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Chemical, Antimicrobial, Antioxidant and Anti-proliferative Features of the Essential Oil Extracted from the Invasive Plant *Solidago canadensis* L.

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Abstract: *The essential oil from inflorescences of S. canadensis L. (Goldenrod) obtained by hidrodistillation was analysed by gas chromatography-mass spectrometry and it was qualitatively and quantitatively tested against Gram-positive and Gram-negative bacteria and fungi. The samples were also subjected to screening for their possible antioxidant activity by using DPPH assay and the influence on intracellular ROS (reactive oxygen species). The main components identified were α-pinene, germacrene D, and limonene. The tested microbial strains proved to be susceptible to S. canadensis essential oil which exhibited good anti-biofilm activity, inhibiting the adhesion to the inert and cellular substrate, decreasing the Acinetobacter baumannii adhesion index to 17.52% and changing the adherence pattern. Goldenrod essential oil showed good free-radical scavenging activity, but it increased the production of free radicals in Hep-2 tumor cells.*

Keywords*: essential oil, antimicrobial activity, antioxidant activity, ROS, free radicals, Solidago canadensis*

1. Introduction

Solidago canadensis (*S. canadensis;* Goldenrod) is an erect perennial plant originating in North America classified in the list of extremely dangerous invasive species. Its strong invasiveness is due the abundant vegetative propagation through rhizomes and shoots [1] and its high resistance to alkaline sandy loams with a significant salt content, explaining its invasive-aggressive behaviour in such areas [2]. The propagation strategy of this species is called falanx and consists of plant propagation / clonal so dense that excludes all other species from the clonal territory through the formation of branched short internodes and under the ground. On the other hand, the plant produces allelopathy substances that are able to exclude competitors from its development niche [1]. Also, it induces a considerable decrease in total nitrogen, mineral nitrogen as NO_3^- ~~-N~~ and phosphorus soil content, while organic carbon, mineral nitrogen as NH_4^+ ~~-N~~ content and pH increase significantly [3].

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In addition, a recent study [4] found that water extract of *S. canadensis* could decrease the mitotic index and interfere with the normal process of mitosis in silkworm root tip cells thus generating a genotoxic effect and rapid diffusion ability.

Solidago canadensis L. (*Asteraceae* family) has many traditional uses which are based on the high content of active ingredients such as flavonoids, saponins and hydroxycinnamic. These compounds are responsible for its anti-inflammatory, spasmolytic and diuretic effects [5]. According to Elshafie, *S. canadensis* essential oil obtained from roots has as major compounds germacrene D (which was correlated with the antimicrobial activity), limonene, *α*-pinene, *β*-elemene and bornyl acetate [6]. Germacrene-D, among other compounds, could be considered an important marker of *Solidago canadensis* honeys because it has not been identified in other monofloral honeys [7].

There is a report that essential oil isolated from flowers of *S. canadensis* showed slightly cytotoxic activities against MDA-MB-435 (breast cancer cell), HepG2 (hepatoma cell) A549 (lung carcinoma cell), HeLa (cervical carcinoma), PLC (liver carcinoma), and no cytotoxic activities against LOVO (colon carcinoma cell) and HL-60 (peripheral blood promyeloblast cell) human tumor cells [8].

According to Synowiec et al. [9] the *S. canadensis* essential oil showed phytotoxicity against the germination of Avena sativa, Brassica napus and Zea mays. The main components responsible for this effect are oxygenated monoterpenes, well known for their antimicrobial and antioxidant activity.

The intracellular ROS production assay of inflorescences *Solidago canadensis* essential oil in tumoral cells has never been reported. The antioxidant properties of this essential oil were not also reported.

Harnessing the therapeutic potential of the *S. canadensis* species could represent an economical solution, but also a strategy for the control of their spread. The purpose of the present study consisted in extraction, chemical characterization and evaluation of antioxidant, antimicrobial and cytotoxic potential of the *S. canadensis* essential oil.

2. Materials and methods

2.1. Plant material

Solidago canadensis inflorescences were collected from Bucharest, Romania in late August 2014. Their taxonomic affiliation was confirmed, and voucher specimens were deposited in the herbarium of the Botanical Garden "Dimitrie Brândză" from the University of Bucharest (No. 400640). The plants were manually sorted and dried at room temperature.

2.2. Isolation of the essential oil

The air-dried inflorescences of *S. canadensis* were subjected for 4 h to water distillation using a Clevenger-type apparatus. 100g of inflorescences hand ground with 400 mL distilled water were used at each extraction. The obtained essential oil was stored at +4°C until tested and analysed [10].

2.3. GC-MS analysis

The GC-MS (Gas Chromatography - Mass Spectrometry) instrumentation consisted of the Thermo Electron system, provided with a Triplus Autosampler. The GC-MS analyses were performed with a Focus GC chromatograph coupled with a Polaris Q ion trap mass detector. A DB-5MS capillary column (25 m × 0.25 mm; 0.25 μm of film thickness) was used, and the carrier gas was helium at 1 mL/min. The GC oven temperature program was: initial temperature 60°C (3 min) followed by an increase of 10°C/min up to 200°C (2 min) and then 12°C/min to the final temperature of 240°C (2 min). The source and interface temperature were 200 and 250°C, respectively. Detector operated in electron impact mode (70 eV). Detection was performed in the range of m/z 35-300. The mass spectrometer was operated in the full scan mode. All peaks of the chromatograms were analysed using Xcalibur® software and NIST 11 Mass Spectral Library in order to identify the corresponding compound. Alkane standard solution for GC (C_8-C_{20} in hexane, from Sigma Aldrich Co., St. Louis, USA) was used for retention indexes (RI) calculation [11]. Relative percent of individual components

was calculated based on GC peak areas.

2.4. Antimicrobial activity

Microbial strains: For testing the antimicrobial activity there were used both reference and clinical isolates, belonging to Gram-positive (*Staphylococcus aureus*, *S. aureus; Bacillus subtilis*, *B. subtilis; Enterococcus faecalis*, *E. faecalis*), and Gram-negative (*Pseudomonas aeruginosa*, *P. aeruginosa; Escherichia coli*, *E. coli; Klebsiella pneumoniae*, *K. pneumoniae; Acinetobacter baumannii*, *A. baumannii*) bacteria, as well as yeasts (*Candida famata*, *C. famata; Candida utilis*, *C. utilis*; *Candida albicans*, *C. albicans*). This assay was performed in triplicate.

Antimicrobial assay: The stock solutions of *S. canadensis* essential oil used for further assays were prepared 1:1 in DMSO (dimethylsulfoxide, Merck KGaA, Darmstadt, Germany). The antimicrobial activity screening was determined by employing an adapted disk diffusion technique. The minimum inhibitory concentrations (MICs) were measured as described previously [12]. Briefly, serial dilutions of the stock solutions in liquid medium (Brain heart infusion broth for bacterial strains and Sabouraud broth for yeasts, Scharlab, S.L., Barcelona, Spain) were prepared in a microtiter plate (96 wells). Then 10 µL of the microbial suspension with the standard density of 0.5 Mc Farland (prepared were in sterile distilled water) was added to each well. For each strain, the growth conditions and the sterility of the medium were checked, and the plates were incubated for 24 h at 37°C. MICs were determined as the lowest concentrations preventing visible growth and spectrophotometrically by measuring the absorbance at 620 nm with an Apollo LB 911.

Influence of *S. canadensis* essential oil on the microbial adherence capacity to the inert surface: The influence on the ability of microbial adherence to the inert substrate was measured after running the quantitative analysis of the antimicrobial activity, through the microtiter method, evaluating the biofilm biomass, after fixation with cold methanol (5 minutes) (Sigma Aldrich Co., St. Louis, USA) and 1% crystal violet staining (for 15 min) (Sigma Aldrich Co., St. Louis, USA). The optical density of the biological material resuspended in acetic acid 33% (Sigma Aldrich Co., St. Louis, USA), stirring 150 rev/min., 15 min was determined by reading the absorbance at 490 nm.

Influence of *S. canadensis* essential oil on microbial ability to adhere to mammalian cells: The adherence index of microbial strains treated with subinhibitory concentration of essential oil (MIC/4) to the HEp-2 (Human Epithelioma) cells and the adherence pattern were established by the adapted Cravioto method [13]. Briefly, Hep-2 cell monolayers (70-80% confluence) were washed with sterile PBS (phosphate buffer saline) and 1 mL of fresh medium without antibiotics was aseptically added to each well. PBS suspensions of bacterial strains treated with subinhibitory concentration of essential oil were adjusted to 10^8 CFU/mL and 1 mL was used for the inoculation of each well. The inoculated plates were incubated for 2 h at 37°C [14]. After incubation, the monolayers were washed 3 times with sterile PBS (Sigma Aldrich Co., St. Louis, USA), fixed in cold methanol (3 min) and stained with 1:10 v/v Giemsa solution (neutral *p*H, Scharlab, S.L., Barcelona, Spain) for 20 min. The plates were washed, dried at room temperature overnight, and examined by optic microscopy using wet objective (×2500 magnification), in order to evaluate the adherence indexes and patterns. The adherence indexes were expressed as the ratio between the number of the eukaryotic cells with adhered bacteria and 200 eukaryotic cells counted on the microscopic field using an Axiolab (Zeiss) microscope for each version.

2.5. Antioxidant activity

The antioxidant activity of the essential oil based on the scavenging activity of the stable 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical (Sigma Aldrich Co., St. Louis, USA) was determined by the method described by Robu et al. [15] with few modifications. Initially, four dilutions in DMSO (5 mg/mL; 7.5 mg/mL; 10 mg/mL and 12.5 mg/mL) were carried out. Briefly, an aliquot of each dilution (0.5 mL) was mixed with a solution of DPPH in methanol (4 mg%) (1.5 mL) and the absorbance was measured at 517 nm for 30 min, using a Spectrophotometer Shimadzu UV-1800.

Thymol (Merck KGaA, Darmstadt, Germany) were used as reference standards and dissolved in DMSO to make solutions within the same range of concentrations (12.5 mg/mL-0.05 mg/mL). Methanol (Merck KGaA, Darmstadt, Germany) was used as blank. The DPPH free-radical scavenging activity (%) was calculated as 100 x [(Acontrol - Asample)/Acontrol], where Acontrol is the absorbance of the solvent and Asample is the absorbance of the sample. The IC_{50} value (mg/mL), which is the concentration of the extract/standard that reduces 50% of the free-radical concentration, was calculated through linear interpolation between values above and below 50% activity.

2.6. Cytotoxicity assay

HEp-2 cells were cultivated in DMEM: F12 (Dulbecco's Modified Eagle's Medium: Nutrient Mixture F-12, Invitrogen, NY, SUA) supplemented with 10% heat-inactivated FBS (Fetal bovine serum, Thermo Fischer Scientific Life Sciences CA, USA) at 37°C with 5% CO_2. After 24 h of cells treatment with volatile oil in the final dilution 1:3000 and 1:10000, the cells were harvested from the substrate, stained with Tripan blue (Merck KGaA, Darmstadt, Germany), observed and quantified under light microscope [8].

2.7. Cell cycle assay

3 x 10^5 cells were plated in each well of 6 well plates and treated for 24 h with volatile oil in the final dilution 1:3000 and 1:1000. In order to evaluate cell cycle distribution, the cells were harvested from the substrate, fixed in 70% cold ethanol (Sigma Aldrich Co., St. Louis, USA) over night at -20°C, washed twice in PBS, and then incubated 15 min, at 37°C, with 1 mg/mL RNase A (ribonuclease A, Merck KGaA, Darmstadt, Germany), and 1 h with propidium iodide, 100 µg/mL (Merck KGaA, Darmstadt, Germany). The acquisition was done using Epics Beckman Coulter flow cytometer and data were analysed using FlowJo software [16].

2.8. Intracellular ROS production assay

The intracellular ROS production was measured *in vitro* by labelling eukaryotic cells with a fluorogenic dye, respectively 2',7'-dichlorofluorescein diacetate (DCFH-DA, Sigma-Aldrich Co., St. Louis, USA), a non-fluorescent compound which is split in a first step to DCFH (a non-fluorescent compound) by cellular esterases which is further oxidized by ROS or peroxidase into a green fluorescent product (DCF; λex = 504 nm, λem = 529 nm) [17,18]. The cells (1×10^6 cells/mL) were incubated with DCFH-DA (10 µM) for 30 min, then washed, incubated with H_2O_2 (40µM) (Sigma Aldrich Co., St. Louis, USA) with and without *S. canadensis* essential oil for 90 min. After incubation the cells were visualized by fluorescent microscopy (x 20 objective), calculating the fluorescence index: IF (%) = (no. fluorescing cells / no. total cells in visible) x100.

3. Results and discussions

3.1. Essential oil composition by GC-MS

The average content in the essential oil of *S. canadensis* samples (15 determinations) was 0.51 ± 0.11% (mL essential oil / 100 g plant). The essential oil was yellow with a specific odour. The medium density of the obtained essential oil was 0.45 ± 0.01 g/mL. The results are in line with the literature data, stating a range of 0.3-1.9% yields, depending on the time of harvest, physiological maturity period proved to be optimal [19]. Table 1 shows the relative content of volatile compounds from essential oil of *S. canadensis* growing in Romania, expressed as percentage from the total area and Figure 1 exhibits the essential oil chromatogram obtained by GC.

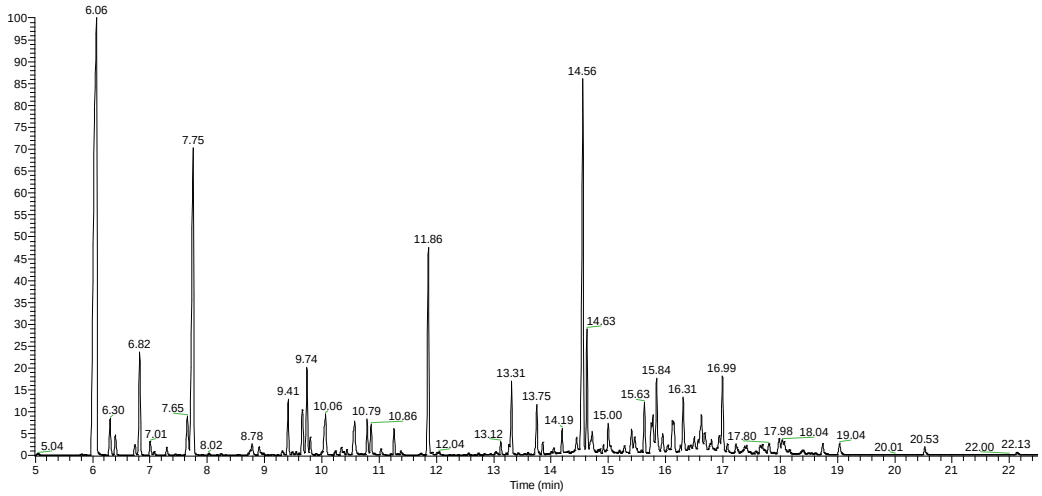

Figure 1. GC Chromatogram of *Solidago canadensis* essential oil

A number of 51 compounds were identified in *S. canadensis* essential oil, representing 96.30% of the total area and are similar to the data obtained by Amtmann et al. [7]. The essential oil contains monoterpene hydrocarbons (49.02%), sesquiterpene hydrocarbons (24.26%), monoterpene alcohols and ethers (7.13%), sesquiterpene alcohols and ethers (6.03%) and monoterpene carbonyl compounds (3.88%).

Table 1. Chemical composition of *S. canadensis* essential oils seen by GC-MS

Compound	RI	Relative area [%]
α-Thujene	930	0.09
α -Pinene	944	27.89
Camphene	957	1.10
Dehydrosabinene (2,4-Thujadiene)	963	0.66
Sabinene (β-Thujene)	981	0.31
β -Pinene	985	3.18
β-Myrcene	996	0.39
α-Phellandrene	1012	0.24
p-Cymene	1033	1.38
Limonene	1038	12.28
trans-β-Ocimene (*E*)	1054	0.07
γ-Terpinene	1067	0.05
p-Cymenene	1098	0.59
Linalool	1106	0.25
α-Campholenal	1138	1.46
trans-*p*-Menth-2,8-dien-1-ol	1142	0.08
cis-*p*-Menth-2,8-dien-1-ol	1147	0.08
trans-Pinocarveol	1154	1.51
cis-Verbenol	1159	2.48
trans-Verbenol	1179	1.62
p-Cymen-8-ol	1197	0.16
α-Terpineol	1203	0.15
Myrtenal	1212	1.49
Verbenone	1227	0.93

Compound	RI	Relative area [%]
trans-Carveol	1232	0.79
cis-Carveol	1244	0.17
Carvone	1260	0.66
Perilla aldehyde	1291	0.10
Bornyl acetate	1301	5.76
δ-EIemene	1352	0.05
α-Cubebene	1364	0.04
Cyclosativene	1387	0.15
α-Copaene	1393	0.33
β-Bourbonene	1404	0.10
β-Elemene	1408	2.24
cis-Jasmone	1417	0.07
α-Gurjunene	1430	0.04
E-*β*-Caryophyllene	1443	1.43
β-Gurjunene (calarene)	1450	0.31
Humulene (*α*-caryophyllene)	1477	0.68
γ-Muurolene	1498	0.62
Germacrene D	1507	13.17
β-Selinene	1513	3.02
α-Muurolene	1520	1.06
γ-Cadinene	1537	0.20
δ-Cadinene	1544	0.82
Spathulenol	1610	1.45
Caryophyllene oxide	1615	1.89
Viridiflorol	1651	0.13
δ-Cadinol	1689	0.46
6-Isopropenyl-4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-naphthalen-2-ol	1715	2.09
Total		96.30

RI = Kovats Index, measured relative to n-alkanes (C_8 – C_{20}) on a DB-5MS capillary column;
Relative area = relative contents expressed as percentages of the total oil composition.

The main identified compounds were *α*-pinene, germacrene D, limonene and bornyl acetate, these compounds have the largest relative areas, i.e. 27.89, 13.17, 12.28 and 5.76% respectively.

These results are broadly comparable to those obtained in various studies on *S. canadensis* volatile oil isolated from aerial parts [20–22], leaves [23] or roots [24] and similar with essential oil extracted from the inflorescences [6,8].

3.2. Antimicrobial activity

The qualitative testing of the microbial susceptibility to the essential oil from *S. canadensis* inflorescences revealed the presence of growth inhibition zones for both the reference and clinical, resistant microbial strains: *S. aureus, B. subtilis* (Figure 2), *P. aeruginosa, E. coli*, *K. pneumoniae, A. baumannii, E. faecalis, C. albicans* (Table 2). DMSO solvent used to solubilise the essential oil did not show any antimicrobial activity on the tested strains. These results are confirmed by other literature data [23–25].

The strains that have been proven susceptible to the studied essential oil in the qualitative assay were further studied to determine the MIC value (Table 2).

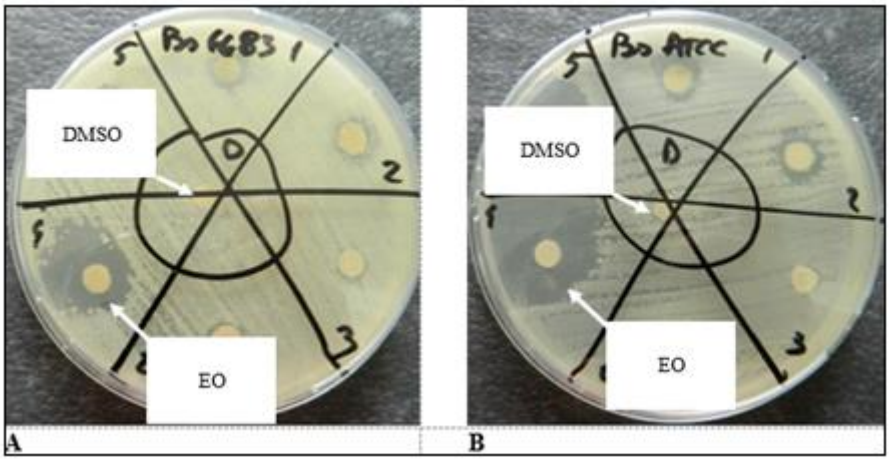

Figure 2. The appearance of the qualitative antimicrobial activities of the tested *S. canadensis* essential oil by disk diffusion method (plate **A**- *Bacillus subtilis* 6683, plate **B**- *Bacillus subtilis* ATCC)

Table 2. The antimicrobial and anti-adherent activity of essential oil obtained from *S. canadensis* inflorescence

Strains	Qualitative (mm)	Quantitative (MICs – mg/mL)	Minimum biofilm eradication concentration on inert substrate (mg/mL)	Adherence index to cellular substrate (%)		Adherence pattern (1 – localized; 2 – diffuse; 3 – aggregative)	
				EO	DMSO	EO	DMSO
S. aureus ATCC 6538	22.67±0.47	2.81	1.41	0.69	0.46	3	3
S. aureus MRSa1263	12.33±0.47	1.41	0.7	1.65	0	3	3
B. subtilis 12488	21.5±0.41	1.41	0.7	57.45	0	1	1
B. subtilis ATCC 6683	15±0.82	1.41	0.7	34.55	1.08	1	2
E. faecalis ATCC 29212	10.67±0.47	2.81	-	11.72	3.75	1	1
P. aeruginosa ATCC 27853	7±0.0	2.81	-	0.19	0.19	2	2
P. aeruginosa 134202	8±0.82	11.25	-	2.88	3.29	2	2
K. pneumoniae ATCC 134202	7.67±0.47	11.25	-	15.8	4.96	2	1
K. pneumoniae 11	8±0.82	22.5	-	15.93	0.62	1	2
E. coli ATCC 13202	8.33±0.47	11.25	-	50.22	5.24	1	1
E. coli $O_{126}B_{16}$	6.67±0.47	11.25	-	3.3	1.3	2	2
A. baumannii 77 sc	7.67±0.47	11.25	-	82.48	0.7	1	2
C. famata 945	8.33±0.47	5.63	2.81	-	-	-	-
C. albicans 393	7.67±0.47	5.63	-	-	-	-	-
C. utilis 15	-	-	-	-	-	-	-
C. famata CMGBy.14	-	-	-	-	-	-	-
C. albicans ATCC 101103	± *	2.81	0.7	-	-	-	-

*viable colony inside the diameter of inhibition; EO = essential oil; DMSO = dimethylsulfoxide.

The MIC of the essential oil varied between 1.41-2.81 mg/mL for the Gram-positive bacterial strains and was in the range of 2.81 - 22.5 mg/mL for the Gram-negative ones. The fact that Gram-negative bacteria are more resistant also reported by other literature data [23,26] correlates with the structural differences in the cell walls of Gram-negative and Gram-positive bacteria, the outer membrane of Gram-negative bacteria being an additional barrier for the active principles of *S. canadensis* essential oil. Similar results were obtained by Kolodziej et al. [26] for hexane and ethanolic extracts from *S.*

canadensis on the same Gram-positive bacterial strains (*S. aureus*, *B. subtilis*), with higher MIC values.

In Table 2 there are presented the MIC values and the concentrations which inhibited the adhesion capacity of microorganisms to an inert substrate.

The essential oil from *S. canadensis* inhibited the microbial ability to adhere to the inert substrate. These results suggested the capacity of the essential oil to interfere with the microbial adhesion which represents the initial stage of the infectious process, assuring the substrate colonization. The ability of adhesion to the inert substrate was inhibited only for the Gram-positive bacterial strains tested and for some of the yeasts strains (*C. albicans* and *C. famata*), at concentrations ranging from 0.70 to 2.81 mg/mL.

Adhesion to cellular substrate was carried out only for variants that showed antimicrobial activity in the quantitative assay. Thus, in the presence of *S. canadensis* essential oil, the microbial adhesion index ranged between 0.19 and 82.48% the most intensive inhibitory effect being noticed in the case of *A. baumannii* strain at a concentration of MIC/4 (Table 2). The adhesion type was modified from a diffuse to a localized pattern for *B. subtilis*, *K. pneumonia* and *A. baumannii* strains treated with subinhibitory concentrations of essential oil. The adhesion pattern remained aggressive for *S. aureus* strains.

3.3. Antioxidant activity

DPPH method was used to evaluate the antioxidant properties of essential oil compared to the action of thymol (a phenolic compound commonly found in essential oils with remarkable antioxidant properties). *S. canadensis* essential oil showed good free-radical scavenging activity (IC_{50}= 7.82 mg/mL) but lower than thymol (IC_{50}= 1.31 mg/mL). Although there are numerous data on the antioxidant activity of different types of *S. canadensis* extracts [27,28], essential oil has not been analysed from this point of view.

3.4. Cytotoxicity activity

The decrease in cell viability is usually related to two physiological phenomena, cell death and / or inhibition of cell division. The viability of cells treated with *S. canadensis* essential oil at the concentration of 0.15 mg/mL was 68.54%. Huang et al. [8] have already demonstrated that the essential oils showed mild *in vitro* cytotoxic activity against A-549, MDA-MB-435 and HepG2 cells, but the flow cytometry has never been applied for this type of essential oil.

3.5. Cell cycle assay

Flow cytometry assay was used to observe cell population distribution of cell cycle progression after treatment with *S. canadensis* essential oil for 24 h. The presence of *S. canadensis* essential oil (0.15 mg/mL) induced only a slow increase of S phase from 13.75 to 20.01%. The influence of *Solidago canadensis* essential oil on cell cycle has never been reported.

3.6. Intracellular ROS production assay

S. canadensis essential oil stimulated intracellular production of free radicals from 64.85% (for H_2O_2) to 93.59% (for H_2O_2 and essential oil) which suggests its promising potential to induce cytotoxic effects on tumor cells.

According with Huang et al. (2013), *S. canadensis* extracts play a fundamental role in stimulation of intracellular ROS in *Microcystis aeruginosa* cells, so it could have the same algistatic mechanisms as hydrophytes [29]. On the other hand, compounds that increase the intracellular accumulation of these radicals can be used in targeted therapy of tumor cells [30].

4. Conclusions

Our results demonstrated that among other biological activities, the essential oil extracted from *S. canadensis* inflorescence contains antimicrobial active compounds with selective activity on Gram-positive, Gram-negative bacterial and yeasts species and interfere with the microbial adhesion and

biofilm development on inert and cellular substrates. The ability of *Solidago canadensis* essential oil to generate an increased production of free radicals in tumoral cells has never been reported and suggests its anti-proliferative potential. Although there are a lot of preoccupation nowadays for the control of *S. canadensis* spread, exploiting its therapeutic potential could be a strategy and also an economical solution.

References

1.ABHILASHA, D., QUINTANA, N., VIVANCO, J., JOSHI, J., Do allelopathic compounds in invasive *Solidago canadensis* s.l. restrain the native European flora?, *J. Ecol.*, **96**(5), 2008, 993-1001. https://doi.org/10.1111/j.1365-2745.2008.01413.x
2.LI, J., LIU, H., YAN, M., DU, L., No evidence for local adaptation to salt stress in the existing populations of invasive *Solidago canadensis* in China, *PLoS One*, **12**(4), 2017, 1-13. https://doi.org/10.1371/journal.pone.0175252
3.ZHANG, C.B., WANG, J., QIAN, B. Y., LI, W. H., Effects of the invader *Solidago canadensis* on soil properties, *Appl. Soil Ecol.*, **43**(2–3), 2009, 163-169. https://doi.org/10.1016/j.apsoil.2009.07.001
4.GONG, Z., Genetic toxicity of *Solidago canadensis, Trends Genet. Evol.*, **1**(1), 2018, 1-4. https://doi.org/10.24294/tge.v1i1.309.
5. APÁTI, P., HOUGHTON, P. J., KITE, G., STEVENTON, G. B., KÉRY, A., In-vitro effect of flavonoids from *Solidago canadensis* extract on glutathione S-transferase, *J. Pharm. Pharmacol*., **58**(2), 2006, 251-256. https://doi.org/10.1211/jpp.58.2.0013
6.ELSHAFIE, H. S., GRUĽOVÁ, D., BARANOVÁ, B., CAPUTO, L., DE MARTINO, L., SEDLÁK, V., CAMELE, I., DE FEO, V., Antimicrobial activity and chemical composition of essential oil extracted from *Solidago canadensis* L. growing wild in Slovakia, *Molecules*, **24**(7), 2019, 1-12. https://doi.org/10.3390/molecules24071206
7.AMTMANN, M., The chemical relationship between the scent features of goldenrod (*Solidago canadensis* L.) flower and its unifloral honey, *J. Food Compos. Anal.*, **23**(1), 2010, 122-129. https://doi.org/10.1016/j.jfca.2009.10.001
8.HUANG, B., LEI, Y., QIN, L., LIU, J., Chemical composition and cytotoxic activities of the essential oil from the inflorescences of *Solidago canadensis* L., an invasive weed in Southeastern China, *J. Essent. Oil-Bear. Plants*, **15(**4), 2012, 667-671. https://doi.org/10.1080/0972060X.2012.10644103
9.SYNOWIEC, A., KALEMBA, D., DROZDEK, E., BOCIANOWSKI, J., Phytotoxic potential of essential oils from temperate climate plants against the germination of selected weeds and crops, *J. Pest Sci*., **90**(1), 2017, 407-419. https://doi.org/10.1007/s10340-016-0759-2
10.MAYRS, E. B. C. *British Pharmacopoeia*, 2017, Appendix 9 (vol IV) A238.
11.VAN DEN DOOL, H., KRATZ, P. D., A generalization of the retention index system including linear temperature programmed gas liquid partition chromatography, *J. Chromatogr*., **11**, 1963, 463-471. https://doi.org/10.1016/S0021-9673(01)80947-X
12. RĂDULESCU, V., SAVIUC, C., CHIFIRIUC, C., OPREA, E., ILIEŞ, D. C., MĂRUŢESCU, L., LAZĂR, V., Chemical composition and antimicrobial activity of essential oil from shoots spruce (*Picea abies* L), *Rev. Chim.*, **62**(1), 2011, 69-74.
13. HOLBAN, A. M., CHIFIRIUC, M. C., COTAR, A. I., BLEOTU, C., GRUMEZESCU, A. M., BANU, O., LAZĂR, V., Virulence markers in *Pseudomonas aeruginosa* isolates from hospital acquired infections occurred in patients with underlying cardiovascular disease, *Rom. Biotechnol. Lett*., **18**(6), 2013, 8843-8854.
14. FLEISZIG, S. M. J., ZAIDI, T. S., PRESTON, M. J., GROUT, M., EVANS, D. J., PIER, G. B., The relationship between cytotoxicity and epithelial cell invasion by corneal isolates of *Pseudomonas aeruginosa*, *Infect. Immun.*, **64**(6), 1996, 2288-2294.

15. ROBU, S., APROTOSOAIE, A. C., MIRON, A., CIOANCĂ, O., STĂNESCU, U., HĂNCIANU, M., *In vitro* antioxidant activity of ethanolic extracts from some *Lavandula* species cultivated in Romania, *Farmacia*, **60**(3), 2012, 394-401.
16. GRUMEZESCU, A. M., ANDRONESCU, E., FICAI, A., BLEOTU, C., MIHĂIESCU, D. E., CHIFIRIUC, M. C., Synthesis, characterization and in vitro assessment of the magnetic chitosan–carboxymethylcellulose biocomposite interactions with the prokaryotic and eukaryotic cells, *Int. J. Pharm.*, **436**(1–2), 2012, 771-777. http://dx.doi.org/10.1016/j.ijpharm.2012.07.063
17. BRATOSIN, D. *Explorarea structurii şi funcţiilor celulare prin citometrie în flux*, "Vasile Goldiş" University Press, Arad, 2007, 153-156.
18. KANUPRIYA, PRASAD, D., RAM, M. S., KUMAR, R., SAWHNEY, R. C., SHARMA, S. K., ILAVAZHAGAN, G., KUMAR, D., BANERJEE, P. K., Cytoprotective and antioxidant activity of *Rhodiola imbricata* against tert-butyl hydroperoxide induced oxidative injury in U-937 human macrophages, *Mol. Cell. Biochem.*, **275**(1–2), 2005, 1-6.
19.KALEMBA, D., GÓRA, J., KUROWSKA, A., Analysis of the essential oil of *Solidago canadensis*, *Planta Med.*, **56**(2), 1990, 222-223. http://dx.doi.org/10.1055/s-2006-960930
20. KALEMBA, D., THIEM, B., Constituents of the essential oils of four micropropagated *Solidago* species, *Flavour Fragr. J.*, **19**(1), 2004, 40-43. https://doi.org/10.1002/ffj.1271
21.GRUĽOVÁ, D., BARANOVÁ, B., IVANOVA, V., DE MARTINO, L., MANCINI, E., DE FEO, V., Composition and bio activity of essential oils of *Solidago* spp. and their impact on radish and garden cress, *Allelopath. J.*, **39**(2), 2016, 129.
22.SHELEPOVA, O., VINOGRADOVA, Y., ZAITCHIK, B., RUZHITSKY, A., GRYGORIEVA, O., BRINDZA, J. Potravin. Slovak J., Constituents of the essential oil in *Solidago canadensis* L. from Eurasia, *Food Sci.*, **12**(1), 2018, 20-25. https://dx.doi.org/10.5219/847
23.MISHRA, D., JOSHI, S., SAH, S. P., BISHT, G., Chemical composition, analgesic and antimicrobial activity of *Solidago canadensis* essential oil from India, *J. Pharm. Res.*, **4**(1), 2011, 63-66.
24. MISHRA, D., JOSHI, S., BISHT, G., PILKHWAL, S., Chemical composition and antimicrobial activity of *Solidago canadensis* Linn. root essential oil, *J. Basic Clin. Pharm.*, **1**(3), 2010, 187-190.
25.CHAO, S., YOUNG, G., OBERG, C., NAKAOKA, K., Inhibition of methicillin-resistant *Staphylococcus aureus* (MRSA) by essential oils, *Flavour Fragr. J.*, **23**(6), 2008, 444-449. https://doi.org/10.1002/ffj.1904
26. KOŁODZIEJ, B., Kowalski, R., Kędzia B., Antibacterial and antimutagenic activity of extracts aboveground parts of three *Solidago* species: *Solidago virgaurea* L., *Solidago canadensis* L. and *Solidago gigantea* Ait., *J. Med. Plants Res.*, **5**(31), 2011, 6770-6779. https://doi.org/10.5897/JMPR11.1098
27.WOŹNIAK, D., ŚLUSARCZYK, S., DOMARADZKI, K., DRYŚ, A., MATKOWSKI, A., Comparison of polyphenol profile and antimutagenic and antioxidant activities in two species used as source of *Solidaginis herba* – Goldenrod, *Chem. Biodivers.*, **15**(4), 2018, 1-16. https://doi.org/10.1002/cbdv.201800023.
28. APÁTI, P., HOUGHTON, P. J., KÉRY, A., HPLC investigation of antioxidant components in *Solidago herba*, *Acta Pharm. Hung.*, **74**(4), 2004, 223-231.
29.HUANG, Y., BAI, Y., WANG, Y., KONG, H., Allelopathic effects of the extracts from an invasive species *Solidago canadensis* L. on *Microcystis aeruginosa*, *Lett. Appl. Microbiol*, **57**(5), 2013, 451-458. https://doi.org/10.1111/lam.12133
30. ZHU, C., HU, W., WU, H., HU, X., No evident dose-response relationship between cellular ROS level and its cytotoxicity – a paradoxical issue in ROS-based cancer therapy, *Sci. Rep.*, **4**, 2014, 1-10. https://doi.org/10.1038/srep05029

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