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Antioxidant properties of alcoholic extracts of Canadian goldenrod*

Zlata Ziaziulia[1], Adam Klimowicz[2, A] ✉

[1] Pomeranian Medical University in Szczecin, Graduate of Cosmetology, Powstańców Wlkp. 72, 70-111 Szczecin, Poland
[2] Pomeranian Medical University in Szczecin, Department of Cosmetic and Pharmaceutical Chemistry, Powstańców Wlkp. 72, 70-111 Szczecin, Poland

[A] ORCID: 0000-0001-6239-2853

✉ adam.klimowicz@pum.edu.pl

ABSTRACT
Introduction: Antioxidant activity is a key parameter that determines the potential of active ingredients in skin care products. Antioxidants play an important role in neutralizing reactive oxygen species, the excess of which leads to oxidative stress, accelerating the skin ageing process. Therefore, newer and newer products are being implemented, especially based on antioxidants of plant origin. One such plant, known for its numerous health-promoting properties, is Canadian goldenrod (*Solidago canadensis*).
The aim of this study was to assess the antioxidant properties of alcohol extracts obtained from different parts of Canadian goldenrod in order to assess its potential use as a source of antioxidants.
Materials and methods: The study material consisted of alcohol extracts obtained from dry leaves, flowers and stems of goldenrod, which were prepared using ultrasound-assisted extraction. Four low-molecular-weight alcohols (methanol, ethanol, n-propanol and isopropanol) were used as solvents at 3 concentrations (40% v/v, 70% v/v and concentrated) using 3 different extraction times (15, 30 or 60 min). Antioxidant activity was determined using 2 frequently used spectrophotometric methods: ABTS and DPPH. These methods allowed for the assessment of the ability of extracts to neutralize radicals and allowed for the comparison of antioxidant activity of extracts obtained from different parts of the plant.
Results: The highest antioxidant activity was demonstrated by extracts from dried flowers of Canadian goldenrod, while the lowest potential was demonstrated by extracts from dried stems. The highest extraction efficiency was obtained using alcohol-water mixtures of medium concentration (70%), regardless of the type of alcohol. In most cases, the optimal extraction time was 30 min. Extended extraction time was not always associated with an increase in activity, which may indicate that some of the bioactive compounds may be degraded.
Conclusions: *Solidago canadensis* extracts are a promising phytochemical raw material for use in functional cosmetics and prophylactic products that support the fight against the effects of oxidative stress.
Keywords: *Solidago canadensis*; antioxidant activity; DPPH method; ABTS method; ultrasound-assisted extraction; antioxidants.

INTRODUCTION

Oxygen, essential for respiration, undergoes a 4-stage reduction process in organisms, which finally leads to the formation of a water molecule. During aerobic respiration, however, not all oxygen is fully reduced, but some of it is converted into reactive oxygen species (ROS), which play a key role in various biological processes. Under normal conditions, ROS act as mediators, regulating cellular metabolism. They are involved in processes such as cell differentiation, gene activation, and apoptosis induction. Furthermore, they participate in cell signaling, both within and between cells, influencing gene expression. Reactive oxygen species act as secondary messengers in processes such as cell growth, cell death, and the activation of proteins responsible for controlling cell division [1, 2].

They also play a role in the body's defense mechanisms. Under conditions of equilibrium, their levels are carefully regulated, modulating cellular functions and maintaining homeostasis. However, changes in their levels, leading to their excessive production, can cause a number of health problems, indicating the complex role of ROS in both maintaining health and the development of disease [3].

Reactive oxygen species, which also include free oxygen radicals, encompass a wide range of molecules. Also important are reactive nitrogen species (RNS), reactive sulfur compounds, and reactive carbon compounds. The most common ROS and RNS include the superoxide anion radical ($\bullet O_2^-$), the hydroxyl radical (•OH), singlet oxygen ($^1O_2$), hydrogen peroxide (H_2O_2), nitric oxide (•NO), and peroxynitrite ($ONOO^-$). These molecules are particularly harmful to the skin because they can damage skin cells and tissues [1, 4, 5, 6].

Reactive oxygen and nitrogen species are produced by natural metabolic processes involving the electron transport chain and can also be generated by various external factors. These include UVA, UVB, visible light, infrared radiation, environmental pollutants, and psychological stress. These factors can induce the production of ROS in the skin, leading

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to cell damage [1, 4]. Free radicals are highly reactive molecules that typically possess a missing electron. Therefore, they seek out the missing electron, attacking healthy cells to rebalance their structure. This process disrupts normal cell function and triggers a cascade of uncontrolled chemical reactions that can lead to the development of various pathological conditions, such as premature skin aging, inflammation, and even cancer [1, 7].

Oxidative stress occurs when cells or tissues are exposed to elevated levels of free radicals or when their endogenous production increases. It is a state in which there is an imbalance between pro-oxidants and antioxidants, leading to the dominance of oxidative reactions. The metabolic consequences of oxidative stress include, among others, decreased adenosine triphosphate levels, decreased total glutathione, and changes in the ratio of reduced to oxidized glutathione (GSH/GSSG) [8, 9].

Increased levels of ROS result in damage to lipids, proteins, and DNA. Reactive oxygen species, in particular, affect the structure of lipid membranes, disrupting their integrity. This damage includes amino acid modifications, peptide chain fragmentation, aggregation of reaction products, changes in electrical charge, enzyme inactivation, and increased susceptibility of proteins to proteolysis [8]. Reactive oxygen species can also damage DNA through deoxyribose oxidation, leading to strand breaks, nucleotide removal, nitrogenous base modifications, and DNA-protein cross-linking. This can have serious consequences for cellular function and even lead to mutations and cancer development [9, 10, 11].

Ultraviolet radiation, especially the UVA (320–400 nm), but also UVB (280–320 nm), is one of the main factors stimulating the production of ROS in the skin [12, 13]. Exposure to UV radiation increases the levels of hydrogen peroxide (H_2O_2) and hydroxyl radicals (•OH). Furthermore, both visible light (400–700 nm) and infrared radiation (700–4000 nm), originating either from natural or artificial sources, can induce the formation of ROS, particularly in mitochondria [1, 14, 15].

The effect of free radicals on cells depends primarily on their concentration and exposure time. In small amounts, the body uses oxygen radicals as a defense against microorganisms, as well as regulators and mediators of numerous cellular processes [16, 17, 18].

Free radicals play a crucial role in stimulating glucose transport into cells, activating mitogenic factors, and eliminating pathogens present in the oral cavity. One of the key defense mechanisms is the so-called "respiratory burst" – an intense increase in oxygen uptake by immune cells in response to a bacterial or viral infection. This oxygen is then utilized by the enzyme NADPH oxidase to synthesize free radicals, which effectively neutralize microorganisms [17, 19, 20].

Antioxidants are substances that have the ability to transfer electrons [1]. When they encounter free oxygen radicals, electron transfer occurs, neutralizing the radicals and converting them into water or other compounds that are easily removed from the body during metabolic processes [2]. The human body has a natural antioxidant defense system that includes a number of enzymes, such as superoxide dismutase (SOD), catalase, and glutathione peroxidase. In addition, there are non-enzymatic antioxidants, such as glutathione, vitamin C, and vitamin E. These substances play an important role in neutralizing free radicals and mitigating potential damage caused by external factors [8, 21, 22].

Antioxidants exhibit characteristic mechanisms of action that determine their antioxidant activity [23, 24]. These include the ability to bind free radicals by stabilizing or delocalizing unpaired electrons, possessing reducing properties involving electron transfer, the ability to interrupt free radical reactions, and to inhibit the activity of enzymes responsible for oxidative processes [25, 26]. Therefore, antioxidants play a key role in scavenging and neutralizing free radicals [27, 28]. As a result, they protect epidermal lipids from oxidative processes, strengthen blood vessels, and exhibit anti-inflammatory and antimutagenic effects [28, 30].

The skin is the body's first line of defense against environmental stressors. The aging process is multifaceted, involving biological, psychological, and social aspects [31, 32]. Biological aging is first visible in the skin, but changes also affect muscle tissue, subcutaneous tissue, fascia, and bone structures. The rate of these processes varies and depends on many factors, such as skin phototype, morphotype, and exposure to external factors [33, 34, 35].

The skin aging process depends directly on many external factors, including, to a large extent, exposure to UV radiation [36]. Furthermore, extrinsic aging accelerates by increasing amount of ROS and the activation of enzymes that degrade essential skin components, leading to wrinkles, flacidity, roughness, and loss of elasticity [37, 38]. Skin aging is often accompanied by damage to the skin's protective barrier. Anti-aging cosmetics are designed to repair the skin barrier and strengthen the skin's protection against external factors [39].

In recent years, there has been a growing interest in the use of cosmetics containing natural ingredients, often obtained from plants. One such plant is the Canadian goldenrod (*Solidago canadensis* L.), commonly found as a weed, particularly in ruderal areas, wastelands, and along roadsides. It is an erect, rhizomatous perennial plant native to North America [40] belonging to the Asteraceae family [41]. It is 1 of 138 members of the genus Solidago, found primarily in North America [42]. Several species also occur in South America, Asia, and Europe [43].

This species is considered one of the most invasive plants, and the European and Mediterranean Plant Protection Organization defines it as an invasive species with a high potential for spreading and posing a significant threat to the environment and biodiversity in the region [44, 45].

On the other hand, goldenrod is considered a medicinal plant. The beneficial properties of *S. canadensis* have been known for centuries. Goldenrod is a valued honey plant, and the honey produced from it is characterized by a high content of enzymes and polyphenols [46, 47]. The herbal raw material

obtained from this invasive species has long been used in European phytotherapy to treat diseases of the urinary and genital tract [48]. This species is known for its complex composition of specialized metabolites, such as polyphenols, which contribute to its antioxidant, antimicrobial, and anti-inflammatory effects [49, 50, 51, 52].

Nowadays, there' a growing desire to keep the body in good condition. One of the key factors is the search for products to maintain a youthful appearance for as long as possible. To this end, cosmetics containing, among other, antioxidants which have anti-aging properties, are used. Growing public awareness of the adverse effects of synthetic antioxidants has led to increased interest in plant-based antioxidants. One such plant is Canadian goldenrod. Therefore, it was decided to investigate the antioxidant activity of alcohol extracts from selected parts of this plant.

The aim of this study was to examine the antioxidant properties of extracts from selected parts of the wild Canadian goldenrod, prepared using methanol, ethanol, n-propanol, and isopropanol as extractants, to determine the effect of the type and concentration of short-chain aliphatic alcohol used to prepare the extracts on their antioxidant activity and to evaluate the effect of ultrasound-assisted extraction time on the antioxidant potential of extracts from the analyzed parts of *S. canadensis*.

MATERIALS AND METHODS

Reagents used in this study are as follows: 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azinobis[3-ethyl-2,3-dihydrobenzothiazole-6-sulphonate] diammonium salt (ABTS) and 6-hydroxy-2,5,7,8-teramethylchroman-2 carboxylic acid (Trolox) were purchased from Sigma-Aldrich (St. Louis, MO, USA), methanol, isopropanol and n-propanol and potassium persulphate were from Chempur (Piekary Śląskie, Poland) and ethanol – from Linegal Chemicals (Warsaw, Poland). Reagents were of analytical grade.

Leaves, flowers, and stems of *S. canadensis* L. – Figure 1 – were used to prepare the extracts. The plants were collected on the outskirts of Szczecin, near a forest, away from busy roads, at the turn of August and September 2024. After collection, the material was dried in a dryer at 40°C. After drying, their quality was assessed and then they were ground. The crushed dried raw material was used to prepare the extracts.

To prepare the extracts of different parts of *Solidago canadensis* 4 short-chain alcohols, i.e. methanol. ethanol, isopropanol and n-propanol at 3 different concentrations: 40% (v/v), 70% (v/v) and undiluted, were applied. The procedure was similar to that described previously [53, 54]. Shortly, to 0.5 g of raw material placed in glass test tube 10 cm^3 of alcohol was added. The tubes were closed with a plastic stopper and put into ultrasonic (frequency 40 kHz) bath for 15, 30 or 60 min (Sonic 0.5, Polsonic, Warsaw). The ultrasound-assisted extraction, is classified as a green extraction technique due to shorted extraction time and low solvent consumption [55, 56]. After ultrasound-assisted extraction the extracts were separated by filtration, transferred to stoppered plastic tubes and stored in dark place at room temperature until analysis of antioxidant properties [53, 54].

FIGURE 1. Flowering *Solidago canadensis* L.

To evaluate the antioxidant activity of the obtained extracts 2 frequently applied methods, i.e. the DPPH and the ABTS, were applied as described in previous papers [57, 58]. These 2 methods are based on spectrophotometric determinations. Three samples were prepared from each extract. Trolox was used as a standard for methods and antioxidant activity was expressed as Trolox equivalents in mmol/dm^3 based on calibration curves. For the DPPH method calibration curve presenting the relationship of absorbance vs. Trolox concentration was $y = -1.2305x + 0.9999$, $R = 0.9936$, and for the ABTS method $y = -0.2409x + 0.8824$, $R = 0.9971$).

Statistical analysis was performed using Microsoft Office Excel. The obtained antioxidant activity results are presented as the arithmetic mean ±standard deviation (SD). To establish the calibration curve the parameters of linear regression between absorbance vs. Trolox concentration and correlation coefficient was calculated. Correlations between concentrations obtained by individual methods (DPPH and ABTS) and between the activities of extracts obtained from individual plant parts were also examined.

RESULTS

Figures 2–5 present the effect of ultrasound-assisted extraction time on the antioxidant activity of extracts from dried flowers, leaves, and stems of Canadian goldenrod with respect to the individual alcohols used as extractants. The results presented here refer to determinations using the ABTS method and are expressed as Trolox equivalents (mmol/dm^3). Figure 2 shows

the antioxidant activity of extracts from the tested parts of Canadian goldenrod in methanol, Figure 3 – in ethanol, Figure 4 – in n-propanol, and Figure 5 shows extracts prepared in isopropanol. Vertical lines in the graphs represent standard deviations.

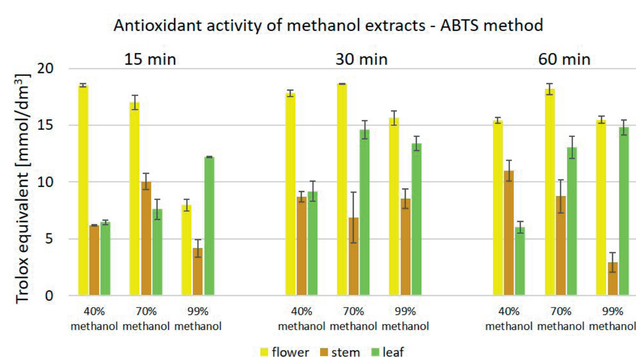

FIGURE 2. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of methanol extracts of *Solidago canadensis* determined using the ABTS method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

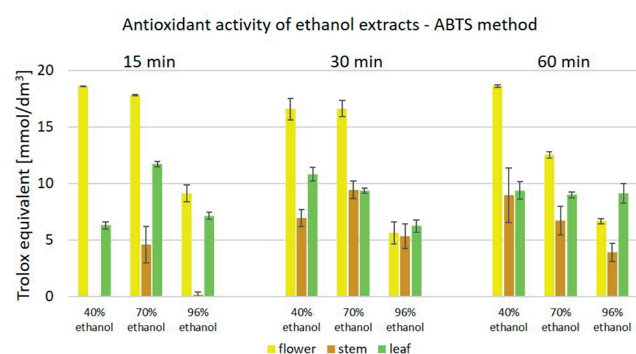

FIGURE 3. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of ethanol extracts of *Solidago canadensis* determined using the ABTS method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

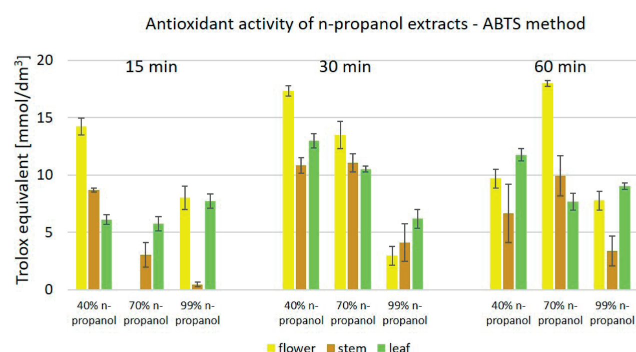

FIGURE 4. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of n-propanol extracts of *Solidago canadensis* determined using the ABTS method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

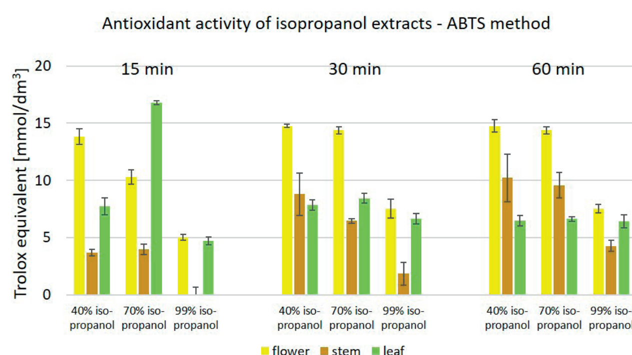

FIGURE 5. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of isopropanol extracts of *Solidago canadensis* determined using the ABTS method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

Using the ABTS method it was found that dried flower extracts exhibit the highest antioxidant potential, while extracts obtained from dried stems exhibit the lowest. Among the extracts from *S. canadensis* flowers, the highest antioxidant activity determined by the ABTS method was obtained using 70% (v/v) methanol as the solvent after 30 min extraction (18.68 ±0.01 mmol/dm³). In contrary, among the extracts from *S. canadensis* flowers, the lowest antioxidant activity determined by the ABTS method was found for extracts obtained after 30 min extraction using 99% (v/v) n-propanol as the solvent (2.96 ±0.81 mmol/dm³). Among the extracts from *S. canadensis* stems, the highest antioxidant activity determined by the ABTS method was obtained using 70% (v/v) n-propanol as the solvent after 30 min extraction (11.03 ±0.79 mmol/dm³). In contrary, the lowest antioxidant activity determined by the ABTS method for stem extracts was found for the extracts obtained after 15 min extraction using 96% (v/v) ethanol as the solvent (0.31 ±0.03 mmol/dm³). For the extracts from *S. canadensis* leaves, the highest antioxidant activity determined by the ABTS method was observed after 15 min extraction using 70% (v/v) isopropanol as the solvent (16.78 ±0.15 mmol/dm³), while the lowest antioxidant activity determined by the same method was obtained using 99% (v/v) isopropanol as the solvent after 15 min extraction (4.71 ±0.32 mmol/dm³).

Figures 6–9 present the effect of ultrasound-assisted extraction time on the antioxidant activity of extracts from dried flowers, leaves, and stems of Canadian goldenrod with respect to the individual alcohols used as extractants. The results presented here refer to determinations using the DPPH method and are expressed as Trolox equivalents (mmol/dm³). Figure 6 shows the antioxidant activity of extracts from the tested parts of Canadian goldenrod in methanol, Figure 7 – in ethanol, Figure 8 – in n-propanol, and Figure 9 shows extracts prepared in isopropanol.

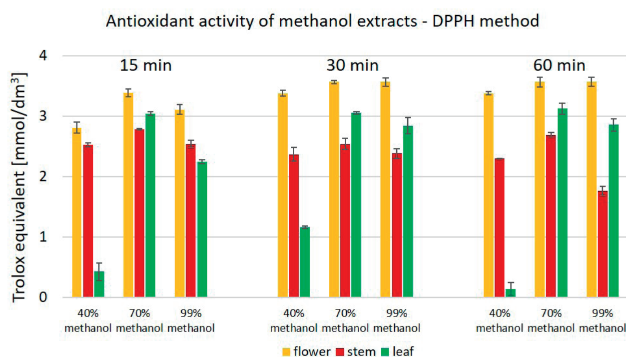

FIGURE 6. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of methanol extracts of *Solidago canadensis* determined using the DPPH method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

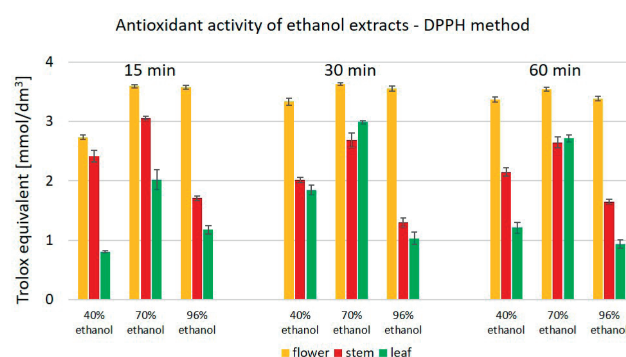

FIGURE 7. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of ethanol extracts of *Solidago canadensis* determined using the DPPH method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

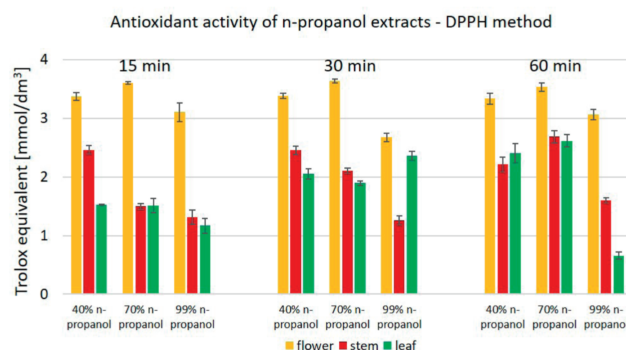

FIGURE 8. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of n-propanol extracts of *Solidago canadensis* determined using the DPPH method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

Using the DPPH method it was found that dried flower extracts exhibit the highest antioxidant potential, while extracts obtained from dried leaves exhibit the lowest. Among the extracts from *S. canadensis* flowers, the highest antioxidant activity determined by the DPPH method was obtained using 40% (v/v) isopropanol as the solvent after 15 min extraction (3.67 ±0.03 mmol/dm³). In contrary, among the extracts from *S. canadensis* flowers, the lowest antioxidant activity determined by the DPPH method was found for extracts obtained after 15 min extraction using 40% (v/v) ethanol as the solvent (2.73 ±0.37 mmol/dm³). Among the extracts from *S. canadensis* stems, the highest antioxidant activity determined by the DPPH method was obtained using 70% (v/v) ethanol as the solvent after 15 min extraction (3.05 ±0.04 mmol/dm³). In contrary, the lowest antioxidant activity determined by the DPPH method for stem extracts was found for the extracts obtained after 30 min extraction using 99% (v/v) isopropanol as the solvent (1.09 ±0.07 mmol/dm³). For the extracts from *S. canadensis* leaves, the highest antioxidant activity determined by the DPPH method was observed after 60 min extraction using 70% (v/v) methanol as the solvent (3.13 ±0.09 mmol/dm³), while the lowest antioxidant activity determined by the same method was obtained using 40% (v/v) methanol as the solvent after 60 min extraction (0.14 ±0.10 mmol/dm³).

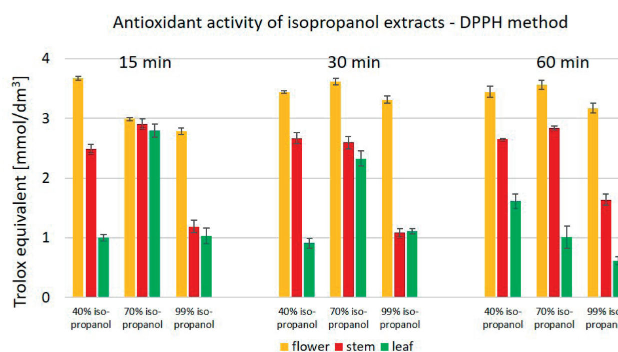

FIGURE 9. Mean (±standard deviation – SD) antioxidant activities expressed as Trolox equivalents (mmol/dm³) of isopropanol extracts of *Solidago canadensis* determined using the DPPH method taking into account the solvent concentration and the time of ultrasound-assisted extraction. Vertical lines represent SD

Statistically significant correlations were found between the antioxidant activity determined by the DPPH and ABTS methods for extracts obtained from dry leaves ($r = 0.6538$, $p = 0.00002$) and stems ($r = 0.5936$, $p = 0.0001$) of *S. canadensis*.

DISCUSSION

From a cosmetic perspective, antioxidant activity is a key parameter determining the potential of active ingredients in skincare products. Antioxidants play a crucial role in neutralizing ROS, the excess of which leads to oxidative stress, accelerating the skin aging. Effective antioxidants, such as those found in goldenrod extracts, can protect against oxidative damage to lipids, proteins, and DNA, as well as strengthen the epidermal barrier and support skin regeneration [59].

In the medical context, compounds with antioxidant properties have the potential to prevent chronic diseases such as cancer, neurodegenerative diseases, diabetes, and atherosclerosis, the pathogenesis of which is linked to chronic oxidative stress.

This means that the phenolic compounds and flavonoids present in *S. canadensis* extracts can be used not only in cosmetology but also in phytotherapy and dietary supplementation [60].

The results of the study showed that alcohol extracts from different parts of the *S. canadensis* L. are characterized by varying antioxidant activity, depending on both the type plant material and the extraction conditions – the type and concentration of solvent, as well as the duration of ultrasound-assisted extraction. The highest antioxidant potential was found in extracts obtained from dried flowers, while the lowest was found in extracts from stems, which is consistent with previous scientific reports indicating a high content of phenolic compounds mainly in the flowers and leaves of the plant.

The type and concentration of alcohol used as extractant, as well as the extraction time, had a significant effect on the ability of the extracts to neutralize free radicals. In most cases, better results were obtained using medium-concentration solvents (70% v/v), which may be due to the better solubility of phenolic compounds in alcohol-water mixtures than in pure alcohols. These results are consistent with those obtained by others, who indicate that the presence of water in the extraction system improves the leaching of hydrophilic compounds while maintaining the alcohol's ability to extract lipophilic compounds [61, 62].

The use of ultrasound-assisted extraction could have increased the efficiency of the process by disrupting cell walls and facilitating mass transfer. Therefore, this technique has found application in modern cosmetology and pharmaceutical applications, where not only effectiveness but also safety and rapid extraction of active substances are important [63].

The phytochemical composition of a plant is heterogeneous and can vary significantly depending on its morphological part. Flowers, leaves, and stems, although derived from the same biological entity, perform different physiological functions and contain different groups of secondary metabolites, such as flavonoids, phenolic acids, saponins, and tannins. In the context of assessing antioxidant potential, this diversity is particularly important because it directly affects the biological activity of extracts obtained from individual plant parts [64, 65].

For cosmetic and medical applications, it is important to select those parts of the plant material characterized by the highest content of bioactive compounds capable to effectively neutralize free radicals. This approach not only increases the effectiveness of dermocosmetic and supplementary preparations but also optimizes the production of plant extracts.

In this study, particular attention was paid to the evaluation of the antioxidant activity of extracts from 3 morphologically distinct parts of the Canadian goldenrod: dried flowers, leaves, and stems. Analysis of the results allows for the identification of the most valuable components of the plant material for their potential application in formulations aimed at anti-aging, protective, and regenerative effects.

As previously mentioned, the highest antioxidant activity determined by the ABTS method was observed in dried flower extracts extracted with 70% methanol for 30 min (18.7 ±0.3 mmol/dm^3), suggesting the presence of significant amounts of phenolic compounds and flavonoids with high a high ability to neutralize free radical. Determinations performed using the DPPH method also confirmed the strong antioxidant properties of these extracts (3.67 ±0.03 mmol/dm^3) obtained by extraction with 40% isopropanol for 15 min.

Uzelac Božac et al. also demonstrated that extracts from Canadian goldenrod flowers exhibit stronger antioxidant activity than leaf extracts, which is associated with a higher content of phenolic compounds. The presence of numerous phenolic compounds, such as rutin and chlorogenic acid, indicates the potential use of *S. canadensis* in phytopharmacy [66].

High activities determined by the ABTS method were also obtained for *S. canadensis* leaves, particularly in the case of extraction with 70% isopropanol (16.8 ±0.2 mmol/dm^3). A similarly high antioxidant potential was found in extracts prepared in 70% methanol during 1 hour of extraction and determined using the DPPH method (3.13 ±0.09 mmol/dm^3). This means that the leaves, although less rich than the flowers, are also a valuable source of antioxidants.

In contrary, stem extracts showed lower activity. In the case of ABTS determinations the least effective extract was prepared in 96% ethanol within 15 min (0.31 ±0.03 mmol/dm^3), while in the case of DPPH assays the least effective extract was prepared in 99% isopropanol after 30 min (1.09 ±0.07 mmol/dm^3), which suggests a lower content of bioactive components in this part of the plant.

Marksa et al. also confirmed that Canadian goldenrod contains phenolic compounds, such as chlorogenic acid, rutin, and isoquercitrin, which exhibit significant antioxidant activity. The use of ABTS and DPPH methods to determine the antioxidant activity of components separated by HPLC enabled accurate identification and assessment of the activity of individual compounds with antioxidant properties in plant extracts [67].

Deng et al. evaluated the antioxidant properties of Canadian goldenrod extracts using the ABTS and DPPH methods and also demonstrated high antioxidant activity of extracts obtained by ultrasound-assisted extraction (also used in our own study) from *S. canadensis* leaves, especially those harvested at full flowering stage, which demonstrated high polyphenol content and the greatest ability to scavenge free radicals. This may indicate that this plant exhibits significant antioxidant activity, which depends on the extraction method, plant development stage, and tissue type [68].

The most important goal of most research on new cosmetic preparations is to select those fractions of the plant material characterized by the highest content of bioactive compounds capable to effectively neutralize free radicals, as confirmed by Hrytsyk et al. [69]. Their results indicate that Canadian goldenrod extract, obtained using 40% ethanol, exhibits promising anti-inflammatory, hepatoprotective, and antimicrobial properties. Due to their low toxicity, these extracts may provide a basis for the development of new herbal drugs with hepatoprotective effects. This approach allows not only to increase the effectiveness of dermocosmetics or supplements, but also optimizes the technological processes involved in the production of plant extracts [69].

In summary, *S. canadensis* has proven to be a valuable raw material, suitable for use in cosmetics, among other applications. The most optimal antioxidant properties were found for flower extracts, which may demonstrate its usefulness in practical applications.

CONCLUSIONS

1. Extracts from dried Canadian goldenrod flowers exhibit the highest antioxidant activity, suggesting their greatest potential for use in cosmetology as anti-aging ingredients and supporting epidermal regeneration. Extracts obtained in 70% methanol and 40% isopropanol with short extraction times proved to be particularly effective.
2. Goldenrod leaves also exhibit high antioxidant activity, especially when using 70% methanol and isopropanol for extraction. Their bioactive profile makes them a valuable ingredient in dermocosmetics with protective properties and those that help reduce the effects of oxidative stress.
3. Extracts from dried stems show lower antioxidant activity, which suggests that they are not an optimal source of phenolic compounds and their use in the cosmetics or pharmaceutical industry may be limited.
4. The duration of ultrasound-assisted extraction affected the efficiency of antioxidant compound extraction, with the most favorable results obtained after 30 min for most samples. Extended extraction times did not always result in increased activity, which may indicate the possibility of potential degradation of some bioactive compounds.
5. The highest extraction efficiency was achieved using medium-concentrated alcohol-water mixtures (70%), regardless of the alcohol type (methanol, ethanol, isopropanol, n-propanol). This may indicate the important role of solvent polarity in the effective release of both hydrophilic and lipophilic active compounds.
6. Canadian goldenrod extracts seem to be a promising phytochemical raw material for use in functional cosmetics and products with medical and preventive potential, supporting the fight against the effects of oxidative stress, both at the skin and systemically.

REFERENCES

1. Chen J, Liu Y, Zhao Z, Qiu J. Oxidative stress in the skin: impact and related protection. Int J Cosmet Sci 2021;43:495-509.
2. Leung MHY, Tong X, Bastien P, Guinot F, Tenenhaus A, Appenzeller BM, et al. Changes of the human skin microbiota upon chronic exposure to polycyclic aromatic hydrocarbon pollutants. Microbiome 2020;8(1):100.
3. Cadenas E, Davies KJ. Mitochondrial free radical generation, oxidative stress, and aging. Free Radic Biol Med 2000;29(3-4):222-30.
4. Bertino L, Guarneri F, Cannavo SP, Casciaro M, Pioggia G, Gangemi S. Oxidative stress and atopic dermatitis. Antioxidants 2020;9(3):196.
5. Serre C, Busuttil V, Botto JM. Intrinsic and extrinsic regulation of human skin melanogenesis and pigmentation. Int J Cosmet Sci 2018;40(4):328-47.
6. Boo YC. Human skin lightening efficacy of resveratrol and its analogs: from in vitro studies to cosmetic applications. Antioxidants 2019;8(9):332.
7. Wołosik K, Sikora W, Topczewska K, Świderska M, Chylińska N. Wodór cząsteczkowy (H_2) – naturalny przeciwutleniacz z potencjalnymi korzyściami terapeutycznymi dla skóry. Aesth Cosmetol Med 2024;13(1):33-9.
8. Sharifi-Rad M, Anil Kumar NV, Zucca P, Varoni EM, Dini L, Panzarini E, et al. Lifestyle, oxidative stress, and antioxidants: back and forth in the pathophysiology of chronic diseases. Front Physiol 2020;11:552535.
9. Ungvari Z, Bagi Z, Feher A, Recchia FA, Sonntag WE, Pearson K. Resveratrol confers endothelial protection via activation of the antioxidant transcription factor Nrf2. Am J Physiol Heart Circ Physiol 2010;299(1):18-24.
10. Zduńska K, Dana A, Kolodziejczak A, Rotsztejn H. Antioxidant properties of ferulic acid and its possible application. Skin Pharmacol Physiol 2018;31:332-6.
11. Wolosik K, Chalecka M, Palka J, Surazynski A. Protective effect of amaranthus cruentus L. seed oil on UVA-radiation-induced apoptosis in human skin fibroblasts. Int J Mol Sci 2023;24(13):10795.
12. Chen Q, Zhang H, Yang Y, Zhang S, Wang J, Zhang D, et al. Metformin attenuates UVA-induced skin photoaging by suppressing mitophagy and the PI3K/AKT/mTOR pathway. Int J Mol Sci 2023;23(13):6960.
13. Arfin S, Jha NK, Jha SK, Kesari KK, Ruokolainen J, Roychoudhury S. Oxidative stress in cancer cell metabolism. Antioxidants 2021;10(5):642.
14. Bernerd F, Passeron T, Castiel I, Marionnet C. The damaging effects of long UVA (UVA1) rays: A major challenge to preserve skin health and integrity. Int J Mol Sci 2022;23:8243.
15. Rysava A, Vostalova J, Rajnochova Svobodova A. Effect of ultraviolet radiation on the Nrf2 signaling pathway in skin cells. Int J Radiat Biol 2021;97:1383-403.
16. Bartosz G., Druga twarz tlenu. Wolne rodniki w przyrodzie. Warszawa: Wyd. Naukowe PWN; 2008. p. 6-84.
17. Skotnicka M, Golan M, Szmukała N. Rola naturalnych przeciwutleniaczy pochodzenia roślinnego w profilaktyce nowotworowej. Ann Acad Med Gedan 2017;47:119-27.
18. Bartoszek A, Łukowicz J, Peszyńska-Sularz G, Cieślak A, Piasek A, Popadiuk S. Przeciwdziałanie kardiotoksyczności w trakcie chemioterapii nowotworów przy użyciu roślinnych antyoksydantów: przegląd literatury i badania własne. Konferencja naukowa. Gdańsk: Politechnika Gdańska. Akademia Medyczna w Gdańsku; 2007.
19. Antosiewicz J, Herman-Antosiewicz A. Przeciwutleniacze z czosnku indukują stres oksydacyjny w komórkach nowotworowych. Konferencja naukowa. Gdańsk: Uniwersytet Gdański, Akademia Medyczna w Gdańsku; 2007.
20. Sieniawska E. Losy roślinnych antyoksydantów w ludzkim organizmie. Praca przeglądowa. Lublin: Uniwersytet Medyczny w Lublinie; 2008.
21. Stefanovic N, Irvine AD, Flohr C. The role of the environment and exposome in atopic dermatitis. Curr Treat Options Allergy 2021;8(3):222-41.
22. De Pessemier B, Grine L, Debaere M, Maes A, Paetzold B, Callewaert C. Gut-skin axis: current knowledge of the interrelationship between microbial dysbiosis and skin conditions. Microorganisms 2021;9(2):353.
23. Shanmuganayagam D, Warner TF, Crueger CG, Reed JD, Folts JD. Concord grape juice attenuates platelet aggregation, serum cholesterol and development of atheroma in hypercholesterolemic rabbits. Atherosclerosis 2007;190:135-42.
24. Sikora J, Markowicz M, Mikiciuk-Olasik E. Rola i właściwości lecznicze aronii czarnoowocowej w profilaktyce chorób cywilizacyjnych. Bromat Chem Toksykol 2009;42:10-7.
25. Palozza P, Simone R, Catalano A, Parrone N, Monego G, Ranelletti FO. Lycopene regulation of cholesterol synthesis and efflux in human macrophages. J Nutr Biochem 2011;22(10):971-8.
26. Ried K, Fakler P. Protective effect of lycopene on serum cholesterol and blood pressure: meta-analyses of intervention trials. Maturitas 2011;68(4):299-310.
27. Łuczaj W, Skrzydlewska E. Antioxidative properties of black tea. Prevent Med 2005;40(6):910-8.
28. Miller E, Malinowska K, Gałęcka E. Rola flawonoidów jako przeciwutleniaczy w organizmie człowieka. Pol Merk Lek 2008;24(144):556-60.
29. Anunciato TP, RochaFilho PA. Carotenoids and polyphenols in nutricosmetics, nutraceuticals, and cosmeceuticals. J Cosmet Dermatol 2012;11(1):51-4.
30. Scarmo S, Cartmel B, Lin H, Leffell DJ, Welch E, Bhosale P, et al. Significant correlations of dermal total carotenoids and dermal lycopene with their respective plasma levels in healthy adults. Arch Biochem Biophys 2010;504(1):9-34.

31. Ruprich M, Cieśla-Panek I, Cegiełko E. Wybrane przyczyny starzenia skóry oraz analiza procesów zachodzących w poszczególnych strukturach anatomicznych. Zesz Nauk Akad Górnośl 2023;(11):98-105.
32. Girsang E, Lister INE, Ginting CN, Bethasari M, Amalia A, Widowati W. Comparison of antiaging and antioxidant activities of Protocatechuic and Ferulic acids. Mol Cell Biomed Sci 2020;4(2):68-75.
33. Shin S, Cho SH, Park D, Jung E. Anti-skin aging properties of protocatechuic acid in vitro and in vivo. J Cosmet Dermatol 2020;19(4):977-84.
34. Sheng YY, Xiang J, Lu JL, Ye JH, Chen ZJ, Zhao JW, et al. Protective effects of gallocatechin gallate against ultraviolet B induced skin damages in hairless mice. Sci Rep 2022;12(1):1310.
35. Nutho B, Tungmunnithum D. Anti-aging potential of the two major flavonoids occurring in Asian Water Lily using in vitro and silico molecular modeling assessments. Antioxidants 2024;13(5):601.
36. Kaszuba A, Szepietowski J, Adamski Z. Dermatologia geriatryczna. Lublin: Wyd. Czelej; 2016. p. 21-24.
37. Shen ZQ, Chang CY, Yeh CH, Lu CK, Hung HC, Wang TW, et al. Hesperetin activates CISD2 to attenuate senescence in human keratinocytes from an older person and rejuvenates naturally aged skin in mice. J Biomed Sci 2024;31(1):15.
38. Choi YJ, Alishir A, Jang T, Kang KS, Lee S, Kim KH.,Antiskin aging effects of indole alkaloid N-glycoside from Ginkgo fruit (Ginkgo biloba fruit) on TNF-α-exposed human dermal fibroblasts. J Agric Food Chem 2022;70(42):13651-60.
39. Ahmed IA, Mikail MA, Zamakshshari N, Abdullah ASH. Natural anti-aging skincare: role and potential Biogerontology 2020;21(3):293-310.
40. Borsch T, Berendsohn W, Dalcin E, Delmas M, Demissew S, Elliott A, et al. World Flora Online: Placing taxonomists at the heart of a definitive and comprehensive global resource on the world's plants. Taxon 2020;69(6):1311-41.
41. Tokarska-Guzik B, Dajdok Z, Zając M, Zając A, Urbisz A, Danielewicz W, et al. Rośliny obcego pochodzenia w Polsce. Warszawa: Generalna Dyrekcja Ochrony Środowiska; 2012.
42. Semple JC, Beck JB. Revised infrageneric Classification of Solidago (Asteraceae: Astereae). Phytoneuron 2021;10:1-6.
43. Poljuha D, Sladonja B, Uzelac Božac M, Šola I, Damijani´c D, Weber T. The invasive alien plant *Solidago canadensis*: Phytochemical composition, ecosystem service potential, and application in bioeconomy. Plants 2024;13:1745.
44. Radušiene J, Karpavicien B, Vilkickyte G, Marksa M, Raudone L. Comparative analysis of root phenolic profiles and antioxidant activity of five native and invasive Solidago L. species. Plants 2024;13:132.
45. Apáti P, Szentmihályi K, Kristó TS, Papp I, Vinkler P, Szöke É, et al. Herbal remedies of Solidago – correlation of phytochemical characteristics and antioxidative properties. J Pharm Biomed Anal 2003;32(4-5):1045-53.
46. Mohammed HA, Eldeeb HM, Khan RA, Al-Omar MS, Mohammed SAA, Sajid MSM, et al. Sage, Salvia officinalis L., constituents, hepatoprotective activity, and cytotoxicity evaluations of the essential oils obtained from fresh and differently timed dried herbs: A comparative analysis. Molecules 2021;26 (19):5757.
47. Fedotova VV, Chelombitko VA, Vidy roda zolotarnik (*Solidago*): znachenie dlia meditcinskoi praktiki, perspektivy izucheniia. Nauchnye vedomosti BelGU. Ser Med Farmat 2012;6(135):136-45.
48. Benelli G, Pavela R, Cianfaglione K, Nagy DU, Canale A, Maggi F. Evaluation of two invasive plant invaders in Europe (*Solidago canadensis* and *Solidago gigantea*) as possible sources of botanical insecticides. J Pest Sci 2019;92(2):805-21.
49. Den Y, Zhao Y, Padilla-Zakou O, Yang G. Polyphenols, antioxidant and antimicrobial activities of leaf and bark extracts of *Solidago canadensis* L. Ind Crops Prod 2015;74:803-9.
50. Marksa M, Zymone K, Ivanauskas L, Radušienė J, Pukalskas A, Raudone L. Antioxidant profiles of leaves and inflorescences of native, invasive and hybrid *Solidago* species. Ind Crops Prod 2020;145:112123.
51. Quinty V, Nasreddine R, Colas C, Launay A, Nehmé R, El-Khiraoui A, et al., Antioxidant and anti-lipase capacities from the extracts obtained from two invasive plants: *Ambrosia artemisiifolia* and *Solidago canadensis*. Food Biosci 2023;55:103069.
52. Fursenco C, Calalb T, Uncu L, Dinu M, Ancuceanu R, *Solidago virgaurea* L. A review of its ethnomedicinal uses, phytochemistry, and pharmacological activities. Biomolecules 2020;10(12):1619.
53. Wąsik A, Klimowicz A. Extracts from Corylus avellana as a source of antioxidants useful in cosmetic preparations. Pomeranian J Life Sci 2022;68(4):55-66.
54. Kęsik M, Klimowicz A. Antioxidant potential of extracts from different parts of Cichorium intybus L. Pomeranian J Life Sci 2024;70(1):59-63.
55. Witaszczyk A, Klimowicz A. Usefulness of aloe vera (Aloe vera) as a potential ingredient of cosmetic preparations. Pomeranian J Life Sci 2023;69(3):76-87.
56. Albero B, Tadeo JL, Perez RA. Ultrasound-assisted extraction of organic contaminants. Tr Anal Chem 2019;118:739-50.
57. Oshetkova D, Klimowicz A. Antioxidative and photoprotective activity of Pinus nigra, Pinus strobus and Pinus mugo. Appl Sci (Basel) 2025;15(1):209.
58. Nowak A, Duchnik W, Muzykiewicz-Szymańska A, Kucharski Ł, Zielonka-Brzezicka J, Nowak A, et al. The changes of antioxidant activity of three varieties of nalewka, a traditional Polish fruit alcoholic beverage during long-term storage. Appl Sci (Basel) 2023;13(2):1114.
59. Olivero-Verbel J, Quintero-Rincón P, Caballero-Gallardo K. Aromatic plants as cosmeceuticals: benefits and applications for skin health. Planta 2024;260(6):132.
60. Pal J. Substancje o potencjale antyoksydacyjnym stosowane w preparatach kosmetycznych, nutrikosmetykach i dermokosmetykach. [Praca magisterska]. Kraków: Wydział Farmaceutyczny. Uniwersytet Jagielloński; 2020.
61. Do QD, Angkawijaya AE, Tran-Nguyen PL, Huynh LH, Soetaredjo FE, Ismadji S, et al. Effect of extraction solvent on total phenol content, total flavonoid content, and antioxidant activity of Limnophila aromatica. J Food Drug Anal 2014;22(3):296-302.
62. Phong HX, Viet NT, Quyen NTN, Van Thinh P, Trung NM, Ngan TTK. Phytochemical screening, total phenolic, flavonoid contents, and antioxidant activities of four spices commonly used in Vietnamese traditional medicine. Materials Today: Proceedings 2022;56:A1-A5.
63. Mikucka W, Zielinska M, Bulkowska K, Witonska I. Recovery of polyphenols from distillery stillage by microwave-assisted, ultrasound-assisted and conventional solid-liquid extraction. Sci Rep 2022;12(1):3232.
64. Dores RG, Guimarães SF, Braga TV, Fonseca MC, Martins PM, Ferreira TC. Phenolic compounds, flavonoids and antioxidant activity of leaves, flowers and roots of goat weed. Horticult Brasil 2014;32(4):486-90.
65. Dalawai D, Murthy HN, Dewir YH, Sebastian JK, Nag A. Phytochemical composition, bioactive compounds, and antioxidant properties of different parts of Andrographis macrobotrys Nees. Life 2023;13(5):1166.
66. Uzelac Božac M, Poljuha D, Dudaš S, Bilić J, Šola I, Mikulič-Petkovšek M, et al. Phenolic profile and antioxidant capacity of invasive *Solidago canadensis* L.: Potential applications in phytopharmacy. Plants 2024;14(1):44.
67. Marksa M, Radušienė J, Jakštas V, Ivanauskas L, Marksienė R. Development of an HPLC post-column antioxidant assay for *Solidago canadensis* radical scavengers. Nat Product Res 2016;30(5):536-43.
68. Deng Y, Zhao Y, Padilla-Zakou O, Yang G. Polyphenols, antioxidant and antimicrobial activities of leaf and bark extracts of *Solidago canadensis* L. Ind Crops Prod 2015;74:803-9.
69. Hrytsyk Y, Koshovyi O, Hrytsyk R, Ain R. Extracts of the Canadian goldenrod (*Solidago canadensis* L.) – promising agents with antimicrobial, anti-inflammatory and hepatoprotective activity. ScienceRise: Pharm Sci 2024;4(50):78-87.