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STUDIES REGARDING THE ANTIOXIDANT ACTIVITY OF SOME BIOPRODUCTS OBTAINED FROM *CURCUMA LONGA* AND *ZINGIBER OFFICINALE* RHIZOMES

Magdalina Ursu[1], Nicoleta Radu[1,2*], Lucia Camelia Pirvu[3], Narcisa Elena Babeanu[1], Raluca Madalina Senin[2], Mihaela Begea[4]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Biotechnology, 59 Marasti Boulevard, District 1, Bucharest, Romania
[2]National Institute of Chemistry and Petrochemistry, R&D of Bucharest, Biotechnology Department, 202 Splaiul Independentei, District 6, Bucharest, Romania
[3]National Institute of Pharmaceutical Chemistry R&D, Bucharest, 112 Calea Vitan, District 3, Bucharest, Romania
[4]National University of Sciences and Technology POLITEHNICA Bucharest, Faculty of Biotechnical Systems Engineering, 313 Splaiul Independentei, District 6, Bucharest, Romania

*Corresponding author: nicoleta.radu@biotehnologii.usamv.ro

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Abstract: The study aimed to investigate the chemical composition and antioxidant activity of extracts and essential oils obtained from the rhizomes of *Zingiber officinale* (ginger) and *Curcuma longa* (turmeric). Gas chromatography coupled with mass spectrometry was used to evaluate the chemical composition, while chemiluminescence was employed to assess antioxidant properties. The results indicated that the ginger extract obtained from ginger rhizomes and chloroform had the highest polyphenol content (398 ± 7.56 mg GAE·L^{-1}) and exhibited superior antioxidant activity compared to all tested bioproducts, with IC_{50} = 0.000625 µL·mL^{-1} at t = 5 s and IC_{50} = 0.053 L·mL^{-1} at t = 60 s. Ginger essential oils demonstrated greater antioxidant properties than those obtained from turmeric rhizomes, due to their higher content of geraniol and nerol. In conclusion, the essential oils and crude extracts from ginger rhizomes in chloroform exhibited the highest antioxidant activity, attributed to polyphenolic compounds and bioactive molecules such as geraniol and nerol.

Keywords: *antioxidant properties, bioproducts, curcuma, ginger*

INTRODUCTION

To maintain the functionality of vital systems, the body naturally produces certain amounts of free radicals during cellular metabolism. Although free radicals are physiologically generated within the body, their excessive production poses a significant health risk. Their accumulation leads to the phenomenon known as oxidative stress, a major cause of cellular tissue damage. This phenomenon is involved in the initiation and progression of chronic conditions such as cancer, neurological disorders, diabetes mellitus, neurodegenerative diseases, and cardiovascular conditions [1, 2]. To counteract oxidative stress, the human body requires antioxidants, which can either be synthesized endogenously in situ or absorbed exogenously through diet and/or nutritional supplements [1]. Antioxidant compounds act on free radicals by interrupting chain reactions or inhibiting other oxidation processes, resulting in the neutralization of free radicals and the formation of stable molecules [3]. The plant-derived bioproducts have been the subject of numerous studies; among these, essential oils [4 – 6] and natural extracts [7, 8] are widely used and are attracting growing interest due to their free radical-neutralizing properties [9]. The essential oils obtained from turmeric (*Curcuma longa*) and ginger (*Zingiber officinale*) rhizomes stand out due to their rich chemical composition of bioactive compounds, which are associated with health benefits [10]. Turmeric is well known for its anti-inflammatory and antioxidant properties. The ginger rhizomes, an essential ingredient in traditional Asian medicine, contain a large variety of compounds with significant biological activity [11, 12]. The present study aimed to evaluate the antioxidant activity of two biopreparations obtained through chloroform extraction from ginger and turmeric rhizomes, as well as some essential oils obtained from turmeric and ginger rhizomes, purchased from two different producers: NJoy and Oleya.

MATHERIALS AND METHODS

Essential oils

The ginger and turmeric essential oils used in this study were purchased from the local market (Plafar, Bucharest), supplied by two companies: NJoy and Oleya. Fresh ginger rhizomes of Chinese origin and fresh turmeric rhizomes from Peru (both grown in organic agriculture), were sourced from the Romanian market.

Extraction

Fresh ginger and turmeric rhizomes were cleaned, washed, and cut into small pieces. The prepared plant material was placed in brown glass containers and fully submerged in chloroform. Chloroform was used as a solvent for extraction due to its intermediate polarity and strong solvating power enable it to dissolve a wide range of bioactive compounds, including terpenoids, fatty acids, sterols, chlorophylls, and certain alkaloids in their free-base form [13]. The maceration process was carried out in the dark for two weeks at room temperature, with manual shaking every two days. After two weeks, the liquid phase was separated by filtration using a 150 mm diameter filter paper (Prat Dumas, France, Solantis). Chloroform was removed by evaporation at 50 °C using a rotary

evaporator (Heidolph, Schwabach, Germany). The crude extract obtained after chloroform removal (crude extract of ginger GC; crude extract of curcuma, TC) was resuspended in a minimal volume of dimethyl sulfoxide (DMSO) and stored in the dark.

Total polyphenol content evaluation

The total polyphenol content of the chloroform extracts was determined using the Folin–Ciocalteu method, following the protocol described by Agbor *et al*. [14]. The samples were treated with Folin–Ciocalteu reagent (Merck, Bucharest, Romania) and a saturated sodium carbonate solution (Na_2CO_3), then stored in the dark. After two hours, the absorbance of the samples was measured at 765 nm using a Jenway 6305 UV-VIS spectrophotometer (AMEX, Bucharest, Romania). The results were expressed in milligrams of gallic acid equivalents per liter (mg GAE·mL^{-1}). The total polyphenol content values of the chloroform extracts (coded GC for ginger and TC for turmeric) are presented in Table 1.

Antioxidant activity evaluation

The antioxidant activity was determined by chemiluminescence [15], according to the methodology detailed by Zaharie *et al*. [7]. The reagents used in the chemiluminescence studies were the following: saturated sodium carbonate solution (Merck, Bucharest, Romania) prepared in bidistilled water; gallic acid (Merck, Bucharest, Romania); chloroform (Sigma-Aldrich, Bucharest, Romania); dimethyl sulfoxide (DMSO) (Sigma-Aldrich, Bucharest, Romania); luminol (Sigma-Aldrich, Bucharest, Romania) at a concentration of 2.5×10^5 M in DMSO; hydrogen peroxide (Merck, Bucharest, Romania) 30 mM solution; and TRIS-HCl buffer solution (Sigma-Aldrich, Bucharest, Romania), 50 mM, *p*H 8.5. Chemiluminescence measurements were conducted using a GLOMAX 20/20-PROMEGA chemiluminometer (Madison, USA), operated $\lambda = 430$ nm.

Compounds assay analysis from essential oils and the extracts of turmeric and ginger rhizomes

The chemical composition of the essential oils and extracts of ginger and turmeric was analysed using a gas chromatograph coupled with a mass spectrometer (GC-MS), model Clarus 500 (Perkin Elmer, Shelton, Connecticut, USA). Separation was performed on a 60 m long capillary column with an internal diameter of 0.32 mm. The injector temperature was set at 250 °C. Helium was used as the carrier gas at a constant flow rate of 1 mL·min^{-1}. The initial oven temperature was set at 100 °C and increased by 4 °C·min^{-1} to a final temperature of 280 °C.

Statistical analysis

All determinations were performed in triplicate for each sample. The results are presented as average value with their corresponding standard deviations.

RESULTS AND DISCUSSIONS

The evaluation of the total polyphenol content of the two crude extracts obtained in chloroform and dissolved in DMSO (Table 1) showed that the bioproducts obtained from ginger rhizomes have the highest polyphenol content (398 ± 7.56 mg GAE·L^{-1}). The extract obtained from turmeric rhizomes contains (12.48 ± 0.12 mg GAE·mL^{-1}).

Table 1. *Bioproducts used in studies: type of bioproducts, abbreviation name, source, and polyphenols content*

Bioproduct	Abbreviation name	Content of polyphenols [mg GAE·mL^{-1} ± STDEV]	Source
Zingiber officinale (ginger rhizoma)	GC	398±7.56	China
Curcuma longa (turmeric rhizoma)	TC	12.48±0.12	Peru
Essential derived from rhizome of *Zingiber officinale* NJoy	E.O-1.1	-	Plafar Bucharest Romania
Essential derived from rhizome of *Zingiber officinale* Oleya	E.O-1.2	-	
Essential derived from rhizome of *Curcuma longa* Oleya	E.O-2.1	-	
Essential derived from rhizome of *Curcuma longa NJoy*	E.O-2.2	-	

The chemical composition analysis of turmeric and ginger essential oils, as well as the chloroform extracts obtained from the rhizomes of these plants, was performed by gas chromatography coupled with mass spectrometry (GC-MS). The chromatograms corresponding to the analyzed essential oils and extracts are shown in Figure 1a – f. Based on retention times and mass spectra, the compounds in each sample were identified using the NIST database, and their relative content was expressed as a percentage. In the ginger essential oil provided by NJoy (E.O-1.1; Table 2), 16 compounds were identified (Figure 1a), with the major constituents being geraniol and nerol. In the ginger essential oil supplied by Oleya (E.O-1.2; Figure 1b, Table 2), eight compounds were identified, predominantly zingiberene, cedrene, and himachalene. The turmeric essential oil from Oleya (E.O-2.1; Table 2, Figure 1c) contains nine identified compounds, while that from NJoy (E.O-2.2; Table 2, Figure 1d) contains six compounds. The major compounds common to both turmeric samples were ar-turmerone and turmerone. Regarding the crude extracts, obtained from chloroform, in the turmeric extract (TC; Figure 1e) dominate turmerone, an isomer of turmerone, and curlone dominate. In the ginger extract (GC; Figure 1f), the major compounds found were trans-α-bergamotene, substituted benzene (1-(1,5-dimethyl-4-hexenyl)-4-methyl), and (E)-β-farnesene.

The antioxidant activity (A.A.) of ginger essential oils was evaluated for two types of commercial bioproducts: NJoy (E.O-1.1) and Oleya (E.O-1.2). The results obtained from tests performed over a concentration range of (0.39 ÷ 50) µL·mL^{-1} revealed significant differences depending on the manufacturer and the time of measurement. For the E.O-1.1 bioproduct, the antioxidant activity values determined at the start of the reaction (t = 5 s) (Figure 2a) varied between 64.94 % and 90.51 %.

Table 2. *The GC-MS analyses of the bioproducts derived from ginger and turmeric rhizomes*

Nr. crt.	Compound	Concentration [%]	Retention time [minutes]
Essential oil of ginger NJoy (E.O-1.1)			
1.	Geraniol	40.43	13.992
2.	Nerol	21.86	13.465
3.	Geraniol acetate	7.15	12.978
4.	Elemicin	6.89	17.756
5.	Caryophyllene	3.76	11.168
6.	*Trans*-p-Mentha-2,8-dineol	3.39	11.477
7.	Borneol	3.2	12.353
8.	Carveol	2.98	14.426
9.	Limonene	2.74	5.692
10.	*Cis*-p-Mentha-2,8-dineol	2.02	11.984
11.	Eucalyptol	1.57	5.81
12.	Linalool	1.52	10.444
13.	Camphene	1.08	3.79
14.	α-Pinene	0.64	3.316
15.	Terpinolene	0.59	6.929
16.	γ-Terpinene	0.17	3.158
Essential oil of ginger Oleya (E.O-1.2)			
1.	Zingiberene	47.31	12.662
2.	Cedrene	29.13	13.215
3.	Himachalene	10.46	12.708
4.	Farnesene	6.35	12.912
5.	Eucalyptol	4.25	5.823
6.	Camphene	1.65	3.79
7.	α-Pinene	0.5	3.316
8.	β-Pinene	0.36	5.185
Essential oil of turmeric Oleya (E.O-2.1)			
1.	Ar-tumerone	37.35	18.053
2.	Tumerone	18	17.342
3.	Terpinolene	11.19	6.936
4.	α-Curcumene	9.17	13.195
5.	Zingiberene	7.89	12.59
6.	Curlone	6.25	17.928
7.	Cedrene	4.35	13.149
8.	Himachalene	4.09	12.241
9.	Germacron	1.7	18.691
Essential oil of turmeric NJoy (E.O-2.2)			
1.	Ar-tumerone	44.61	18.033
2.	Tumerone	23.91	17.328
3.	Curlone	19.92	17.921
4.	α-Curcumene	5.44	13.182
5.	Cedrene	3.53	13.142
6.	Germacron	2.58	18.691

***Table* 2.** *Continuation*

Nr. crt.	Compound	Concentration [%]	Retention time [minutes]
Crude extract of turmeric (TC)			
1.	Tumerone	32.9	15.54
2.	Tumerone, izomer	16.9	15.61
3.	Curlone	16.1	16.09
4.	(E)-Atlantone	1.66	17.09
5.	(6R, 7R)-Bisabolene	0.68	16.63
Crude extract of ginger (GC)			
1.	Trans, -alpha-Bergamotene	21.2	12.99
2.	Benzene, 1-(1,5-dimethyl-4-hexenyl)-4-methyl	15.2	12.83
3.	(E)-*β*-Farnesene	11.0	13.42
4.	*β*-Bisabolene	5.28	13.17
5.	*γ*-Muurolene	1.98	13.28

After 60 s (Figure 2b), the antioxidant activity decreased, with values ranging between 43.90 % and 83.51 % over the same concentration range.

In the case of essential oil E.O-1.2, for a concentration range of (0.097 ÷ 12.5) $\mu L \cdot mL^{-1}$, the antioxidant activities determined at 5 s (Figure 3a) varied between 36.52 % and 89.08 %. At a concentration of 25 $\mu L \cdot mL^{-1}$, a pro-oxidant effect was observed (A.A. < 0). After 60 seconds (Figure 3b), for the same concentration range, the essential oil exhibited antioxidant properties, with A.A. values ranging from 7.55 % to 67.93 %. In contrast, for concentrations ranging between 12.5 and 50 $\mu L \cdot mL^{-1}$, the ginger essential oil obtained from Oleya showed a pro-oxidant effect (A.A. < 0). Regarding the antioxidant activity of the two essential oils obtained from turmeric rhizomes, for Oleya (E.O-2.1) and NJoy products (E.O-2.2), the results were as follows:

1) in the case of the essential oil E.O-2.1, tests conducted over a concentration range of (0.097 ÷ 50) $\mu L \cdot mL^{-1}$, showed that, at the start of the process (5 seconds) (Figure 4a), antioxidant activity values ranged between 82.96 % and 96.62 %. After 60 seconds (Figure 4 b), within the same concentration range, the antioxidant activities varied between 82.89 % and 94.72 %, indicating that the antioxidant activity remained relatively constant;

2) for essential oil E.O-2.2, at 5 seconds (Figure 5a), the antioxidant activity values ranged between 80.99 % and 95.2 %. At the end of the process (60 seconds), the antioxidant activities showed slightly lower values, ranging between 60.83 % and 91.34 % (Figure 5 b).

The evaluation of antioxidant capacity, based on the IC_{50} values obtained, shows that:

1) the essential oil E.O-1.1 appears to be the most potent antioxidant agent (Figure 6), with an IC_{50} of 0.000625 $\mu L \cdot mL^{-1}$, at t = 5 s and 0.053 $\mu L \cdot mL^{-1}$, at t = 60 s. It is important to note that, in this case, the correlation coefficients for the chosen mathematical model were below 0.5 (Table 3);

2) In second place is the essential oil E.O-1.2 (Figure 6), which showed an IC_{50} of 6.64 $\mu L \cdot mL^{-1}$ at t = 5 s and 1.69 $\mu L \cdot mL^{-1}$ at t = 60 s;

3) Third is the essential oil E.O-2.1 (Figure 6), with an IC_{50} value of 47.939 $\mu L \cdot mL^{-1}$ at t = 5 s, followed by the turmeric essential oil purchased from NJoy, which had an IC_{50} of 72.64 $\mu L \cdot mL^{-1}$ at t = 60 s;

4) Fourth is the essential oil E.O-2.2 (Figure 6), with an IC_{50} of 97.759 µL·mL^{-}at t = 60 s, followed by the turmeric essential oil from NJoy, which had an IC_{50} of 102.35 µL·mL^{-1}, at t = 5 s.

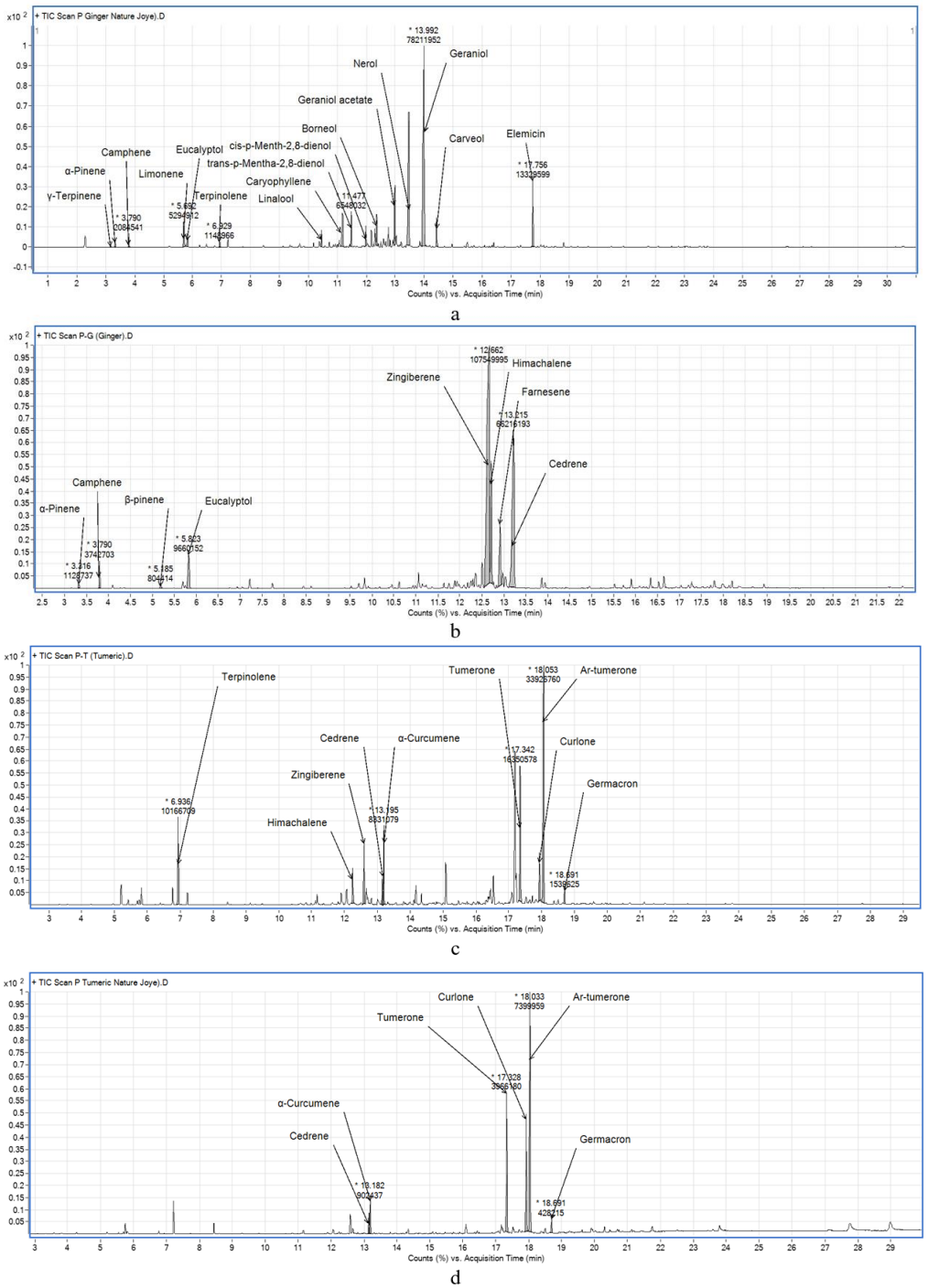

Figure 1. *Chromatograms derived from GC-MS analysis: a) ginger essential oil NJoy: E.O-1.1; b) ginger essential oil NJoy E.O-1.2; c) turmeric essential oil from Oleya: E.O-2.1d) turmeric essential oil from NJoy: E.O-2.2*

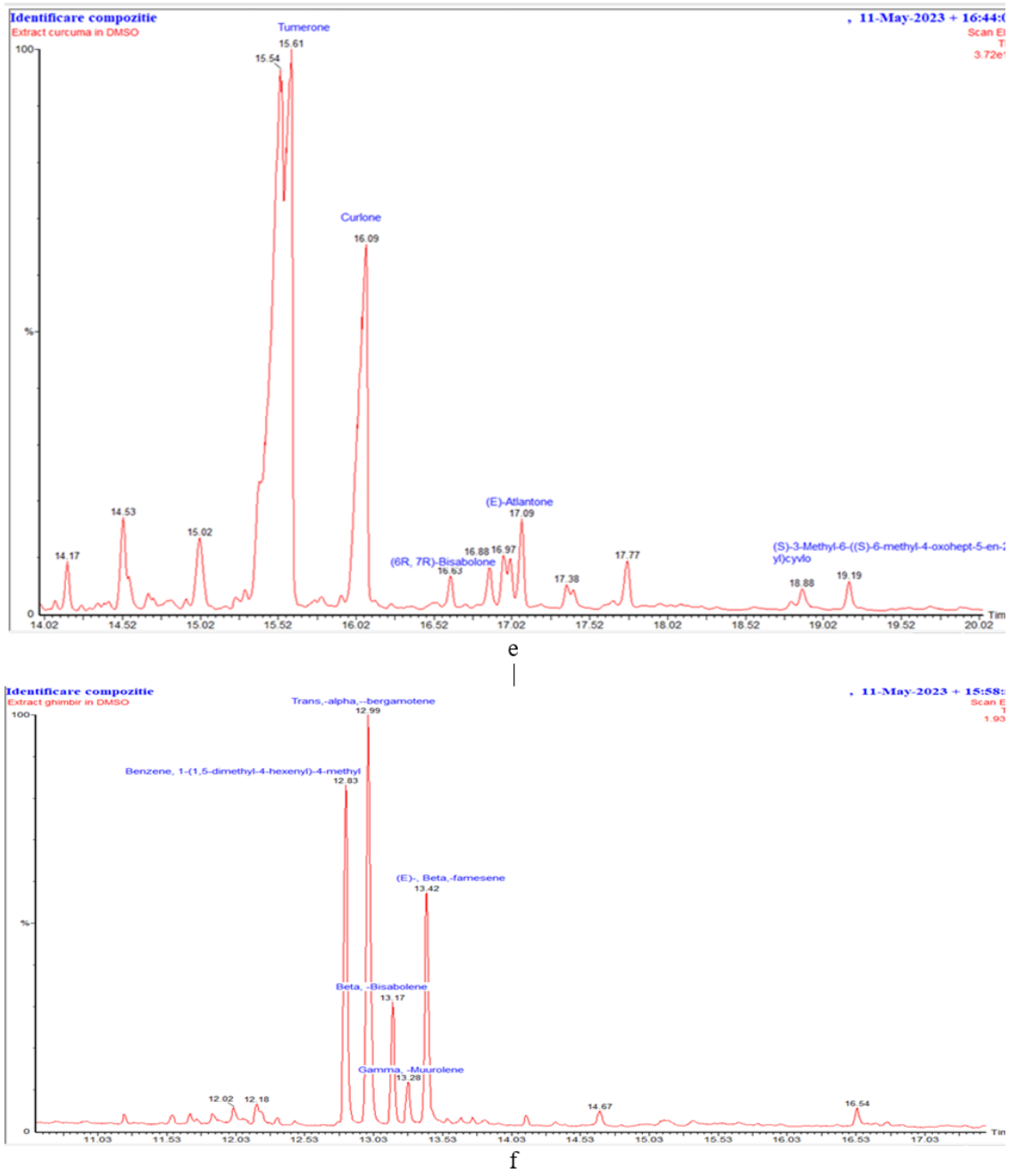

Figure 1. *Continuation Chromatograms derived from GC-MS analysis: e) crude extract of turmeric (TC); f) crude extract of ginger (GC)*

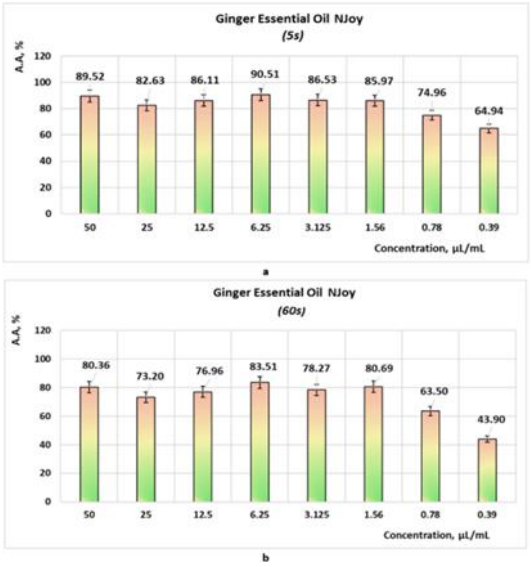

Figure 2. *Antioxidant activity of essential oil obtained from ginger rhizomes from NJoy (E.O-1.1), at: a) t = 5 s; b) t = 60 s*

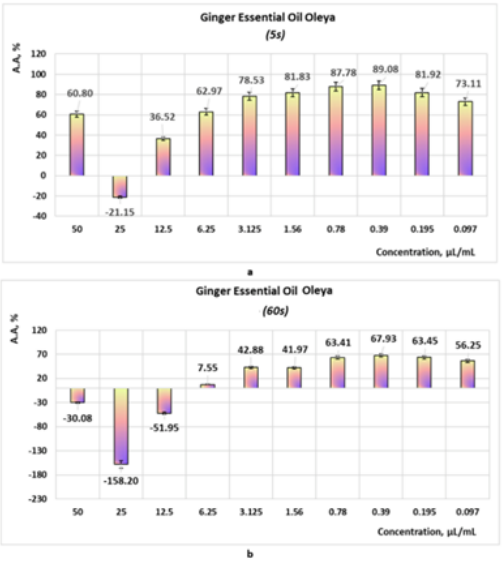

Figure 3. *Antioxidant activity of essential oil obtained from ginger rhizomes from Oleya (E.O-1.2), at: a) t = 5 s; b) t = 60 s*

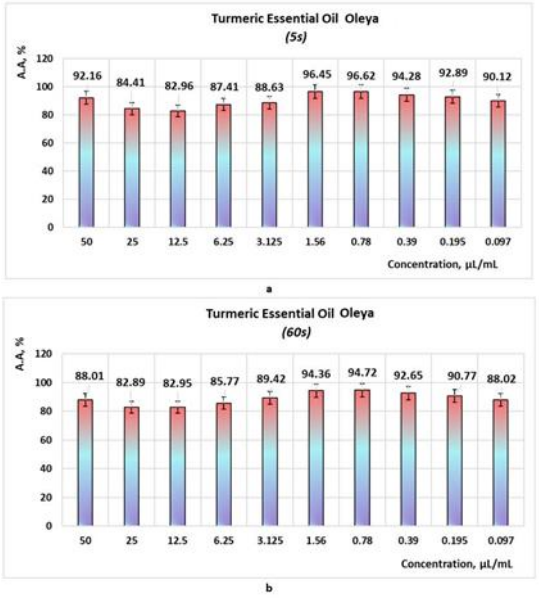

Figure 4. *Antioxidant activity of the essential oil obtained from turmeric rhizomes from Oleya (E.O-2.1), at: a) t = 5 s; b) t = 60 s*

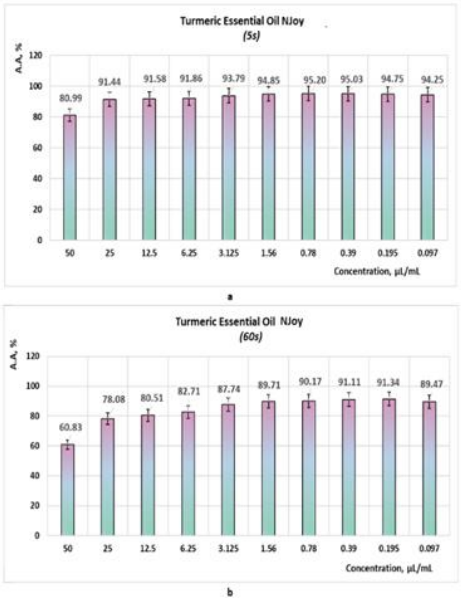

Figure 5. *Antioxidant activity of essential oil obtained from ginger rhizomes from Oleya (E.O-1.2), at: a) t = 5 s; b) t = 60 s*

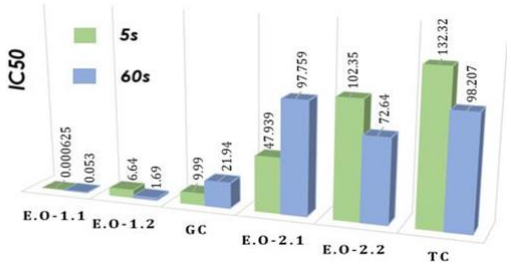

Figure 6. *Evaluation of the antioxidant activity of the studied bioproducts through the IC_{50} values at t = 5 s and t = 60 s, respectively*

Antioxidant activities of crude extracts obtained in chloroform

The chemiluminescence tests performed to evaluate the antioxidant activity of the crude extract obtained from *C. longa* rhizomes and chloroform showed the following:
1) At the beginning of the process (5 s), the antioxidant activity for an extract concentration range between 0.39 ÷ 50 µL·mL^{-1}, ranging between 91.35 ÷ 96.15 % (Figure 7a);
2) At the end of the process (60 s), for the same concentration range, antioxidant activities vary between 69.43 ÷ 87.8 % (Figure 7b).
In the case of the bioproducts obtained from *Z. officinale* rhizomes in chloroform, chemiluminescence studies indicate:
1) After 5 s (Figure 8a), for an extract concentration range between 0.39 ÷ 1.56 µL·mL^{-1}, the bioproducts exhibit pro-oxidant effects (A.A. < 0). In contrast, over a concentration range between 3.125 and 50 µL·mL^{-1}, it exhibits antioxidant properties, with A.A. values varying between 41.6 ÷ 79.11 %;
2) At 60 s (Figure 8b), the range in which the sample exhibits pro-oxidant character extends to include concentrations between 0.39 and 3.125 µL·mL^{-1}.

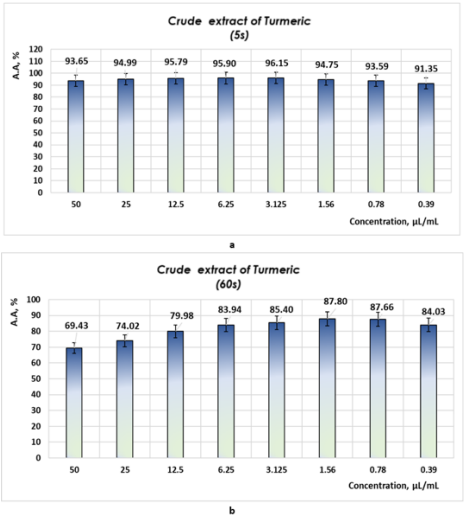

Figure 7. *Antioxidant activity of the crude extract obtained in chloroform from Curcuma longa rhizomes at: a) at t = 5 s; b) at t = 60 s*

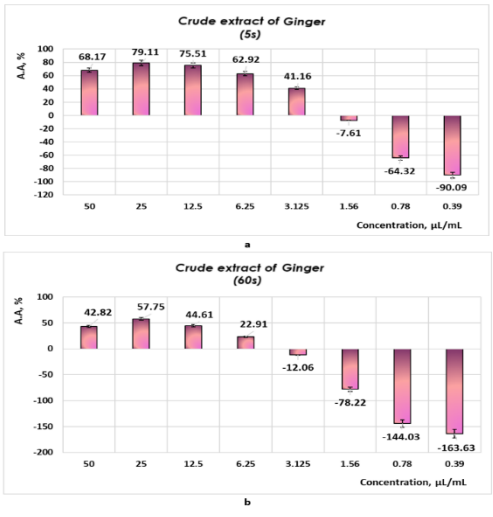

Figure 8. *Antioxidant activity of the crude extract obtained in chloroform from Zingiber officinale rhizomes at: a) t = 5 s; b) t = 60 s*

At concentrations between 6.25 ÷ 50 µL·mL^{-1} the bioproduct continues to exhibit antioxidant activity, the A.A. values varying between 22.91 ÷ 57.75 %. Regarding antioxidant activity, the best results were obtained for the ginger extract (bioproduct obtained from ginger rhizomes and chloroform), for which an IC_{50} of 9.99 µL·mL^{-1} was measured at 5 s; after 60 s, IC_{50} increased to 21.94 µL·mL^{-1} (Figure 6, Table 3). The second-best results were obtained for the crude extract from turmeric rhizomes in chloroform, with an IC_{50} of 98.21 µL·mL^{-1}.

Table 3. *Evaluation of the antioxidant effect of the studied bioproducts*

Bioproduct	Math function / R^2	IC_{50} [µL·mL^{-1}]	Time [s]	Observations
EO - 1.1	y = a ln(x) + b R^2 = 0.5283	0.00063	5	The best antioxidant activity; The values of correlation coefficients are small.
	y = a ln(x) + b R^2 = 0.4389	0.053	60	
E.O - 1.2	y = ax^2+bx+c R^2 = 0.9017	6.64	5	Lower antioxidant activity compared to ginger essential oil. Antioxidant activity is better after t = 60 s. Correlation coefficients with high values.
	Y = ax^2+bx+c R^2 = 0.9653	1.69	60	
E.O- 2.1	y = ax + b R^2 = 0.6925	47.94	5	Lower antioxidant activity compared to ginger essential oils. Low values for correlation coefficients.
	y = ax + b R^2 = 0.6115	97.76	60	
E.O - 2.2	y = ax^2+bx+c R^2 = 0.9472	102.35	5	Lower antioxidant activity compared to the essential oil produced by Oleya. Antioxidant activities are better at t = 60 s. High values for correlation coefficients.
	y = ax^2+bx+c R^2 = 0.9629	72.64	60	
TC	y = ax^2+bx+c R^2 = 0.3052	132.32	5	The weakest anti-oxidant activity of all the tested bio-products. The math model chosen for evaluating IC_{50} at 5 s is unsuitable (R^2 < 0.8).
	y = -ax + b R^2 = 0.9156	98.21	60	
GC	y = a ln(x) - b R^2 = 0.8391	9.99	5	Good antioxidant activity. Relatively suitable math model; the correlation coefficients R^2 > 0.8.
	y = a ln(x) - b R^2 = 0.886	21.94	60	

Gas chromatography coupled with mass spectrometry analysis of essential oils and chloroform crude extracts obtained from the rhizomes of *Zingiber officinale* and *Curcuma longa* led to the identification of potentially bioactive compounds, including monoterpenes and sesquiterpenes. Among the monoterpenes identified in NJoy ginger essential oil (E.O-1.1), geraniol and nerol are well known for their antioxidant properties. Malik *et al*. [16], in their studies on geraniol, demonstrated its ability to reduce oxidative stress and inflammation, protecting against inflammatory arthritis. Similarly, Prasad and Muralidhara [17] proposed the potential use of geraniol as an adjuvant in the prevention of neurodegenerative diseases, highlighting its efficiency in scavenging free radicals, reducing lipid peroxidation, and protecting nerve cells from hyperglycemia-induced

oxidative stress. Regarding the antioxidant activity of nerol, Mondal *et al.* [18] demonstrated that it protects the liver from damage caused by toxic substances such as carbon tetrachloride, by reducing oxidative stress and enhancing the activity of antioxidant enzymes, thereby improving liver function. The antioxidant activity observed in NJoy ginger essential oil (E.O-1.1), which contains geraniol and nerol as major components, is consistent with these previously reported findings [16 – 18]. Among all tested samples, NJoy ginger essential oil exhibited the highest antioxidant activity, with the lowest IC_{50} value (IC_{50} = 0.000625 µL·mL^{-1}) at 5 seconds. This strong antioxidant activity remained high even after 60 seconds (IC_{50} = 0.053 µL·mL^{-1}) making this essential oil the most effective among the studied bioproducts. The strong antioxidant properties of geraniol and nerol can be attributed to their molecular structures - specifically, the presence of hydroxyl groups capable of donating a proton and conjugated double bonds that stabilize the radicals temporarily formed after deprotonation. These structural features enable them to neutralize reactive oxygen species such as ROO· and OH· through proton transfer mechanisms [19]. Oleya ginger essential oil (E.O-1.2) exhibited lower antioxidant activity compared to that produced by NJoy (E.O-1.1), due to the predominant presence of the sesquiterpenes zingiberene, cedrene, and himachalene, which possess a more limited antioxidant potential compared to oxygenated monoterpenes such as geraniol and nerol [20].

Regarding turmeric essential oils, both bioproducts - Oleya (E.O-2.1) and NJoy (E.O-2.2) - contain significant concentrations of turmerones (ar-turmerone, turmerone, and curlone). At t = 5 s, the turmeric essential oil from Oleya (E.O-2.1) showed an IC_{50} value of 47.94 µL·mL^{-1}, which is nearly half that of the essential oil from NJoy (E.O-2.2), which exhibits an IC_{50} value of 102.35 µL·mL^{-1}. This suggests a higher antioxidant activity in the Oleya bioproducts. At 60 seconds, the IC_{50} values for the two turmeric essential oils were relatively close (E.O-2.1: IC_{50} = 97.759 µL·mL^{-1}); E.O-2.2: IC_{50} = 72.64 µL·mL^{-1}). The differences observed between E.O-2.1 and E.O-2.2 in terms of antioxidant activity can be correlated with variations in their chemical compositions. Qiang *et al.* [21] demonstrated that the phytochemical profile of turmeric essential oils varies depending on the cultivar, significantly influencing both the content of volatile compounds and the ability to neutralize free radicals. These variations can result in either a more rapid or delayed antioxidant response, depending on the predominance of specific sesquiterpene types. The results obtained regarding total polyphenol content and antioxidant activity suggest that the chloroform extract from fresh ginger rhizomes exhibits a superior antioxidant capacity compared to the chloroform extract from fresh turmeric rhizomes. The IC_{50} values for the ginger extract were significantly lower than those for the turmeric extract, indicating a more efficient and faster inhibition of free radicals by the compounds present in the ginger extract. These findings are consistent with the studies conducted by Panpatil *et al.* [22], which reported higher antioxidant activity for ginger extract compared to turmeric extract. Maizura *et al.* [23] also observed a correlation between polyphenol content and antioxidant activity. They found better antioxidant activity in ginger extract, which had a polyphenol content of 101.6 ± 0.6 mg GAE·100 g^{-1} compared to turmeric extract, which contained 67.9 ± 1.0 mg GAE·100 g^{-1}. In the present study, the polyphenol content of the ginger extract was 398 ± 7.56 mg GAE·L^{-1}, while that of the turmeric extract was 12.48 ± 0.12 mg GAE·L^{-1}.

CONCLUSIONS

The study conducted on bioproducts obtained through chloroform extraction from turmeric rhizomes, as well as on two types of essential oils produced by NJoy and Oleya from turmeric and turmeric rhizomes, revealed significant differences in both chemical composition and antioxidant activity. Ginger essential oil produced by NJoy exhibited the highest antioxidant activity (IC_{50} = 0.000625 µL·mL^{-1} at 5 s and IC_{50} = 0.053 µL·mL^{-1} at 60 s), which is attributed to its high content of geraniol and nerol - oxygenated monoterpenes with antioxidant properties. In contrast, the ginger essential oil from Oleya is dominated by sesquiterpenes such as zingiberene, cedrene, and himachalene. This oil showed lower antioxidant activity compared to the NJoy formulation. Moreover, at higher concentrations, the ginger essential oil from Oleya displayed prooxidant behaviour. Regarding the turmeric essential oils, the biopreparation marketed by Oleya (E.O-2.1) demonstrated higher antioxidant activity than that from NJoy (E.O-2.2), likely due to the presence of multiple compounds that may act synergistically or additively. Analysis of crude extracts obtained by chloroform extraction indicated that the extract from ginger rhizomes contained significantly more polyphenols (398±7.56 mg GAE·L^{-1}) than the extract from turmeric rhizomes (12.48 ± 0.12 mg GAE·L^{-1}), resulting in greater antioxidant activity in the ginger extract. This conclusion is supported by the IC_{50} values obtained for the two extracts: 1) Ginger extract: IC_{50} = 9.99 µL·mL^{-1}, at t = 5 s; IC_{50} = 21.94 µL·mL^{-1}, at t = 60 s; 2) Turmeric extract: IC_{50} = 132.32 µL·mL^{-1}, at t = 5 s; IC_{50} = 98.207 µL·mL^{-1}, at t = 60 s. The antioxidant activity of bioproducts derived from ginger or turmeric rhizomes whether obtained via hydrodistillation (essential oils) or solvent extraction - is strongly influenced by their phytochemical composition. The composition is affected by pedo-climatic conditions and cultivar differences. Ginger extracts and essential oils, particularly those rich in geraniol, nerol, or polyphenolic compounds, exhibit potent antioxidant activity and hold significant potential for therapeutic applications and the development of functional foods.

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