Evaluation of Antioxidant Activity of Some Common Mosses

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The antioxidant activity of ethanol extracts of Atrichum undulatum, Polytrichum formosum (Polytrichaceae), Pleurozium schreberi (Entodontaceae) and Thuidium tamariscinum (Thuidiaceae) was evaluated by an electrochemical method (cyclic voltammetry) and standard photometric methods: Fe(III) to Fe(II) reducing power, nitric oxide scavenging (NO) assay and simulation of Fenton-type reaction by nonsite-specific (NSSOH) and site-specific (SSOH) hydroxyl radical-mediated 2-deoxy-d-ribose degradation inhibition. The total content of phenols was determined by the Folin-Ciocalteau reagent. All tested species showed antioxidant effects lower than the positive control, caffeic acid. The extracts of A. undulatum and P. formosum contained the highest content of phenols and were the most effective in Fe(III) to Fe(II) reducing power, cyclic voltammetry and SSOH assay. By contrast, only the extract of Pl. schreberi showed activity in the NSSOH assay. A. undulatum and T. tamariscinum extracts were the most active in the NO assay. The results suggest that the extracts of A. undulatum and P. formosum possess stronger antioxidant activity than those of Pl. schreberi and T. tamariscinum, but they affect the Fenton-type reaction mainly by iron chelation.

Key words: Cyclic Voltammetry, Fenton Reaction, Free Radicals

Introduction

Antioxidant and free radical scavenging activities are in the focus of attention of pharmacists and nutrition scientists. Free radicals are supposed to play a key role in the pathogenesis of many diseases (Castro and Freeman, 2001). Oxidation processes may also decrease the stability of drugs and foods. Reactive oxygen species (ROS) and reactive nitrogen species (RNS) have been recognized as fundamental components of stress signal cascades (Haddad, 2002), both abiotic and biotic (Wojtaszek, 1997; Gechev et al., 2006). This has expanded the interest on further fields, such as physiology and biochemistry.

Mosses occupy a special position among higher plants because the haploid gametophyte dominates their life cycle. Some species have been studied for their tolerances to drought and water stress (flooding) (Robinson et al., 2000; Wasley et al., 2006) or high nitrogen concentrations (Koranda et al., 2007). Mosses are common in the vegetation of all continents. They are still margin-
and fatty acids were analyzed in the various genera of families, e.g. Dicranaceae, Ditrichaceae and Entodontaceae (Ichikawa et al., 1983; Dembitsky et al., 1993; Wasley et al., 2006).

The present study was aimed to evaluate the antioxidant activity of ethanol extracts of four commonly occurring mosses: Atrichum undulatum (Hedw.) Pal. de B. (Polytrichaceae), Pleurozium schreberi (Brid.) Mitt. (Entodontaceae), Polytrichum formosum Hedw. (Polytrichaceae), and Thuidium tamariscinum (Hedw.) B. S. G. (Thuidiaceae). A. undulatum and P. formosum contain a series of polyhydroxylated daphnin coumarins and Pl. schreberi flavonoid glycosides; none of these classes of secondary metabolites have been reported from T. tamariscinum (Table I). The evaluation of the antioxidant effects was carried out by cyclic voltammetry, which has been utilized in several studies to evaluate flavonoids (Firuzi et al., 2005; Simïc et al., 2007; Yakovleva et al., 2007), phenolic acids (Simïc et al., 2007; Yakovleva et al., 2007), blood plasma (Chevion et al., 1997) and plant extracts (Cosio et al., 2006). Further, several commonly used photometric methods, iron(III) to iron(II) reducing power (Dorman et al., 2003; Koşar et al., 2005), nitric oxide (NO) scavenging (Marcocci et al., 1994), nonsite-specific (NSSOH) and site-specific (SSOH) hydroxyl radical-mediated 2-deoxy-d-ribose degradation inhibition (Dorman et al., 2004), were applied. Caffeic acid was used as a positive control because its redox properties have been well documented (Giaco-melli et al., 2002; Hotta et al., 2002a; Kallel Trabelsi et al., 2004; Sroka, 2005; Yakovleva et al., 2007).

The total content of phenols in the extracts was determined by the Folin-Ciocalteau reagent (Singleton and Rossi, 1965; Dorman et al., 2003).

**Materials and Methods**

**Chemicals**

Naphthylethylenediamine dihydrochloride and sulphanilamide were obtained from Merck AG (Darmstadt, Germany). All other chemicals and organic solvents used were of analytical grade and purchased from Sigma-Aldrich, Inc (St. Louis, USA). Ultrapure water (18.2 MΩ cm) was prepared using a Millipore Milli-Q 185 plus system (Millipore Corp., Billerica, USA).

**Plant material and extraction**

The moss gametophytes were collected in the south and east regions of The Czech Republic in spring 2005. The samples were identified by Dr. V. Chobot and voucher specimens have been deposited at the Department of Chemical Ecology and Ecosystem Research, Faculty of Life Sciences, University of Vienna, Austria.

The air-dried gametophytes (15 g) were ground and extracted by maceration with 2 ¥ 200 mL of absolute ethanol for 2 ¥ 12 h. The extracts were filtered and concentrated under reduced pressure to dryness. The yields of extracts are reported in Table II.

<table>
<thead>
<tr>
<th>Moss species</th>
<th>Yield of extract (% w/w)</th>
<th>TPC (%a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. undulatum</td>
<td>6.5</td>
<td>8.722 ± 0.803</td>
</tr>
<tr>
<td>P. formosum</td>
<td>3.9</td>
<td>4.387 ± 0.806</td>
</tr>
<tr>
<td>Pl. schreberi</td>
<td>5.6</td>
<td>2.023 ± 0.011</td>
</tr>
<tr>
<td>T. tamariscinum</td>
<td>4.8</td>
<td>3.210 ± 0.773</td>
</tr>
</tbody>
</table>

a Values are presented with ±95% confidence limits (% of gallic acid equivalents in the dried extract).

**Total content of phenols**

Folin-Ciocalteau reagent was prepared and diluted according to the Pharmacopoeia (Europäisches Arzneibuch, 2002). The extract was dissolved in 50% aqueous n-propanol. The concentration was 0.5 mg/mL; 0.2 mL of this solution was mixed with 0.6 mL of Folin-Ciocalteau reagent and after 15 min with 0.6 mL of 10% aqueous Na₂CO₃.

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**Table I. The main classes of constituents reported in the studied species.**

<table>
<thead>
<tr>
<th>Moss species</th>
<th>Reported classes of constituents</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>A. undulatum</td>
<td>Three- and tetraoxygenated coumarin glucosides</td>
<td>Jung et al., 1994</td>
</tr>
<tr>
<td>P. schreberi</td>
<td>Apigenin, apigenin-7-rhamnoglucoside; acetylenic acids and lipids</td>
<td>Vandekerkhove, 1980; Dembitsky et al., 1993; Marsili and Morelli, 1970</td>
</tr>
</tbody>
</table>
After 30 min of incubation at ambient room temperature, the absorbance was measured at 760 nm and compared to a calibration curve of gallic acid (Singleton and Rossi, 1965; Dorman et al., 2003). The controls contained all of the reagents except for the extract. The total phenols were determined as gallic acid equivalents and are presented as means of triplicate analyses.

Iron(III) to iron(II) reducing power (IRP)

The ability of the extracts to reduce iron(III) was assessed by the method described by Dorman et al. (2003). An 1-mL aliquot of each extract dissolved in water was mixed with 2.5 mL of phosphate buffer (0.2 M, pH 6.6) and 2.5 mL of an 1% aqueous potassium hexacyanoferrate, K₃[Fe(CN)₆], solution. After 30 min incubation at 50 °C, 2.5 mL of 10% trichloroacetic acid were added, and the mixture was centrifuged for 10 min. A 2.5-mL aliquot of the upper layer was mixed with 2.5 mL of water and 0.5 mL of 0.1% aqueous FeCl₃, and the absorbance was recorded at 700 nm. The mean absorbance values were plotted against concentration, and a linear regression analysis was carried out. The data are presented as ascorbic acid equivalents in mg per g of extract.

Cyclic voltammetry (CV)

Voltammograms were recorded at room temperature in a three-electrode system μAutolab PGSTAT (EcoChemie, Inc., Utrecht, The Netherlands). The working electrode was a glassy carbon electrode of 3 mm diameter, Ag/AgCl (saturated KCl) was used as the reference electrode and a platinum wire as the counter electrode. The glassy carbon electrode was polished and the platinum electrode was cleaned by flame before every measurement. The CV scan rate was 50 mV s⁻¹. The scan potential was from −300 to +1200 mV. The extracts were dispersed in 0.1 M phosphate buffer, pH 7.4. The concentration was 1 mg/mL. Every experiment was repeated at least twice. The antioxidant activity was calculated as the sum of anodic oxidation peak areas of a cyclic voltammogram, which was compared to a caffeic acid calibration curve. The results are presented as caffeic acid equivalents.

Nitric oxide (NO) scavenging activity

The nitroprusside assay was arranged according to Marcocci et al. (1994) with minor modifications. The extracts were dissolved (2 mg/mL) in a mixture of n-propanol and 0.2 M phosphate buffer, pH 7.4 (1:1 v/v), and serially diluted. 0.9 mL of the extract solution was mixed with 0.1 mL of sodium nitroprusside solution (27.8 mg/mL) in 0.2 M phosphate buffer, pH 7.4. After 1 h of incubation at 25 °C, 1 mL of Griess reagent (1% sulfanilamide, 2% H₃PO₄ and 0.1% naphthylethlenediamine dihydrochloride) was added and the absorbance was read at 546 nm. The negative controls had the same composition without extract. The positive control was caffeic acid. The EC₅₀ values for each moss extract and caffeic acid were obtained by statistical analysis of the linear part of the sigmoid curves of absorbance against the concentration of the moss extract (Table III).

Nonsite-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation (NSSOH)

The ability of the extracts to inhibit nonsite-specific hydroxyl radical-mediated peroxidation was determined essentially as described by Dorman et al. (2004). The reaction mixture contained 500 μL of extract dissolved in KH₂PO₄/KOH buffer (50 mM, pH 7.4), 100 μL of 28 mM 2-deoxy-d-ribose in KH₂PO₄/KOH buffer, 200 μL of premixed 100 μM FeCl₃ and 104 mM ethylenediaminetetraacetic acid (EDTA) (1:1 v/v) solution, 100 μL of 1.0 mM H₂O₂ and 100 μL of 1.0 mM aqueous ascorbic acid. Tubes were vortexed and incubated at 37 °C for 60 min. Thereafter, 50 μL of 2.0% butylated hydroxytoluene were added to each tube followed by 1 mL of 2.8% trichloroacetic acid and 1 mL of 1.0% 2-thiobarbituric acid. The samples were vortexed and heated in a water bath at 100 °C for 20 min. The reaction was stopped by 5 min cooling in an ice water bath. 2 mL of n-butanol were added to each tube, and the mixture was vigorously vortexed. After centrifugation, the extent of oxidation was estimated from the absorbance of the organic layer at 532 nm. EC₅₀ values were estimated using a linear regression of the linear part of the curve.

Site-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation (SSOH)

The ability of the extracts to inhibit site-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation was assayed as described by Dorman et al. (2004), except that EDTA was replaced by KH₂PO₄/KOH buffer (50 mM, pH 7.4).
Results and Discussion

All tested species demonstrated antioxidant and free radical scavenging activities, which were lower in comparison to caffeic acid, a cinnamic acid derivative, which served as positive control (Table III). Of all studied species, those of the family Polytrichaceae showed the highest total phenolic content and the strongest iron(III) to iron(II) reducing power (IRP). These data are also supported by the cyclic voltammograms of the extracts showing the process of anodic oxidation. The voltammograms of A. undulatum and P. formosum display three well visible peaks of oxidation (Fig. 1a). The first anodic peak is quasi-reversible. The voltammetric curves of Pl. schreberi and T. tamariscinum exhibit less pronounced irreversible anodic oxidation peaks (Fig. 1b). Total areas (expressed as caffeic acid equivalents) of the anodic peaks were largest in the voltammograms of the Polytrichaceae. By far, A. undulatum showed the largest values obtained of all extracts (Table III).

A. undulatum and P. formosum were also the most active in the nitric oxide and site-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation (SSOH, a simulation of the Fenton reaction without the presence of the chelator EDTA). The nonsite-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation inhibition activity (NSSOH, a simulation of the Fenton reaction in the presence of the chelator EDTA) was too low for EC50 estimations. In these assays, the Entodontaceae yielded much weaker results compared to the Polytrichaceae. Pl. schreberi was the only active species in the NSSOH test, but the least active in the SSOH test. It contains mainly apigenin derivatives while hydroxycoumarins (daphnin derivatives) are reported constituents of A. undulatum and P. formosum (Table I). The observed effects suggest that the possible dominant mechanism of scavenging of A. undulatum and P. formosum coumarins might comprise not only the direct interaction with ROS but also iron ions chelating. As a consequence, iron(II) ions then become less available for Fenton-type reactions and subsequent hydroxyl radical production (Miller et al., 1990; Dorman et al., 2004). Similar properties were also shown by other moss species, e.g. Ceratodon purpureus (Ditrichaceae) and Dicranum polysetum (Dicranaceae) (Chobot et al., 2006). The iron(II) ions directly participate in Fenton-type reactions of reducing iron(III) to iron(II). Thus they may not only contribute to the antioxidant capacity but also cause pro-oxidative effects via facilitation of the hydroxyl radical production in two steps:

1) Iron(III) is an acceptor of the electron and phenol is a donor:

\[ \text{Fe(III)} + \text{phenolic compound} \rightarrow \text{Fe(II)} + \text{phenoxy}^* \text{ radical.} \]

2) Hydrogen peroxide is an acceptor of the electron and iron(II) is a donor (Miller et al., 1990; Sroka, 2005; see also Fig. 2):

\[ \text{Fe(II)} + \text{H}_2\text{O}_2 \rightarrow \text{Fe(III)} + \cdot\text{OH} + \text{OH}^- \]

This phenomenon might explain the activity of A. undulatum and P. formosum extracts, the species with the strongest activity in the IRP and SSOH assays, but with low activity in the NSSOH assay.

Table III. Iron(III) to iron(II) reducing power, cyclic voltammetry, and 50% effective concentrations (EC50) of antioxidant and free radicals scavenging activities of ethanol extracts of the mosses in comparison with caffeic acid.

<table>
<thead>
<tr>
<th>Moss species</th>
<th>IRP [mg/g]a</th>
<th>CV [mg/g]a</th>
<th>NO [mg/mL]b</th>
<th>NSSOH [mg/mL]c</th>
<th>SSOH [mg/mL]d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. undulatum</td>
<td>79.330 ± 11.911</td>
<td>14.811 ± 5.059</td>
<td>0.088 ± 0.006</td>
<td>&gt; 2.000</td>
<td>0.032 ± 0.005</td>
</tr>
<tr>
<td>P. formosum</td>
<td>48.859 ± 12.086</td>
<td>7.553 ± 1.688</td>
<td>0.029 ± 0.001</td>
<td>&gt; 2.000</td>
<td>0.065 ± 0.006</td>
</tr>
<tr>
<td>Pl. schreberi</td>
<td>2.061 ± 0.352</td>
<td>6.808 ± 1.576</td>
<td>0.728 ± 0.158</td>
<td>0.845 ± 1.316</td>
<td>0.439 ± 0.203</td>
</tr>
<tr>
<td>T. tamariscinum</td>
<td>5.158 ± 0.889</td>
<td>6.286 ± 0.397</td>
<td>0.086 ± 0.003</td>
<td>&gt; 2.000</td>
<td>0.174 ± 0.273</td>
</tr>
<tr>
<td>Caffeic acid</td>
<td>–</td>
<td>–</td>
<td>0.008 ± 0.001</td>
<td>0.033 ± 0.001</td>
<td>0.008 ± 0.001</td>
</tr>
</tbody>
</table>

a IRP, iron(III) to iron(II) reducing power (in mg of ascorbic acid equivalents per g of the dried extract); CV, cyclic voltammetry (in mg of caffeic acid equivalents per g of the dried extract).
b NO, nitric oxide (EC50 in mg/mL).
c NSSOH, nonsite-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation (EC50 in mg/mL).
d SSOH, site-specific hydroxyl radical-mediated 2-deoxy-d-ribose degradation (EC50 in mg/mL); EC50 values were calculated from at least three replicates and are reported with 95% confidence limits.
**Fig. 1.** (a) Cyclic voltammograms of ethanol extracts of *A. undulatum* and *P. formosum*. The curves show three peaks of oxidation (1–3) and one peak of reduction (1'), which is better visible in the *P. formosum* voltammogram. The lower reduction response is caused by polymerization reactions on the surface of the electrode. (b) Cyclic voltammograms of ethanol extracts of *Pl. schreberi* and *T. tamariscinum*. The curves show two oxidation peaks on the *Pl. schreberi* voltammogram (1, 2) and one oxidation peak on the *T. tamariscinum* voltammogram (1). The peaks are in both cases very flat and badly visible. The adsorption of extract constituents and their polymerization reactions on the electrode surface cause the absence of the back reduction.

**Fig. 2.** Reactive oxygen species and their different oxidation stages.

*Pl. schreberi* showed exactly the opposite effects. The scavenging and antioxidant properties of substance mixtures containing flavonoids are crucially influenced by the equilibrium in the reaction mixture, such as the ratio of concentration of the scavenger and the ROS or RNS. The concentration of iron(II) versus iron(III) reflects the possibility of production of highly cytotoxic hydroxyl radicals. The scavenging effect is influenced also by redox reactivity and its reversibility. Thus, a flavonoid can cause also a prooxidative effect after e.g. two electron transfers to oxygen when a quinone and hydrogen peroxide arise (Miura et al., 1998) (Figs. 2 and 3). Their reversible redox equilibrium can be changed by oligomerization with an intermediate phenoxy radical (Hotta et al., 2002b). *T. tamariscinum* scored in the IRP and CV determinations between *P. formosum* and *Pl. schreberi*. It showed similar behaviour in the assays like *A. undulatum* and *P. formosum* but its activity was
weaker. *T. tamariscinum* was the second most active species in the nitric oxide scavenging assay, i.e. it showed good protection against nitric oxide oxidation and nitrite formation or its possible back reduction (Marcocci *et al.*, 1994; Gamal-Eldeen *et al.*, 2007). It remains object of future studies if any of the reported secondary metabolites (Table I) contribute to this effect.

The mixture of compounds present in the cell of a moss fundamentally complicates the predictability of redox reactions because we have to expect both synergistic and antagonistic effects. Their occurrence depends on the experimental milieu (Miura *et al.*, 1998; Simić *et al.*, 2007). Nevertheless, the methanolic extracts of the investigated mosses showed apparent antioxidant activity. The various experimental conditions modulated the effects, which partially correlated with known patterns of secondary metabolites in their tissues. More extensive studies using a combination of various experimental approaches as demonstrated here will certainly contribute to improved insights into the complex interactions of secondary metabolites with redox equilibrium and stress in the cell. The simple organisation of their tissues – moss cells lack a central vacuole, which is usually present in higher plants – reduces the extracted metabolites to mainly those, which we can assume to be active in the cytosol. This, on one hand, might offer attractive models to understand the functionality of these compounds in maintaining stress homeostasis. On the other hand, mixtures of secondary metabolites obtained from moss sources might provide pharmacy with evolutionary optimized model structures with high potential to be developed in medicinal applications.

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