figure S1). After 48 and 72 h of treatment, we observed an increase in the late apoptosis cell population with values of 84% and 91.3%, respectively. In relation to the treatment with EO 2 at 24 h of treatment, 24.7% of cells were in apoptosis and 60% in late apoptosis. In the treatment of 48 h, the percentage of cells in late apoptosis was 80.3% and 66% after 72 h of treatment.

DISCUSSION

In this article, we analyzed, for the first time, the chemical composition and antitumoral potential of the South American species *T. ostenii,* and this work represents the first biological activity described for this species until now. The essential oils from leaves and flowers of *T. ostenii* were characterized by the presence of oxygenated and hydrocarbons monoterpenes. After one week of the extraction, the major components of the leaves essential oil (EO 1) were dihydro-tagetone (65.3%) and (Z)-tagetone (14.9%), while (Z)-β-ocimene (56.3%), (Z)-ocimenone (26.8%) and (E)-ocimenone (11.8%) were the main compounds for the flower's essential oil (EO 2) (Table I). When compared with other plants of the genus Tagetes, the species *T. ostenii* characterized in this work showed a similar chemical composition with *Tagetes minuta*. The review published by Gupta & Vasudeva (2012), found that EOs from leaves of *T. minuta* were dominated by dihydro-tagetone (2.7–54.2%), (Z)-ocimene (1.4–16.1%), (E)-tagetenone (0.1–19.5%), (Z)-tagetenone (tr–31.4%), (E)-tagetone

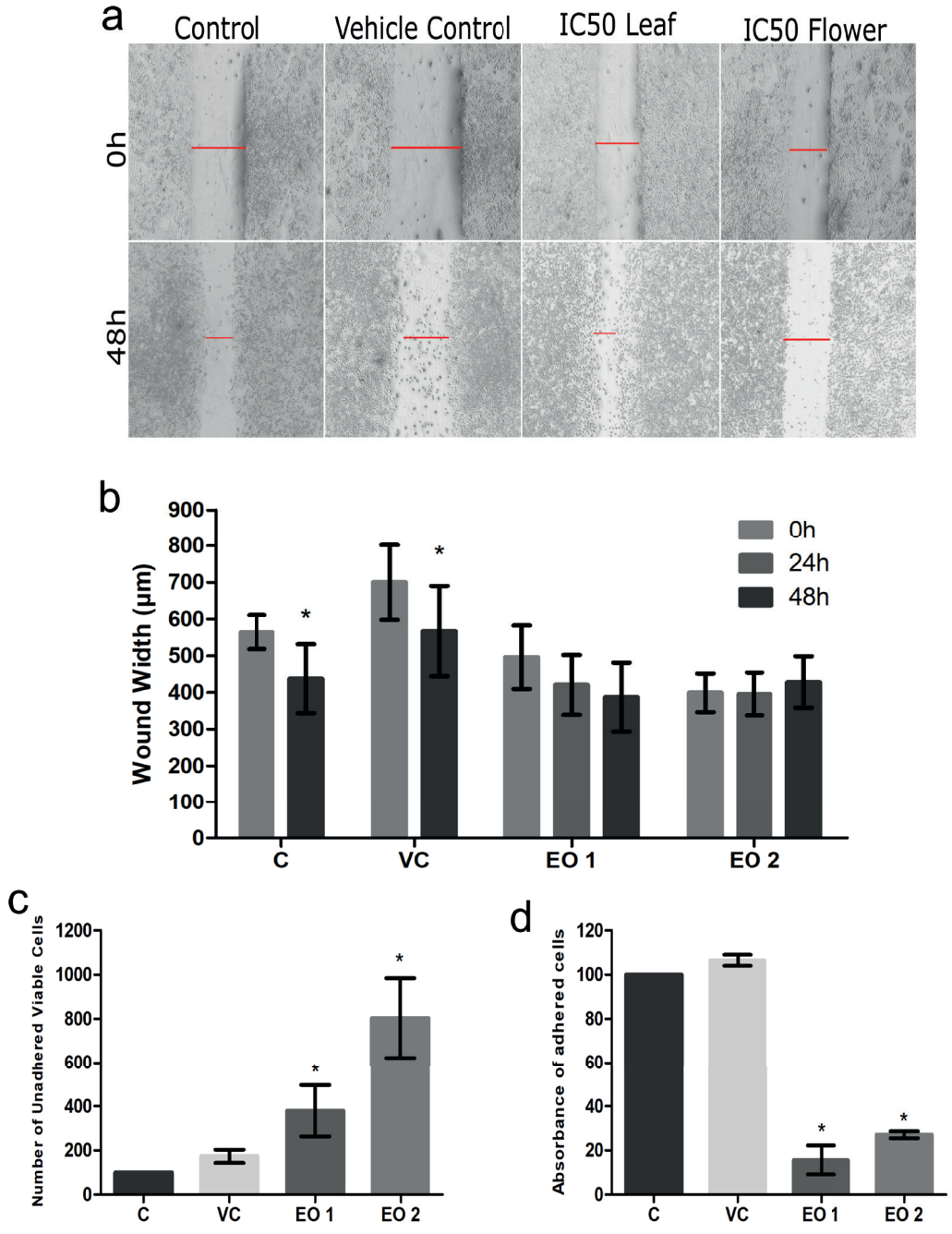

Figure 3. Effect of treatment with IC50 concentration of *T. ostenii's* leaves (EO 1) and flowers (EO 2) essentials oils on cell migration and adhesion capacity. Representative pictures **(a)** and measurement of the wound width **(b)** before and after 24 and 48 hours of treatment with *T. ostenii* essential oils at IC50 concentration (EO 1 = 72 ng/mL and OE 2 = 83 ng/mL) and vehicle control (VC). Data show mean and standard deviation of two independent experiments performed in sextuplicate. * P < 0.05: significant in relation to time 0 h. Effect of treatment with IC50 concentration (EO 1 = 72 ng/mL and EO 2 = 83 ng/mL) of *T. ostenii* essential oils and vehicle control (VC) on the adhesion capacity of SiHa cells for 8 hours. Results were expressed as the number of viable treated cells which were in the supernatant by counting with trypan blue dye **(c)** and the percentage of cells that could adhere to the plate **(d)**. Data show mean and standard deviation of two independent experiments performed in octuplicate. * P <0.05 = significant in relation to control (C). (One-way ANOVA followed by Tukey's test).

(0.8–14.5%), (Z)-tagetone (6.6–28.2%), limonene (2–12.4%) and eugenol (16.5%), as more abundance compounds. Another study reported that in the essential oil of the flowering shoots of *T. minuta* was presented β-ocimene, dihydro-tagetone, tagetone and ocimenones (Hethelyi et al. 1988). Chalchat et al. (1995) reported thirty-seven constituents in the essential oil of the leaves and flowers of *T. minuta* with (Z)-β-ocimene predominating in the oil from flowers and dihydro-tagetone predominating in that from leaves, as was also observed in our analyzes.

The cytotoxicity experiments revealed a significant inhibition of the viability of cervical cancer cells after treatment with leaf and flower essential oils for 24 h. The inhibition of SiHa cells viability was between 31.3% to 95.6% for the treatment with EO 1 and IC50 of 72 ng/mL. The cell viability inhibition induced by EO 2 treatment was between 29.5% to 93.3% and IC50 of 83 ng/mL (Figure 1a and b). It is important to emphasize that inhibition in the viability of SiHa cells were observed at low concentrations and this resulted in low IC50 for both treatments.

In this study we also evaluated the effect of the essential oil of leaves of *T. ostenii* (EO 1) in the viability of cells of another type of tumor of high morbidity and prevalence among women. For this reason, we use the human breast adenocarcinoma cell line, MCF-7. These cells have characteristics of differentiated mammary epithelium and it proves to be a suitable model cell line for breast cancer investigations, including those regarding anticancer drugs (Shirazi et al. 2011). The inhibition of MCF-7 cells viability after 24 hours of treatment with EO 1 was between 3.8% to 92.8, with IC50 of 174.3 ng/mL.

These results demonstrate that EO 1 is also capable of acting in the viability of another type of tumor and with significant, prominent results at low concentrations already after 24 hours of treatment. However, we obtained percentages of inhibition and IC50 distinct in relation to the SiHa cell line. Inhibition percentages were higher and the IC50 lower in the SiHa cell line compared to the MCF-7 lineage, and for this reason the other experiments were performed using the SiHa cells.

This distinct effect is expected since they are cells of different origins, reveal variability of the metabolic profiles, distinct mutations and differentially expressed genes. For this reason, it is important that new drugs are first tested *in vitro* and in different cell types.

Studies had shown the antitumor potential of other species of Tagetes genus. As reported by Ali et al. (2014) the essential oil extracted from the leaves of *T. minuta* showed a cytotoxic activity against MCF-7 breast tumor cells, with an IC50 of 54.7 ± 6.2 ug/mL. Another study also demonstrated cytotoxicity activity of *T. minuta* leaves essential oil against nasopharyngeal cancer cell line (KB) and liver hepatocellular carcinoma cell line (HepG2) with an IC50 of 75 ± 5 and 70 ± 4 µg/mL, respectively (Shirazi et al. 2011).

We also evaluated the cytotoxic effect of treatment in a non-tumoral cell line of human keratinocytes, HaCat. After 24 hours of treatment, the viability inhibition of HaCat cells was between 2% to 95.4% for EO 1 and IC50 of 54.45 ng/mL and 3.8% to 96% for EO 2 with an IC50 of 20.83 ng/mL (Figure 1b and c). Other species of the genus, *Tagetes patula*, also demonstrated cytotoxic potential in a murine macrophage strain for ethanolic extract of the aerial parts and ethanolic extract of flowers (Politi et al. 2016).

We also evaluated the effect of the treatment in SiHa and HaCat cells with the IC50 of essential oils for 24, 48 and 72 h. The treatment of SiHa cells with EO 1 showed an inhibition on cell viability of 53.9%, 25% and

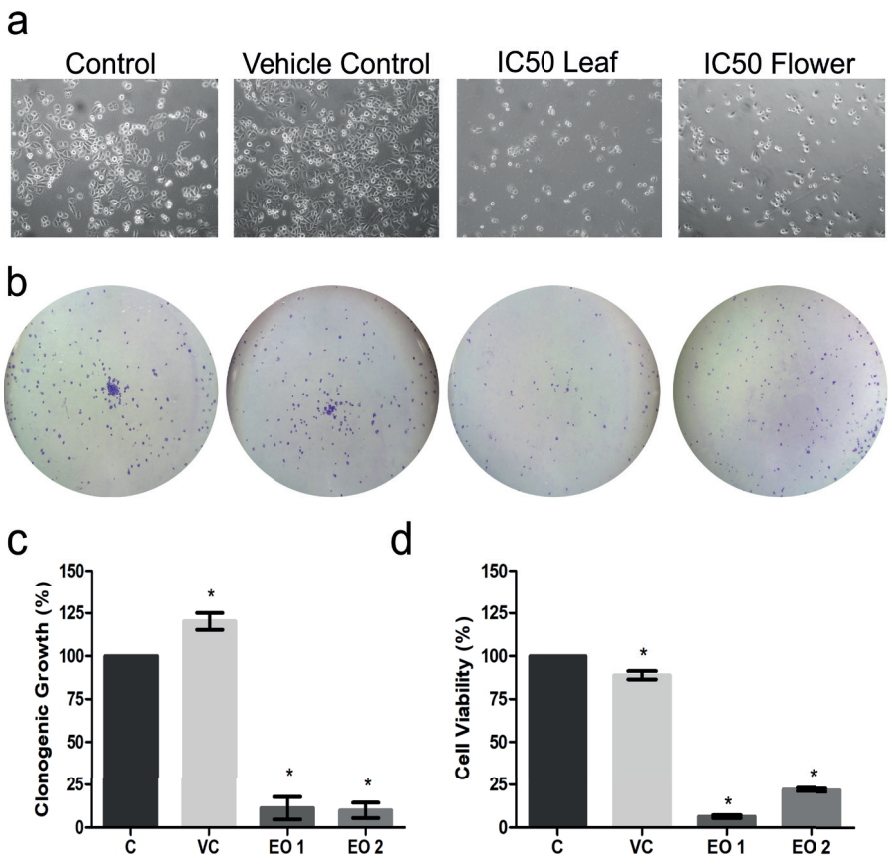

Figure 4. Effect of treatment with IC50 concentration of *T. ostenii's* leaves (EO 1) and flowers (EO 2) essentials oils on clonogenic ability and cell viability recovery capacity. Representative pictures of the cells during treatment (a); the colonies formed (b); and measurement of the colonies formed (c) after 24 hours of treatment with *T. ostenii* essential oils at IC50 concentration (EO 1 = 72 ng/mL and EO 2 = 83 ng/mL) and vehicle control (VC) in SiHa cells. Data show mean and standard deviation of two independent experiments performed in sextuplicate. * P <0.05 = significant in relation to control (C). (One-way ANOVA followed by Tukey's test). (d) Analysis of the cell viability through the washout assay after 24 hours of treatment with *T. ostenii* essential oils at IC50 concentration and vehicle control (VC). Data show mean and standard deviation of two independent experiments performed in sextuplicate. * P <0.05 = significant in relation to control (C). (One-way ANOVA followed by Tukey's test).

64.5% for 24, 48 and 72 hours respectively (Figure 2a). For treatment with EO 2 was observed an inhibition of 47.5%, 68.1% and 92.7% for each time, respectively (Figure 2b). These results showed that the effects of the treatment with both essential oils are maintained for at least 72 h in the tumoral cell line. In relation to the non-tumoral cell line HaCat, the treatment with EO 1 and EO 2 inhibited cell viability in 79.6%, 76.7%, and 22.5%, and 41.5%, 18.4% and 21% for each oil respectively for the three times of treatment (Figure 2c and d). In this case, an increase in cell viability can be observed when the greater the exposure to treatment. This may have been due to the different treatment-induced gene regulation in each cell lines. However, further studies are needed to elucidate the mechanism behind this result.

Synergistic effect of the essential oils and cisplatin chemotherapy was also evaluated. For the combined treatment with EO 1 and the mentioned drug a synergistic effect was

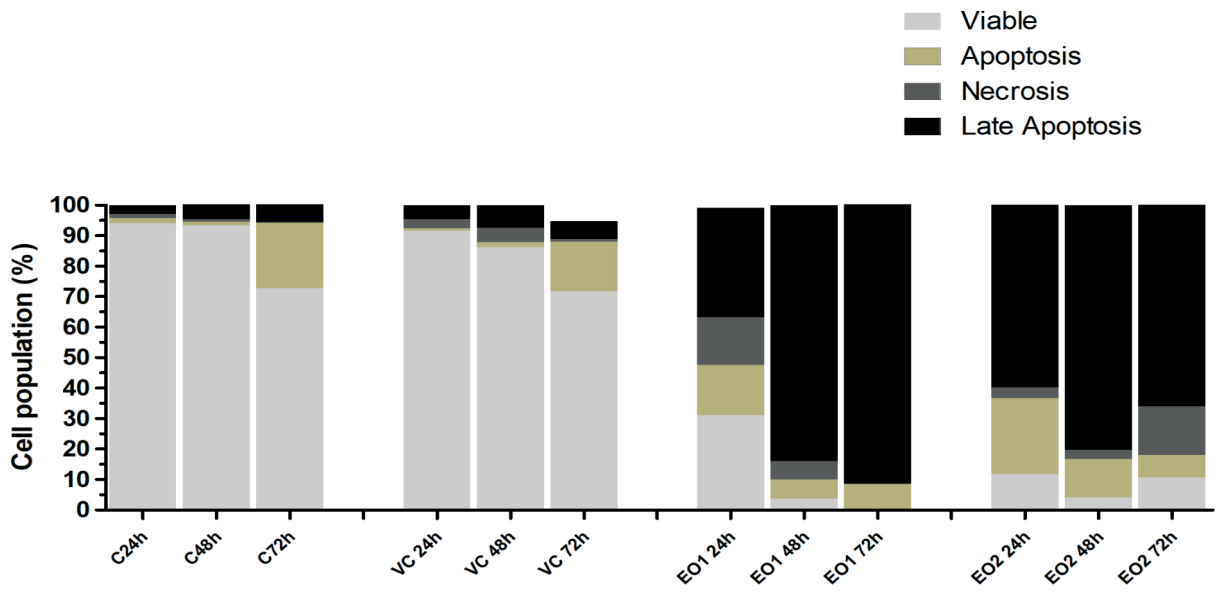

Figure 5. Graphical abstract of results from cell death mechanism analysis by flow cytometry with annexin V/ propidium iodide in SiHa cells treated with *T. ostenii* essential oils at IC50 concentration (EO 1 = 72 ng/mL and EO 2 = 83 ng/mL) and vehicle control (VC) after 24, 48 and 72 h. C = control cells.

Table II. Percentage of cells from Flow cytometry analysis of the cell death mechanism by the labeling with annexin V / propidium iodide in SiHa cells treated with *T. ostenii* essential oils at IC50 concentration (OE 1 = 72 ng/ mL and OE 2 = 83 ng/mL) after 24, 48 and 72 h. C = control and VC = vehicle control.

	Viable (%)			Apoptosis (%)			Necrosis (%)			Late Apoptosis (%)		
	24h	48h	72h	24h	48h	72h	24h	48h	72h	24h	**48h**	**72h**
C	94.07	93.31	72.69	1.68	1.13	21.41	1.25	0.9	0.21	2.99	4.67	5.69
VC	91.45	86.2	71.69	0.83	1.71	16.35	3.2	4.56	0.71	4.51	7.53	5.91
EO 1	31.16	3.83	0.39	16.36	6.15	21.69	15.58	5.97	0.27	35.9	84.04	91.28
EO 2	11.9	4.03	10.59	24.73	12.7	7.47	3.47	2.96	16.02	59.9	80.3	65.92

observed at 48 and 72 hours of treatment (Figure 2e) and for the combined treatment with EO 2, a synergistic effect was observed at 24 and 48 hours of treatment. One of the greatest barriers to the treatment of cancer with chemotherapeutic drugs is the acquisition of drug resistance. For this reason, a strategy combination therapy of drugs aims to achieve synergistic effects and usually acts through different mechanisms to reduce the possibility of drug resistance. Studies have also shown that combinations of chemotherapeutic agents and biologic anticancer agents produce synergistic efficacy and avoid multidrug resistance - MDR (Li & Zhang 2016). According to the systematic review and Network meta-analyses (NMA) reported by Rosen et al. (2017), a cisplatin-paclitaxel-bevacizumab treatment and topotecan-paclitaxel-bevacizumab have a highest probability of being efficacious and demonstrate a trend toward improved overall survival (OS) compared with carboplatin-paclitaxel and other non-bevacizumab-containing therapies.

In this study, we analyze the wound healing capacity of the tumor cells after treatment, since cell migration capacity is an important characteristic for cell survival and colonization. Increased cell migration is a priming process for cancer cells to invade and metastasize during cancer progression. Metastasis is the migration of cancer cells away from the primary tumor, a process called tumor invasion, and the leading cause of mortality among cancer patients (Clark & Vignjevic 2015), (Hanahan & Weinberg 2011). Therefore, evaluating cancer cell motility is a critical step in studying mechanism of cancer cell invasion and metastasis.

The SiHa cells had their wound healing capacity reduced after 48 h of treatment with the EO 2 and we could observe an increase in the wound width in about 7.4% when compared with the initial width (Flower 0 h) (Figure 3b). For the treatment with EO 1, this process appears not to be affected after 48 h. During metastasis, abnormal cells with genomic heterogeneity may undergo epithelial-to-mesenchymal transition (EMT) and phenotypically exhibit increased motility and invasiveness as compared to normal cells (Pavelic et al. 2011). The ability to form solid tumors, like cervical cancer, is also affected by the reduction of cell migration as reported by (Mehta et al. 2015).

As we didn't use an antiproliferative agent during wound healing assay , it's possible that the results observed were influenced by both, cell migration into the scratch and proliferation. As cancer, wound healing capacity are the coordination and regulation of two relatively simple cell behaviors – migration and proliferation. These behaviors are shaped by interactions between various cell types, including epithelial, endothelial, mesenchymal and immune cells, through growth factor/cytokine signalling networks (Sundaram et al. 2018). Therefore a reduction of the wound's closing capacity in our experiments, may reflect in a reduction of both tumor cell abilities (migration and proliferation), influencing the tumor invasion process.

Moreover, both essential oils of *T. ostenii* were able to significantly inhibit the adhesion process by increasing the number of viable cells in the supernatant about 2.8 times for leaf's oil and 7 times for the flower when compared to control cells (Figure 3c). It was also verified a decrease in adhered viable cells after treatment, with a reduction on cell viability of 84.3% for EO 1 treatment and 72.7% for EO 2 when compared to control cells (Figure 3d). The mechanism involving cell adhesion includes the binding of a cell to the extracellular matrix (ECM), other cells, or a specific surface, and it's essential for the growth, survival of the cell and its communication with other cells. This process requires a range of biological events such as three-dimensional re-organization of the cytoskeleton, biochemical reactions and changes in molecules on the surface of the cell (Chen 2011). As SiHa cells constitute an adherent cell line, the decrease in cell adhesion capacity consequently reduced the survival ability of these cells. In addition, cell adhesion to extracellular matrix proteins has been well documented as a key and general determinant of cancer therapy resistance (Dickreuter & Cordes 2017).

Another important factor to be evaluated in tumor cells undergoing treatment is the ability of these cells to form colonies. In order to evaluate the clonogenic ability after treatment clonogenic assay was performed. This assay consists of an *in vitro* cell survival assay based on the ability of a single cell to grow into a colony (Franken et al. 2006). This methodology enables an assessment of the differences in reproductive viability between untreated cells and cells that have undergone various treatments such as exposure to ionizing radiation and various

chemical compounds but can also be used to determine the effectiveness of other cytotoxic agents (Rafehi et al. 2011). The treatment with EO 1 and EO 2 after 24 h reduced markedly the colony forming capacity in 88.7% and 90% respectively, when compared to the control (Figure 4c). The capacity of colony formation is essential to cells to grow and expand in a tumor microenvironment. It is well documented that a reduction of clonogenic capacity is related to a decrease in tumor growth and cancer progression (Toomeh et al. 2018) (Zhang et al. 2016).

The cell washout assay is very informative since it provides insight into how long the effects of treatment are sustained after its withdrawal. Our results suggest that EO 1 and EO 2 have long-lasting inhibitory activity in tumor cells because only 6.4% of the treated cells with EO 1 and 22.1% with EO 2 were able to recover the viability even after the removal of the treatment in relation to control cells (Figure 4d). These data indicate that the *in vitro* inhibitory activity of both essential oils is durable, probably by regulating specific genes in tumor cells. A prolonged phenotypic response following washout may be due to a higher level of target vulnerability or in addition to long residence time, drug rebinding and/or accumulation of drug in the cell or membrane. In addition, prolonged drug effects might also be due to the slow repair of essential processes that were reversibly damaged by drug treatment (Tonge 2017).

The investigation of cell death mechanism is pivotal since the type of cell death can influence the tissue homeostasis and tumor microenvironment. The process of programmed cell death, or apoptosis, is generally characterized by distinct morphological characteristics and energy-dependent biochemical mechanisms. Apoptosis is an organized cell death determines by cell signals that guarantee the integrity of cell membrane and phagocytosis of the death cell. (Elmore 2007). It is known that this mechanism of cell death may be disrupted in tumor cells, conferring a survival advantage. Correspondingly, a major mode of resistance to antitumor treatments may be insensitivity to apoptosis induction (Fisher 1994). Some of the mechanisms involved in early apoptotic cell clearance are also involved in the phagocytosis of late apoptotic and even necrotic cells (Poon et al. 2010). For example, the phosphatidylserine externalization on early apoptotic cells was shown recently to promote the ability of macrophages to recognize and phagocytosis late apoptotic and necrotic cells (Krysko et al. 2006), (Krysko & Vandenabeele 2008). In our study, we can observe that both essential oils tested induced a cell death through late apoptosis in most of the tumor cells studied, at all times of treatments (Figure 5 and Table II).

CONCLUSION

In conclusion, the treatment with the essential oils of leaves and flowers of *T. ostenii* was able to significantly inhibit many biological properties in cervical cancer cells, such as cell viability and adhesion ability, migration, clonogenic ability and recovery capacity after withdrawal of treatment. These parameters are important for the growth of cells derived from solid tumors and reflect the influence of these treatments on metastasis, cancer progression and cell invasion processes.

These findings bring new data in the chemical constitution and the anti-tumor potential of essential oils of *T. ostenii* and highlight the importance of further studies involving plant-derived actives for the development of new approaches to cancer treatment.

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REFERENCES

ADAMS R. 2007. Identification of essential oil components by gas chromatography/mass spectrometry. 4 th ed. Allured Publishing Corporation, USA.

ALI NA, SHAROPOV FS, AL-KAF AG, HILL GM, ARNOLD N, AL-SOKARI SS, SETZER WN & WESSJOHANN L. 2014. Composition of essential oil from Tagetes minuta and its cytotoxic, antioxidant and antimicrobial activities. Nat Prod Commun 9: 265-268.

ANDREOTTI R, GARCIA MV, CUNHA RC & BARROS JC. 2013. Protective action of Tagetes minuta (Asteraceae) essential oil in the control of Rhipicephalus microplus (Canestrini, 1887)(Acari: Ixodidae) in a cattle pen trial. Vet Parasitol 197: 341-345.

BARROSO GM. 1991. Sistemática de angiospermas do Brasil. Imprensa Univ. Univ Fed Viçosa 2: 237-314.

BRANDÃO HN, DAVID JP, COUTO RD, NASCIMENTO JAP & DAVID JM. 2010. Chemistry and pharmacology of antineoplasic chemoterapeutical derivatives from plants. Quim Nova 33: 1359-1369.

BRASIL. 2010. Farmacopéia Brasileira, volume 2. 5 ed. Brasília.

BREMER K & ANDERBERG AA. 1994. Asteraceae: cladistics & classification.

CHALCHAT JC, GARRY RP & MUHAYIMANA A. 1995. Essential oil of Tagetes minuta from Rwanda and France: chemical composition according to harvesting location, growth stage and part of plant extracted. J Essent Oil Res 7: 375-386.

CHEN Y. 2011. Cell adhesion assay. Bio-protocol 1: e98.

CLARK AG & VIGNJEVIC DM. 2015. Modes of cancer cell invasion and the role of the microenvironment. Curr Opin Cell Biol 36: 13-22.

DANG YZ, LI P, LI JP, BAI F, ZHANG Y, MU YF, LI WW, WEI LC & SHI M. 2018. The Efficacy and Late Toxicities of Computed Tomography-based Brachytherapy with Intracavitary and Interstitial Technique in Advanced Cervical Cancer. J Cancer 9: 1635.

DEBLE LP, DE OLIVEIRA AS & MARCHIORI JNC. 2005. Tagetes ostenii Hicken, citação nova para a flora sul-brasileira. Balduinia, p. 4-6.

DICKREUTER E & CORDES N. 2017. The cancer cell adhesion resistome: mechanisms, targeting and translational approaches. Biol Chem 398: 721-735.

ELMORE S. 2007. Apoptosis: a review of programmed cell death. Toxicol Pathol 35: 495-516.

FANG J, ZHANG H & JIN S. 2014. Epigenetics and cervical cancer: From pathogenesis to therapy. Tumor Biol 35: 5083-5093.

FERLAY J, ERVIK M, LAM F, COLOMBET M, MERY L, PIÑEROS M, ZNAOR A, SOERJOMATARAM I & BRAY F. 2018. Global Cancer Observatory: Cancer Today. Lyon, France: International Agency for Research on Cancertle.

FISHER DE. 1994. Apoptosis in cancer therapy: crossing the threshold. Cell 78: 539-542.

FRANKEN NAP, RODERMOND HM, STAP J, HAVEMAN J & VAN BREE C. 2006. Clonogenic assay of cells in vitro. Nat Protoc 1: 2315-2319.

GALLAGHER MJ, BRERETON HD, ROSTOCK RA, ZERO JM, ZEKOSKI DA, POYSS LF, RICHTER MP & KLIGERMAN MM. 1986. A prospective study of treatment techniques to minimize the volume of pelvic small bowel with reduction of acute and late effects associated with pelvic irradiation. Int J Radiat Oncol Biol Phys 12: 1565-1573.

HANAHAN D & WEINBERG RA. 2011. Hallmarks of cancer: the next generation. Cell 144: 646-674.

HISAMATSU T, MABUCHI S, YOSHINO K, FUJITA M, ENOMOTO T, HAMASAKI T & KIMURA T. 2012. Prediction of progression-free survival and response to paclitaxel plus carboplatin in patients with recurrent or advanced cervical cancer. Int J Gynecol Cancer 22: 623-629.

INSTITUTO NACIONAL DE CANCER JOSÉ ALENCAR GOMES DA SILVA. 2017. Estimativa 2018: incidência de câncer no Brasil.

JONKMAN JEN, CATHCART JA, XU F, BARTOLINI ME, AMON JE, STEVENS KM & COLARUSSO P. 2014. An introduction to the wound healing assay using live-cell microscopy. Cell Adh Migr 8: 440-451.

KEYS HM, BUNDY BN, STEHMAN FB, MUDERSPACH LI, CHAFE WE, SUGGS CL, WALKER JL & GERSELL D. 1999. Cisplatin, radiation, and adjuvant hysterectomy compared with radiation and adjuvant hysterectomy for bulky stage IB cervical carcinoma. N Engl J Med 340: 1154-1161.

KRYSKO DV, D'HERDE K & VANDENABEELE P. 2006. Clearance of apoptotic and necrotic cells and its immunological consequences. Apoptosis 11: 1709-1726.

KRYSKO DV & VANDENABEELE P. 2008. From regulation of dying cell engulfment to development of anti-cancer therapy. Cell Death Differ 15: 29.

LEE J, LIN JB, CHANG CL, SUN FJ, WU MH, JAN YT & CHEN YJ. 2017. Impact of para-aortic recurrence risk-guided intensity-modulated radiotherapy in locally advanced cervical cancer with positive pelvic lymph nodes. Gynecol Oncol 148: 291-298.

LI F & ZHANG N. 2016. Ceramide: therapeutic potential in combination therapy for cancer treatment. Curr Drug Metab 17: 37-51.

LIANG CC, PARK AY & GUAN JL. 2007. In vitro scratch assay: a convenient and inexpensive method for analysis of cell migration in vitro. Nat Protoc 2: 329-333.

MEHTA T, VERCRUYSSE K, JOHNSON T, EJIOFOR AO, MYLES E & QUICK QA. 2015. Violacein induces p44/42 mitogen-activated protein kinase-mediated solid tumor cell death and inhibits tumor cell migration. Mol Med Rep 12: 1443-1448.

MELLO P ET AL. 2014. Adenosine uptake is the major effector of extracellular ATP toxicity in human cervical cancer cells. Mol Biol Cell 25: 2905-2918.

MOORE DH, TIAN C, MONK BJ, LONG HJ, OMURA GA & BLOSS JD. 2010. Prognostic factors for response to cisplatin-based chemotherapy in advanced cervical carcinoma: a Gynecologic Oncology Group Study Gynecol Oncol 116: 44-49.

MORRIS M, EIFEL PJ, LU J, GRIGSBY PW, LEVENBACK C, STEVENS RE, ROTMAN M, GERSHENSON DM & MUTCH DG. 1999. Pelvic Radiation with Concurrent Chemotherapy Compared with Pelvic and Para-Aortic Radiation for High-Risk Cervical Cancer. N Engl J Med 340: 1137-1143.

MOSMANN T. 1983. Rapid colorimetric assay for cellular growth and survival: application to proliferation and cytotoxicity assays. J Immunol Methods 65: 55-63.

NAITO Y & URASAKI T. 2018. Precision medicine in breast cancer. Chinese Clin Oncol 7: 29.

NEWMAN D, CRAGG G & SNADER K. 2003. Natural products as sources of new drugs over the period 1981– 2002. J Nat Prod 66: 1022-1037.

NEWMAN DJ, CRAGG GM & SNADER KM. 2000. The influence of natural products upon drug discovery. Nat Prod Rep 17: 215-234.

PAVELIC SK, SEDIC M, BOSNJAK H, SPAVENTI S & PAVELIC K. 2011. Metastasis: new perspectives on an old problem. Mol Cancer 10: 22.

PETERS III WA, LIU PY, BARRETT RJ, STOCK RJ, MONK BJ, BEREK JS, SOUHAMI L, GRIGSBY P, GORDON JR W & ALBERTS DS. 2000. Concurrent chemotherapy and pelvic radiation therapy compared with pelvic radiation therapy alone as adjuvant therapy after radical surgery in high-risk early-stage cancer of the cervix. Obstet Gynecol Surv 55: 491-492.

POLITI FAS, QUEIROZ-FERNANDES GM, RODRIGUES ER, FREITAS JA & PIETRO RCLR. 2016. Antifungal, antiradical and cytotoxic activities of extractives obtained from Tagetes patula L.(Asteraceae), a potential acaricide plant species. Microb Pathog 95: 15-20.

POON IKH, HULETT MD & PARISH CR. 2010. Molecular mechanisms of late apoptotic/necrotic cell clearance. Cell Death Differ 17: 381.

RAFEHI H, ORLOWSKI C, GEORGIADIS GT, VERVERIS K, EL-OSTA A & KARAGIANNIS TC. 2011. Clonogenic assay: adherent cells. J Vis Exp JoVE 13: 2573.

RODRIGUEZ LG, WU X & GUAN JL. 2005. Wound-healing assay. Methods Mol Biol 294: 23-29.

ROMAGNOLI C, BRUNI R, ANDREOTTI E & RAI M. 2005. Chemical characterization and antifungal activity of essential oil of capitula from wild Indian Tagetes patula L. Protoplasma 225: 57-65.

ROSE PG, BUNDY BN, WATKINS EB, THIGPEN JT, DEPPE G, MAIMAN MA, CLARKE-PEARSON DL & INSALACO S. 1999. Concurrent cisplatin-based radiotherapy and chemotherapy for locally advanced cervical cancer. N Engl J Med 340: 1144-1153.

ROSEN VM, GUERRA I, MCCORMACK M, NOGUEIRA-RODRIGUES A, SASSE A, MUNK VC & SHANG A. 2017. Systematic Review and Network Meta-Analysis of Bevacizumab Plus First-Line Topotecan-Paclitaxel or Cisplatin-Paclitaxel Versus Non–Bevacizumab-Containing Therapies in Persistent, Recurrent, or Metastatic Cervical Cancer. Int J Gynecol Cancer 27: 1237.

SAAVEDRA KP, BREBI PM & ROA JCS. 2012. Epigenetic alterations in preneoplastic and neoplastic lesions of the cervix. Clin Epigenetics 4: 13.

SALEHI B, VALUSSI M, MORAIS-BRAGA M, CARNEIRO J, LEAL A, COUTINHO H, VITALINI S, KRĘGIEL D, ANTOLAK H & SHARIFI-RAD M. 2018. Tagetes spp. Essential Oils and Other Extracts: Chemical Characterization and Biological Activity. Molecules 23: 2847.

SATTERWHITE CL ET AL. 2013. Sexually Transmitted Infections Among US Women and Men: Prevalence and Incidence Estimates, 2008. Sex Transm Dis 40: 187-193.

SCHIAVON D, SCHUCH L & FACCIN Â. 2015. A systematic review of Tagetes minuta L.(Asteraceae): popular use, the chemical composition and biological activity. Sci Anim 3: 192-208.

SHIRAZI FH, ZARGHI A, KOBARFARD F, ZENDEHDEL R, NAKHJAVANI M, ARFAIEE S, ZEBARDAST T, MOHEBI S, ANJIDANI N & ASHTARINEZHAD A. 2011. Remarks in successful cellular investigations for fighting breast cancer using novel synthetic compounds. In Breast Cancer-Focusing Tumor Microenvironment, Stem cells and Metastasis InTech.

SUNDARAM GM, QUAH S & SAMPATH P. 2018. Cancer: the dark side of wound healing. FEBS J 285: 4516-4534.

TONGE PJ. 2017. Drug–target kinetics in drug discovery. ACS Chem. Neurosci 9: 29-39.

TOOMEH D, GADOUE SM, YASMIN-KARIM S, SINGH M, SHANKER R, SINGH SP, KUMAR R, SAJO E & NGWA W. 2018. Minimizing the potential of cancer recurrence and metastasis by the use of graphene oxide nano-flakes released from smart fiducials during image-guided radiation therapy. Phys Medica 55: 8-14.

TORRE LA, BRAY F, SIEGEL RL, FERLAY J, LORTET-TIEULENT J & JEMAL A. 2015. Global cancer statistics, 2012. CA. Cancer J Clin 65: 87-108.

VASUDEVAN P, KASHYAP S & SHARMA S. 1997. Tagetes: a multipurpose plant. Bioresour Technol 62: 29-35.

WHITNEY CW, SAUSE W, BUNDY BN, MALFETANO JH, HANNIGAN E V, FOWLER WESLEY C J, CLARKE-PEARSON DL & LIAO SY. 1999. Randomized comparison of fluorouracil plus cisplatin versus hydroxyurea as an adjunct to radiation therapy in stage IIB-IVA carcinoma of the cervix with negative para-aortic lymph nodes: a Gynecologic Oncology Group and Southwest Oncology Group study. J Clin Oncol 17: 1339.

ZHANG W, CHEN L, XIANG H, HU C, SHI W, DONG P & LV W. 2016. Knockdown of GGCT inhibits cell proliferation and induces late apoptosis in human gastric cancer. BMC Biochem 17: 19.

SUPPLEMENTARY MATERIAL

Figure S1.

How to cite

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Author Contributions

Jisette Núñez worked in experimental procedures, data analysis and writing manuscript. Jordânia Pinheiro, Gustavo Padilha, Helana Garcia and Vitória La Porta worked in experimental procedures and data analysis. Miriam Apel worked in essential oils extraction and analysis and writing manuscript. Alessandra Bruno, major supervisor, orientation, data analysis and manuscript writing.