A Comparative Assessment of Sea Buckthorn (*Hippophae rhamnoides* L.) Pruning Waste as a Potential Source of Serotonin

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GRAPHICAL ABSTRACT

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Sea buckthorn (*Hippophae rhamnoides* L.) twigs, remaining after harvesting and pruning, are an underutilized and little-explored biomass resource. This study investigated the content of serotonin in 10 sea buckthorn cultivars (‘Maria Bruvele’, ‘Botanicheskaya Lubitelskaya’, ‘Tatiana’, ‘Otto’, ‘Leikora’, ‘Duet’, ‘Clara’, ‘Lord’, ‘Eva’, ‘Tarmo’) for the first time, and for further adjustment of the extraction conditions, cultivar ‘Maria Bruvele’ was extracted by water and water/ethanol solution with 20-25, 50, 70, and 96% ethanol at different temperatures. The results showed that 50% water/ethanol solutions are the most suitable for extraction, which makes it possible to increase the yield of serotonin. The 2-year-old twigs and bark from ‘Maria Bruvele’ collected in autumn contained higher serotonin content compared to spring-collected biomass. Serotonin sequential purification allowed the serotonin content in the fraction to increase to 26%/DM. The serotonin-rich fraction showed antimicrobial activity against gram-positive and gram-negative bacteria. In tests with salivary amylase, a serotonin-rich fraction at the amount of 0.1-0.4 mg/mL of saliva, under normal physiological conditions, tended to increase amylase activity, resulting in acceleration of starch degradation to glucose. Thus, the results support further study of the serotonin fraction for the treatment of people having underweight, malnutrition, and malabsorption conditions.

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Keywords: Sea buckthorn; Serotonin; Twigs; Bark; Freon; Antimicrobial activity; Amylase activity

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INTRODUCTION

Natural products, in the form of pure compounds or in the form of complex plant extracts, open unlimited possibilities for the discovery of new nutraceuticals due to the unsurpassed chemical diversity. According to the World Health Organization (WHO), 60% of the world’s population relies on herbal medicine, and about 80% of the population in developing countries depends almost totally on it for their primary health care (Ahmad Khan and Khan 2019). In the USA, approximately 49% of the population has tried natural medicines for the prevention and treatment of diseases. Plants used in traditional medicine contain a wide range of biologically active substances that can be used to treat various chronic and infectious diseases. Natural compounds can be obtained from any part of the plant, such as bark, leaves, twigs, berries, flowers, roots, fruits, and seeds (Gradt *et al.* 2017). The synergy of various secondary metabolites activity in plant extracts has been described elsewhere (Janceva *et al.* 2017; Abegaz and Kinfe 2019).

Sea buckthorn (*Hippophae rhamnoides* L.) (SBT) is a unique and valuable plant due to its medicinal and nutritional potential. Approximately 40 countries cultivate SBT, with a total area of cultivation worldwide of about 3 million hectares. China, Northern Europe, Canada, Romania, Russia, and Mongolia cover almost 90% of the world's SBT stocks. China is the world's leading producer. The total annual SBT harvest is 8.5 million tons (Nawaz *et al.* 2019). In Latvia, SBT is mainly grown on private plantations, on area of about 400 hectares, with a production of 12 to 50 kg of fruits per plant (Klovane 2014).

Due to its valuable composition and high biological activity, the most known product of SBT processing is oil. Interest in it has been increasing in the pharmacology, food, and cosmetology industries (Ivanova *et al.* 2019). The therapeutic effect of SBT oil is explained by the presence of vitamins, carotenoids, tocopherols, and a number of other biologically active substances (Kallio *et al.* 2002; Andersson *et al.* 2009). Juice, syrup, and tincture of fresh fruits are also recommended as a multivitamin additive for the prevention of beriberi, and other vitamin-deficiency diseases.

Currently, special attention is paid to the complex and waste-free processing of SBT with the maximum extraction of biologically active substances and the expansion of the range of preparations from the SBT (Janceva *et al.* 2022). In folk medicine, a decoction of leaves is used to treat gastrointestinal diseases, ulcers, and microbial infections (Suryakumar and Gupta 2011; Yue *et al.* 2017; Letchamo *et al.* 2018). There are reports that the extract of bark and shoots has antitumor activity (Christaki 2012; Olas *et al.* 2018). The authors' previous studies revealed anti-inflammatory activity of SBT twigs extracts and the possibility of the extracts to influence pancreatic lipase and salivary amylase activities (Janceva *et al.* 2021; Andersone *et al.* 2023a,b).

The chemical characterization of the extracts of vegetative parts of the SBT is relevant and will help to create a waste-free processing scheme for SBT cultivation. Preliminary studies by the authors, as well as literature reported that SBT twigs contain a complex of nitrogenous compounds, including serotonin in the cortex (Gradt *et al.* 2017) in greater amounts than in the biomass of other plants. Research on serotonin in SBT has just started, and the data are very limited. In plants, serotonin is synthesized differentially whereby tryptophan is first catalyzed into tryptamine by tryptophan decarboxylase, followed by the catalysis of tryptamine by tryptamine 5-hydroxylase to form serotonin (Ramakrishna *et al.* 2011). However, another pathway of transformation of tryptophan to serotonin in plants cannot be ruled out. The function of serotonin is not yet clear as well. The biggest concentration of serotonin in plants so far has been found in walnuts and hickory; it was reported to be implicated in the responses to biotic and abiotic stress, as an antioxidant and growth regulator (Erland *et al.* 2019; Mandal 2023). Serotonin as a neurotransmitter is involved in the regulation of a number of important functions in humans, including sleeping, hunger, thirst, and mood (Ramakrishna *et al.* 2011).

The purpose of this work was to evaluate the twigs of ten SBT cultivars, as well as leaves, bark, and twigs of different ages (1 to 4 years) of the 'Maria Bruvele' cultivar, collected in spring and autumn seasons, as a raw material for obtaining serotonin. A further goal was to find the optimal conditions for the extraction of plant material and fractionation of biomass, in terms of obtaining serotonin. Additionally, the study was aimed at testing the serotonin-rich fraction's antimicrobial activity and effect on the activity of the amylolytic enzyme alpha-amylase in saliva, for assessment of the practical application possibilities.

EXPERIMENTAL

Materials

The different age twigs after harvesting of ten SBT cultivars - ‘Maria Bruvele’, ‘Botanicheskaya Lubitelskaya’ (‘Bot. Lub.’), ‘Tatiana’, ‘Otto’, ‘Leikora’, ‘Duet’, ‘Rumania’, ‘Lord’, ‘Eva’, and ‘Tarmo’ were collected from the SBT plantation area in Latvia, Tukums, with the same growing conditions, in August of 2020. The twigs were dried at 22 to 26 °C temperature, and ground with a knife mill Retsch SM100 (Retsch, Haan, Germany) and sieved to select the particles between 2 and 4 mm. These fractions were stored at −8 °C. Additionally, the one, two, three, and four-year-old twigs, leaves, and bark samples of the SBT cultivar - ‘Maria Bruvele’ were collected from the same plantation area, in March and September of 2021 and 2022.

Isolation of the Serotonin-Rich Extracts from Ten SBT Biomass

For the first comparative evaluation of the serotonin content in ten SBT cultivars, and as a way to select the target cultivar with the biggest serotonin content, serotonin-containing extracts were isolated from twigs according to the scheme shown in Fig. 1.

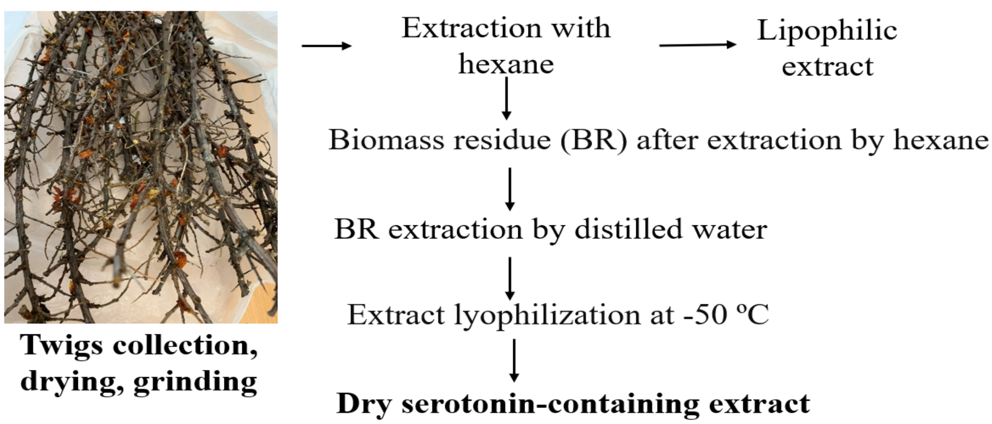

Fig. 1. Scheme of serotonin isolation from SBT twigs for initial comparative assessment of its content in ten SBT cultivars

Lipophilic compounds were separated by biomass extraction at 50 to 60 °C for 30 min by *n*-hexane. The extracts after hexane evaporation were dried at 40 °C to yield a dry extract. The yield of the lipophilic extracts was presented as % of the DM of biomass.

Hydrophilic extracts from residues after lipophilic compounds separation were isolated by extraction at 60 °C for 30 min (3 x 10 min) using distilled water. For study of the influence of extraction conditions on the serotonin yield and its content in the extract, extraction of SBT ‘Maria Bruvele’ biomass was carried out using aqueous solutions with different percentages of ethanol (20, 50, 70, 96%) and at different temperatures (22-25, 50, and 70 °C). The extracts after ethanol evaporation were freeze-dried at -50 °C for 12 h to obtain a dry powder. The yield of the extracts is presented as % of the DM of biomass. The CI for the results did not exceed 3% at $\alpha = 0.05$.

Maria Bruvele Biomass Extraction by 1,1,1,2-Tetrafluoroethane

For assessment of the influence of solvent at the first stage of serotonin-rich biomass extraction, 1,1,1,2-tetrafluoroethane (freon R134a) was used as an alternative solvent, for the isolation of non-polar and semi-polar compounds from 'Maria Bruvele' samples (leaves, twigs, and bark). Extraction was performed in a Nectacel 1L pilot extractor (Celsius, France), within a closed system, under pressure of 4.0 to 4.3 bar and temperature of 17 to 19 °C. The yield of the extracts isolated by freon R134a was presented as a percentage based on the DM of biomass. The CI for the results did not exceed 3% at $\alpha = 0.05$.

Extraction of Hydrophilic Compounds from Biomass Residue After Extraction by 1,1,1,2-Tetrafluoroethane

After 'Maria Bruvele' biomass (twigs, bark, leaves) extraction by freon R134a, biomass residue was extracted by distilled water and ethanol-water solution (1:1, v/v) at 60 °C for 30 min.

Identification and Quantification of Serotonin Content in Extract

Dry crude extracts were dissolved in aqueous acetonitrile (v/v 50:50) with an approximate concentration of 2 mg/mL and filtered (Nylon filter, 0.45 µm pore size), and used for UHPLC-UV-TOF/MS experiments. LC analysis of the samples were performed on the Acquity UPLC (Waters Corp., Milford, MA, USA) coupled with a quadrupole-time of flight (Q-TOF) MS instrument (UPLC/Synapt Q-TOF MS, Waters, Milford, MA, USA) equipped with an electrospray ionisation (ESI) source. The separation was carried out on a U-HPLC column (2.1 mm x 50 mm i.d., 1.7 µm, BEHC18) (Waters Acquity) at a flow rate 0.35 mL/min. The eluent was 0.1% formic acid, water (A), and acetonitrile (B). A gradient solvent system was used: 0 to 1 min, 5% to 20% (B); 1 to 5 min, 20% to 25% (B); 5 to 6 min, 25% to 75% (B), 6 to 7 min, 75% to 80 % (B), 7 to 8.5 min, 80% to 7% (B), 8.5 to 10 min, 5% to 5% (B), and the injection volume was 1.0 µL. The major operating parameters for the Q-TOF MS were set as follows: capillary voltage, 2.5 kV (-) and 2.0 kV (+); cone voltage, 60 V; cone gas flow, 100 L/h; collision energy, 6 eV; source temperature, 120 °C; desolvation temperature, 450 °C; collision gas, argon; desolvation gas, nitrogen; flow rate, 750 L/h; data acquisition range, *m/z* 50 to 1200 Da; ionization mode – positive. Serotonin was identified with its analytical standard (Sigma Aldrich, M_w=176.22 g/moL) (Fig. 2).

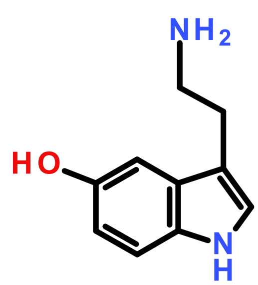

Fig. 2. Chemical structure of serotonin (Mw=176.22 g/moL)

In positive electrospray ionization mode, serotonin was protonated to produce ions in the form $[M+H]^+$, with *m/z* 177. On the basis of detected serotonin fragmentation, a multiple reaction monitoring mode (MRM) was developed for the specific *m/z* transitions 177→160 (the most intensive cleavage ion), 177→132, and 177→115 (Fig. 3).

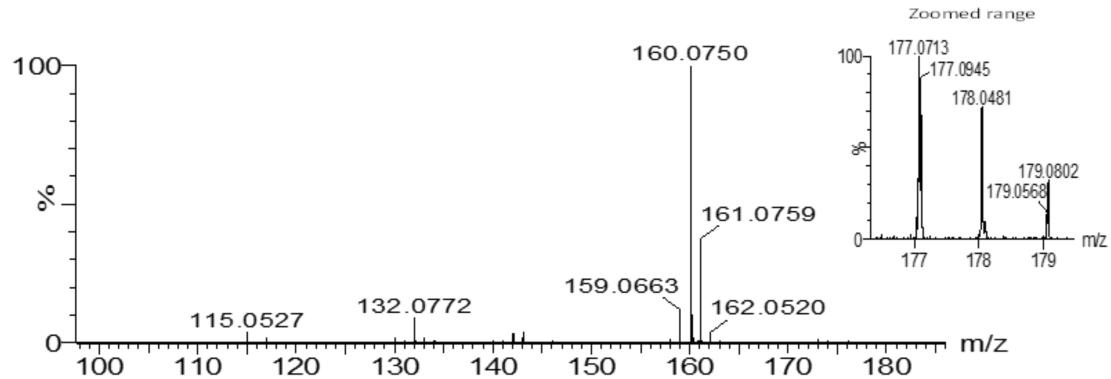

Fig. 3. Serotonin identification by UHPLC-UV-TOF/MS

Serotonin Purification

The serotonin purification was carried out using size exclusion and ion exchange resins (patent pending) for high- and low-molecular-weight polyphenol separation from extracts.

Antimicrobial Analyses

Antimicrobial activity was studied in 96-well plates by the two-fold serial broth microdilution method, which allowed the determination of the minimum inhibitory (MIC) and minimum bactericidal/fungicidal concentrations (MBC/MFC), as described by Andersone *et al.* (2023b).

In-vitro Analysis of Alpha-Amylase Activity

In-vitro analyses were performed at the Department of Human Physiology and Biochemistry of Riga Stradins University based on European standard protocols as described by Krasilnikova *et al.* (2013). The saliva used for research was donated by students with no record of chronic or acute illness, the last meal was 2 hours before the examination to get clean results. The extracts were tested in amounts from 0.1 to 0.4 mg/mL of saliva. The influence of the extracts on salivary amylase was measured by the breakdown of polysaccharides containing linear α-1,4 glucose bonds in starch. The amylase activity was characterized by the amyloclastic force (AF); that is, the volume of the 0.1% starch solution in milliliters that is hydrolyzed by 1 mL of saliva in the test tubes at 38 °C for 30 min. Then, 1% iodine solution was added (as a marker for the presence of starch by color changes). The amyloclastic force is denoted as $D_{30/38°C}$. Saliva without extract was used as a reference. The amyloclastic force of the reference sample was $D_{30/38°C}$ 640.

Statistical Analysis

All measurements were conducted in triplicate (*n*=3). The results are presented as the mean value ± confidence interval (CI). Statistical analyses were performed using Microsoft Excel 2016. CIs were calculated for a mean using a Student's T distribution at a significance level α = 0.05.

RESULTS AND DISCUSSION

Chemical Characterization of Twigs from Ten SBT Cultivars

For the first evaluation of the yield of extracts and content of serotonin in SBT twigs (further in the text – biomass) of ten different cultivars ('Maria Bruvele', 'Bot. Lub', 'Tatiana', 'Otto', 'Leikora', 'Duet', 'Clara', 'Lord', 'Eva', and 'Tarmo') collected in August of 2020 were studied. The yield of lipophilic extracts obtained with hexane from the entire studied biomass was quite close and varied from 1.2 to 1.9% per DM. Further on, distilled water was used as an extractant to test its suitability on serotonin and as the most environmentally friendly, low-cost simple solvent. The yield of hydrophilic extracts from biomass, obtained using distilled water differed statistically significantly and ranged from 19 to 29% per DM. The content of serotonin in hydrophilic extracts ranged from 1.5 to 7.9%/DM (Fig. 4).

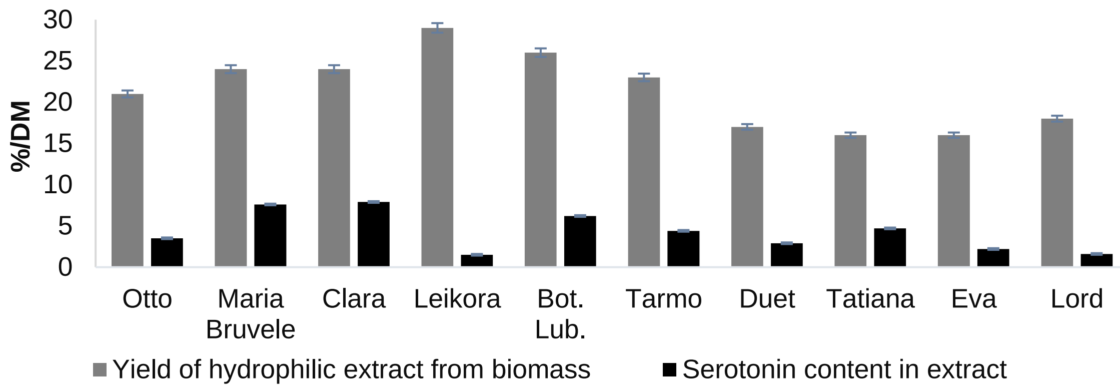

Fig. 4. Comparison of yield of water extracts and serotonin content in the extract for 10 SBT cultivars

The highest content of serotonin in the water extract was in 'Maria Bruvele' (7.6%/DM) and 'Clara' (7.9%/DM). Based on the increase in the growing of 'Maria Bruvele' in the Baltic region and on the results of the chemical characterisation above, 'Maria Bruvele' biomass collected in 2020 was chosen for further extraction optimization experiments.

Extraction Conditions for Serotonin Isolation from 'Maria Bruvele' Biomass

To determine the suitability of ethanol-water solutions for the serotonin extraction, 'Maria Bruvele' biomass with a particle size of 2 to 4 mm was extracted at 60 ºC with a duration time of 30 min, as solvents using ethanol-water solutions (20, 50, 80, and 96% of ethanol, further in the text: 20% EtOH, 50% EtOH, 80% EtOH and 96% EtOH). The content of serotonin in all 'Maria Bruvele' hydrophilic extracts varied from 7.5 to 10.4%/DM. The 50% EtOH ethanol-water solution provided the highest yield of serotonin from biomass (2.2%/DM) with 8.2%/DM of the serotonin in the extract. The serotonin yield from 20 and 80% ethanol-water solutions was similar within the CI. Despite the high content of serotonin in the extract (10.4%/DM) isolated with 96% EtOH, the serotonin yield from the biomass was only 1.1%/DM (Fig. 5).

Generally, high extraction temperature increases the efficiency of extraction. Serotonin isolation from twigs by 50% EtOH at 70 to 80 °C showed a significant serotonin content decrease (2.6 times) in extract composition, which indicated that serotonin is a thermolabile compound. Therefore, to continue the studies, biomass extraction was carried out at 60 °C.

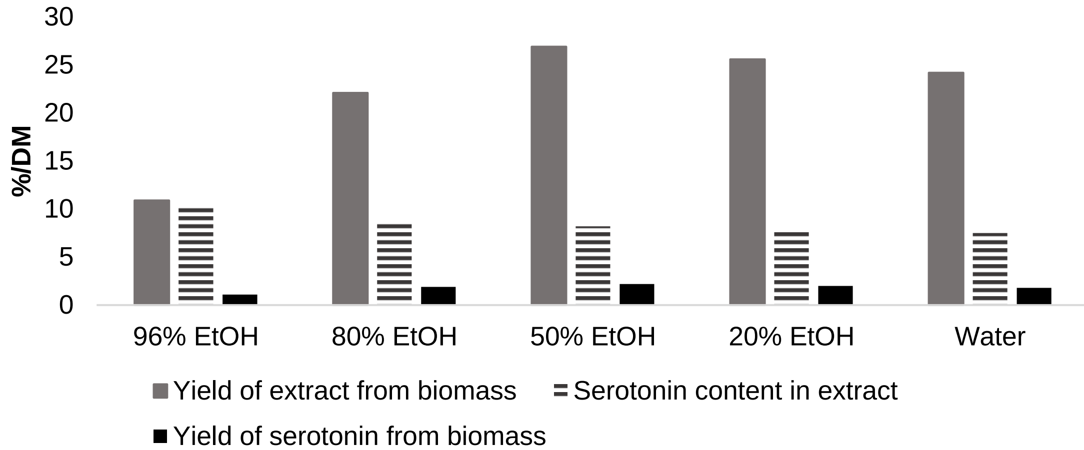

Fig. 5. Effect of the ethanol concentration in extractant on the efficiency of serotonin isolation from SBT ‘Maria Bruvele’ twigs (extraction time 30 min., temperature 60 °C).

Comparison of Extracts Yield and Serotonin Content in ‘Maria Bruvele’ 1–4-Year-Old Twigs

The yield of freon extracts from one, two, three, and four-year-old twigs collected in March 2021 ranged between 0.6 and 1.2%/DM. The yield of an extract isolated by freon from ‘Maria Bruvele’ twigs collected in 2021 was 1.8 times lower than by hexane. This could be due to the lower extraction temperature (up to 20 °C) allowed in the freon extraction equipment for the freon used (R134a).

The yield of hydrophilic extracts from twigs collected in March 2021 ranged between 6 and 22% /DM (Table 1).

Table 1. Serotonin Content in SBT Twigs Depending on Age (Collected in March 2021) and solvent. Extraction Condition: Mass Ratio of Biomass and Solvent (1:8, w/w), Extraction Temperature of 60 °C, Time of 30 min

Samples	Yield of Extract from Biomass (%/DM)	Serotonin Content in Extract (%/DM)	Yield of Serotonin from Biomass (%/DM)
	Extraction with Distilled Water		
1-Year-Old Twigs	11.96±0.05	11.21±0.02	1.34±0.01
2-Year-Old Twigs	12.57±0.06	14.62±0.03	1.84±0.01
3-Year-Old Twigs	15.87±0.05	11.08±0.03	1.76±0.01
4-Year-Old Twigs	8.53±0.04	7.91±0.02	0.67±0.01
	Extraction with 50% EtOH		
1-Year-Old Twigs	22.23±0.04	10.53±0.03	2.34±0.01
2-Year-Old Twigs	19.61±0.03	14.85±0.02	2.91±0.01
3-Year-Old Twigs	17.25±0.02	9.88±0.02	1.70±0.01
4-Year-Old Twigs	8.56±0.04	9.97±0.03	0.85±0.01

The highest yield of hydrophilic extracts was obtained by ethanol-water solution (1:1; v/v or 50% EtOH at 60 °C, 30 min). Based on the Table 1 data, 1- and 2-year-old twigs extracts had the highest content of serotonin (11-15%/DM of extract, 2.3 and 2.9%/DM of biomass). These results were close to the data of other authors for different cultivars, which indicated that the content of serotonin in SBT twigs was 2.0 to 3.16%/DM (Galitsyn *et al.* 2014).

Leaves, 2-year-old twigs, and bark from 2-year-old twigs, collected in September after picking berries, were also tested as the raw materials for serotonin. Compared to the twigs collected in March, the yield of extract and content of serotonin in 1- and 2-year-old twigs collected in autumn was significantly higher. The yield of hydrophilic extract was ~1.3 times higher. The serotonin content in the extract isolated by 50% EtOH increased to 14.02%/DM. The yield of serotonin from twigs extracted by 50% EtOH was 3.7%/DM. This indicated that the twigs pruned in autumn have more potential as a raw material for the isolation of serotonin.

Table 2. Serotonin Content in Biomass Collected in September 2021

Samples	Yield of Hydrophilic Extract from Biomass (%/DM)	Serotonin Content in Extract (%/DM)	Yield of Serotonin from Biomass (%/DM)
	Extraction with Distilled Water		
1- and 2-Year-Old Twigs (Mix)	15.73±0.03	13.67±0.02	2.15±0.01
Bark from 2-Year-Old Twigs	18.02 ±0.04	13.84 ±0.01	2.49±0.01
	Extraction with 50% EtOH		
1- and 2-Year-Old Twigs (Mix)	26.42±0.03	14.02±0.02	3.70±0.01
Bark from 2-Year-Old Twigs	26.07±0.03	14.16±0.03	3.69±0.01

The leaves contained an insignificant amount of serotonin – 0.04%/DM or less. These results were consistent with the literature data, which showed that the content of serotonin in leaves ranged from 0.03 to 0.36%/DM (Galitsyn *et al.* 2014). The authors' previous studies showed that trees debarking biomass had a high amount of biologically active compounds. This was also confirmed by the serotonin data in this study. The high amount of hydrophilic extract from bark made it possible to obtain 26 g of extract/100 g DM of bark with a content of serotonin of 14%/DM (in September 2021). This high amount was also confirmed for bark collected in 2022 from 2-year-old twigs (13.4%/DM of serotonin content in hydrophilic extract).

However, debarking of SBT twigs (with the highest serotonin content) is not economically reasonable at an industrial scale since this process requires much labor and time. Thus, the most suitable raw material for serotonin obtaining could be 1-and 2-year twigs which have bigger content of bark than 4-year-old twigs.

The hydrophilic extracts of 1-and 2-year-old twigs collected in September 2021 contained a high amount of polyphenols, mainly proanthocyanidins (52.98%/DM). Based on the results of our previous studies, where proanthocyanidins are strong inhibitors of amylase activity, their separation from serotonin was essential for this study. Their isolation from extract, as one of the main stages of serotonin purification allowed for twice the increase of serotonin content in the remaining extract.

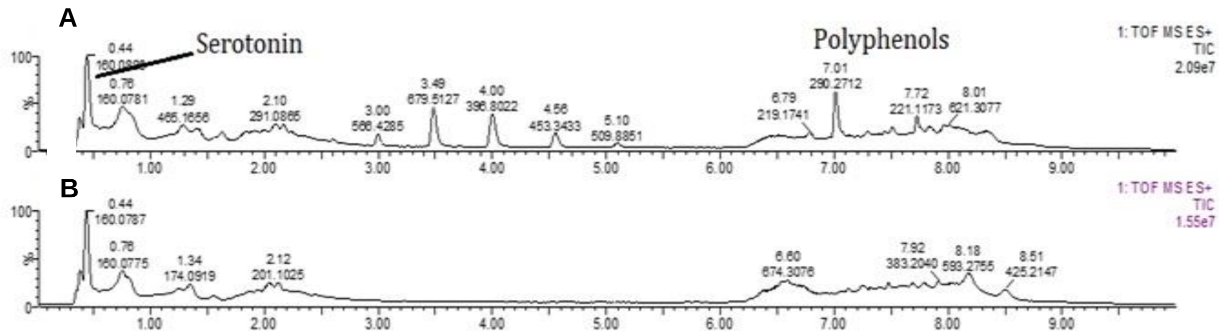

Fig. 6. UHPLC-TOF/MS chromatograms of the 50% EtOH extracts (A: 1- and 2-year-old twigs (mix); B – bark from twigs)

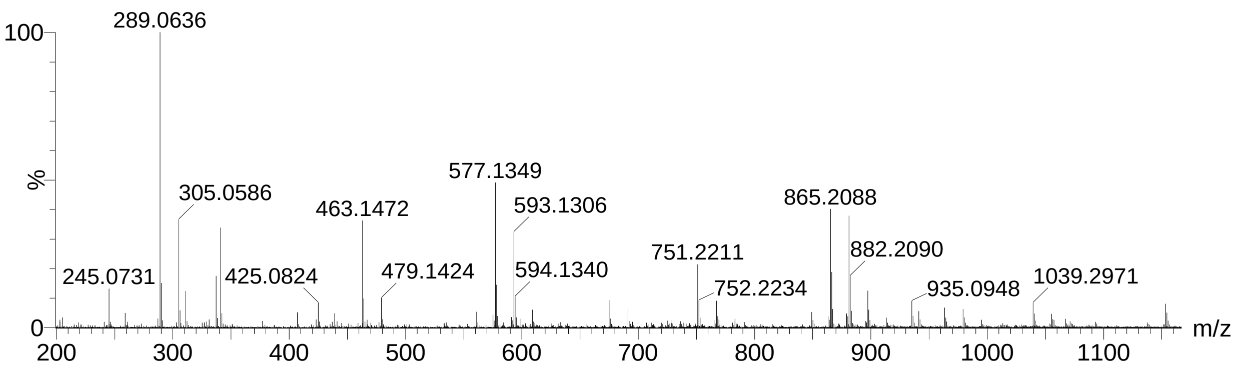

Fig. 7. Mass spectrum of proanthocyanidins from 50% EtOH extract isolated from 1- and 2-year-old twigs of ‘Maria Bruvele’

After sequential serotonin purification, serotonin content in fraction increased to 26.1%.

Antimicrobial Activity of Serotonin-rich Fraction

In the case of physiological disorders, pathogenic bacteria can linger, multiply, and cause pathological processes in human body. In purulent inflammatory processes, representatives of the genus *Pseudomonas* are often found.

Table 3. Antimicrobial Activity of Serotonin-purified Fraction

Samples	*E. coli*	*P. aeruginosa*	*S. aureus*	*B. cereus*	*C. albicans*
Serotonin-rich Fraction (Serotonin Content in Fraction: 26.6%/DM)	MIC/MBC or MIC/MFC (mg/mL)				
	0.78/0.78	0.78/0.78	0.39/0.78	0.78/6.25	0.20/0.20

A certain role is assigned to yeast-like fungi of the genus *Candida*, which in normal flora of healthy people are either absent or found in very small quantities. Serotonin-purified fraction showed significant antimicrobial activity against gram-positive and gram-negative pathogenic bacteria, such as *P. aeruginosa*, *S. aureus*, *E. coli*, *B. cereus*, and fungus *C. albicans*.

Serotonin-rich Fraction Influence on Alpha-Amylase Activity

Under normal physiological conditions, a serotonin-rich fraction at amounts of 0.1 to 0.4 mg showed a significant activation (two times) of amyloclastic force (Table 4).

Table 4. Influence of Serotonin-Rich Fraction (SRF) on Amylase Activity in Normal Physiological Conditions

Sample	SRF Amount In Saliva (mg/mL)	Amyloclastic Force (Saliva pH 7)
Human Saliva Without Extract (Control)	-	640
Serotonin-rich Fraction (Serotonin Content in Fraction: 26.6%/DM)	0.1	1280
	0.2	1280
	0.4	1280

Increased α-amylase activity accelerates the degradation of starch to glucose, which may be useful in the treatment of people having conditions of underweight, malnutrition, and malabsorption.

CONCLUSIONS

1. Sea buckthorn twigs and bark of investigated cultivars are the valuable source of serotonin with an average yield of 2-6% /DM.
2. Biomass extraction with 50% EtOH at 60 °C and the following sequential purification allowed to obtain extract with a serotonin content of 26% /DM.
3. Serotonin-rich fraction had antimicrobial activity showing its perspective as an antimicrobial agent.
4. Serotonin-rich fraction had the ability to activate the amylase activity in normal physiological conditions that could be useful for the treatment of persons with underweight, malnutrition, and malabsorption. Further research is needed.

ACKNOWLEDGMENTS

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REFERENCES CITED

Abegaz, B. M., and Kinfe, H. H. (2019). “Secondary metabolites, their structural diversity, bioactivity, and ecological functions: An overview,” *Physical Sciences Reviews* 4(6), article 20180100. DOI: 10.1515/psr-2018-0100

Ahmad Khan, M. S., and Ahmad, I. (2019). “Chapter 1 - Herbal medicine: Current trends and future prospects,” in: *New Look to Phytomedicine: Advancements in Herbal*

Products as Novel Drug Leads, M. S. Ahmad Khan, I. Ahmad, and D. Chattopadhyay (eds.), Academic Press, Cambridge, MA, USA, pp. 3-13. DOI: 10.1016/b978-0-12-814619-4.00001-x

Andersone, A., Janceva, S., Lauberte, L., Krasilnikova, J., Zaharova, N., Nikolajeva, V., Rieksts, G., and Telysheva, G. (2023b). "Lignocellulosic waste compounds for pancreatic lipase inhibition: Preliminary extraction by Freon, obtaining of proanthocyanidins and testing on lipase activity," *Metabolites* 13(8), article 922. DOI: 10.3390/metabo13080922

Andersone, A., Janceva, S., Lauberte, L., Ramata-Stunda, A., Nikolajeva, V., Zaharova, N., Rieksts, G., and Telysheva, G. (2023a). "Anti-inflammatory, Anti-bacterial, and Anti-fungal activity of oligomeric proanthocyanidins and extracts obtained from lignocellulosic agricultural waste," *Molecules* 28, article 863. DOI: 10.3390/molecules28020863

Andersson, S. C., Olsson, M. E., Johansson, E., and Rumpunen, K. (2009). "Carotenoids in sea buckthorn (*Hippophae rhamnoides* L.) Berries during ripening and use of pheophytinaas a maturity marker," *Journal of Agricultural and Food Chemistry* 57(1), 250-258. DOI: 10.1021/jf802599f

Christaki, E. (2012) "*Hippophae rhamnoides* L.(sea buckthorn): A potential source of nutraceuticals," *Food Public Health* 2(3), 69-72. DOI: 10.5923/j.fph.20120203.02

Erland, L. A. E., Turi, C. E., Saxena P. K. (2019). "Serotonin in plants: Origin, functions, and implications," in: *Serotonin*, P. M. Pilowsky (ed.), Academic Press, pp. 23-46. DOI: doi.org/10.1016/B978-0-12-800050-2.00002-4.

Galitsyn, G. U., Kreymer, V. K., Lomovsky, O. I., and Lomovsky, I. O. (2014). "Sea buckthorn as a source of serotonin," in: *Sea buckthorn. Research for a Promising Crop: A Look at Recent Developments in Cultivation, Breeding, Technology, Health and Environment*, BoD, Berlin, Germany. 208 p.

Galitsyn, G., Lomovskiy, I., and Podgorbunskikh, E. (2023). "Seasonal and geographic variation in serotonin content in sea buckthorn," *Plant Foods Hum. Nutr.* 78(1), 186-192. DOI: 10.1007/s11130-022-01038-2.

Gradt, I., Kühn, S., Mörsel, T., and Zvaigzne, G. (2017). "Chemical composition of sea buckthorn leaves, branches and bark," *Proc. Latvian Acad. Sci., Section B* 71, 211-216. DOI: 10.1515/prolas-2017-0035

Ivanova, G. V., Nikulina, E. O., Kolman, O. Y., and Ivanova, A. N. (2019). "Products of sea-buckthorn berries processing in parapharmaceutical production," *IOP Conference Series: Earth and Environmental Science* 315, article 052020. DOI: 10.1088/1755-1315/315/5/052020

Janceva, S., Lauberte, L., Dizhbite, T., Krasilnikova, J., Telysheva, G., and Dzenis, M. (2017). "Protective effects of proanthocyanidins extracts from the bark of deciduous trees in lipid systems," *Holzforschung* 71(7-8), 675-680. DOI: 10.1515/hf-2016-0185

Janceva, S., Andersone, A., Lauberte, L., Zaharova, N., Telysheva, G., Krasilnikova, J., Nokalne, I., and Janceva, J. (2021). "Influence of extracts from bark of deciduous trees on the activity of the amylolytic enzyme - alpha amylase," *Key Engineering Materials* 903, 34-39. DOI: 10.4028/www.scientific.net/kem.903.34

Janceva, S., Andersone, A., Lauberte, L., Bikovens, O., Nikolajeva, V., Jashina, L., Zaharova, N., Telysheva, G., Senkovs, M., Rieksts, G., Ramata-Stunda, A., and Krasilnikova, J. (2022). "Sea buckthorn (*Hippophae rhamnoides*) waste biomass after harvesting as a source of valuable biologically active compounds with nutraceutical and antibacterial potential," *Plants* 11, article 642. DOI: 10.3390/plants11050642

Kallio, H., Yang, B., and Peippo, P. (2002). "Effects of different origins and harvesting time on vitamin C, tocopherols, and tocotrienols in sea buckthorn (*Hippophaë rhamnoides*) berries," *Journal of Agricultural and Food Chemistry* 50(21), 6136-6142. DOI: 10.1021/jf020421v

Klovane, I. (2014). "Smiltsērkšķi starta taisnē," (https://www.la.lv/smiltserkski-starta-taisne-pieredze), accessed 12 January 2022.

Letchamo, W., Ozturk, M., Altay, V., Musayev, M., Mamedov, N. A., and Hakeem, K. R. (2018). "An alternative potential natural genetic resource: Sea buckthorn [*Elaeagnus rhamnoides* (syn.: *Hippophae rhamnoides*)]," in: *Global Perspectives on Underutilized Crops*, Springer, NY, pp. 25-82. DOI: 10.1007/978-3-319-77776-4_2

Mandal, A. (2023). "Serotonin in plants," (https://www.news-medical.net/health/Serotonin-in-Plants.aspx).

Nawaz, M. A., Khan, A. A., Khalid, U., Buerkert, A., and Wiehle, M. (2019). "Superfruit in the niche—Underutilized sea buckthorn in Gilgit-Baltistan, Pakistan," *Sustainability* 11(20), article 5840. DOI: 10.3390/su11205840

Olas, B., Skalski, B., and Ulanowska, K. (2018). "The anticancer activity of sea buckthorn [*Elaeagnus rhamnoides* (L.) A. Nelson]," *Frontiers in Pharmacology* 9, article 232. DOI: 10.3389/fphar.2018.00232

Ramakrishna, A., Giridhar, P. and Aswathanarayana Ravishankar G. (2011). "Phytoserotonin," *Plant Signaling & Behavior* 6(6), 800-809.

Suryakumar, G., and Gupta, A. (2011). "Medicinal and therapeutic potential of sea buckthorn (*Hippophae rhamnoides* L.)," *Journal of Ethnopharmacology* 138(2), 268-278. DOI: 10.1016/j.jep.2011.09.024

Yue, X.-F., Shang, X., Zhang, Z.-J., and Zhang, Y.-N. (2017). "Phytochemical composition and antibacterial activity of the essential oils from different parts of sea buckthorn (*Hippophae rhamnoides* L.)," *Journal of Food and Drug Analysis* 25(2), 327-332. DOI: 10.1016/j.jfda.2016.10.010

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