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FT-Raman signatures of genomic DNA from plant tissues

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Abstract. The vibrational spectra of eight genomic DNAs from leaf tissues (sword fern (*Nephrolepis exaltata* L.), chrysanthemum (*Dendranthema grandiflora* Ramat.), redwood (*Sequoia sempervirens* D. Don. Endl.), orchids (*Cymbidium* × *hybrida*), common sundew (*Drosera rotundifolia* L.), potato (*Solanum tuberosum* L.) and scopolia (*Scopolia carniolica* Jacq.)) have been analyzed using FT-Raman spectroscopy, in the wavenumber range 500–1800 cm^{-1}.

FT-Raman signatures, spectroscopic assignments and structural interpretations for these plant genomic DNAs are reported. Spectral differences among two genomic DNAs, independently extracted from chrysanthemum leaves, are to be observed between 1000–1200 cm^{-1}. Besides, similarities in the FT-Raman spectra of genomic DNAs from potato and scopolia leaves, respectively, have been found. This might be explained by their belonging to the same family (Solanaceae). Other spectral differences among genomic plant DNAs have also been observed.

These findings demonstrate that Raman spectroscopy may be exploited to distinguish different plant genomic DNAs.

The present study provides a basis for future use of Raman spectroscopy to analyze specific plant DNA–ligand interactions or DNA structural changes induced by plants' stress conditions associated with their natural environment.

Keywords: Molecular structure, genomic DNA, leaf tissue, FT-Raman spectroscopy

1. Introduction

Plants are subjected to a variety of stress conditions associated with their natural environment. Structural features of nucleic acids in biological assemblies are of particular importance, because they can also reflect these types of changes.

Raman spectroscopy offers certain advantages for the investigation of structural, dynamical, thermodynamic and kinetic properties of DNA [1]. This approach can provide definitive information about covalent bonding configurations and is also potentially informative of electrostatic, hydrophobic, and hydrogen-bonding interactions involving specific nucleotide subgroups [2]. The Raman method is not limited by size or state of aggregation of the DNA specimen ([1] and references therein). The utility of the method to distinguish binding of divalent cations to DNA, to establish the low pH-induced DNA structural changes [3–6], to monitor thermal denaturation of DNA and DNA/metal-ion complexes, and

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to measure the kinetics of proton/deuteron exchanges of genomic DNA in condensed and uncondensed states has already been demonstrated ([1] and references therein).

A particular strength of the method is its applicability over a wide range of sample morphologies. For example, Raman spectroscopy has been employed to determine structures, interactions and dynamics of viral chromosomes in native virion assemblies and to map DNA conformation along eukaryotic chromosomes ([2] and references therein).

Besides, Raman difference spectroscopy provides a convenient and powerful approach for quantitatively assessing structural changes in nucleic acids as a function of molecular interactions induced by the addition of binding agents (cations, proteins, drugs, etc.) or of conformational changes induced by altering environmental factors (temperature, pH, salinity, etc.) [7].

In this work the FT-Raman spectra of eight genomic DNAs from leaf tissues (sword fern (*Nephrolepis exaltata* L.), chrysanthemum (*Dendranthema grandiflora* Ramat.), redwood (*Sequoia sempervirens* D. Don. Endl.), orchids (*Cymbidium* × *hybrida*), common sundew (*Drosera rotundifolia* L.), potato (*Solanum tuberosum* L.) and scopolia (*Scopolia carniolica* Jacq.)) have been studied between 500–1800 cm^{-1}. FT-Raman signatures, spectroscopic assignments and structural interpretations for these plant genomic DNAs are reported. Two DNA samples, independently extracted from chrysanthemum leaves, have been considered.

Future plant DNA experiments can be carried out to analyze specific genomic DNA–ligand interactions, to study the effects of solar ultraviolet-B radiation (UV-B) on nucleic acids [8], to determine the influence of the salinity stress [9,10] or of the oxidative stress [11] on DNA structure and dynamics.

2. Materials and methods

2.1. Plant material

Leaves from *in vitro*-grown species were the source material for extraction of genomic DNA. These fully expanded leaves were obtained from plants of: sword fern (*Nephrolepis exaltata* L., Fam. Polypodiaceae), chrysanthemum (*Dendranthema grandiflora* Ramat., Fam. Asteraceae), redwood (*Sequoia sempervirens* D. Don. Endl., Fam. Taxodiaceae), orchids (*Cymbidium* × *hybrida,* Fam. Orchidaceae), common sundew (*Drosera rotundifolia* L., Fam. Droseraceae), carnation (*Dianthus caryophyllus* L., Fam. Caryophyllaceae), potato (*Solanum tuberosum* L., Fam. Solanaceae) and scopolia (*Scopolia carniolica* Jacq., Fam. Solanaceae). The mentioned species were *in vitro* cultured on a Murashige and Skoog (1962) (MS) medium [12] supplemented with 1 mg/l vitamins (Thyamine, Pyridoxine, Nicotinic acid), 30 g/l sucrose and 7 g/l agar (Sigma). The pH was adjusted to 5.7 before autoclaving (15 min at 121°C and 1200 hPa). The plantlets were grown at 24°C during a 16 h light/8 h dark photoperiod with a light intensity of 38 μmol/m^2/s photosynthetic active radiation (PAR) provided by cool white fluorescent tubes. Subcultures of the plantlets were performed every 4 weeks.

2.2. DNA extraction protocol

Genomic DNA was isolated according to the procedure of Doyle and Doyle (1987) [13]. Leaf tissue (100 mg) was ground to a fine powder in liquid nitrogen. The frozen powder was transferred to 500 μl hexadecyltrimethylammonium bromide (CTAB) extraction buffer (2% CTAB, 100 mM Tris HCl (pH 8.0), 1.4 mM NaCl, 20 mM EDTA, 0.2% mercaptoethanol) and incubated at 65°C for 60 min with

occasional shaking. It was centrifuged 10 min at 14,000*g*. The supernatant (500 µl) was transferred to a fresh tube, 200 µl of chloroform: isoamylalcohol (24:1 v/v) was added and mixed by inversion, then centrifuged at 14,000*g* and 4°C for 10 min. The aqueous phase (200 µl) was transferred to a fresh tube and precipitated with 200 µl isopropanol, centrifuged at 10,000*g* and 4°C for 10 min. The supernatant solution was removed and the precipitated DNA was washed with 70% etanol and redisolved in 200 µl TE buffer (10 mM Tris HCl, pH 8.0 and 1 mM EDTA, pH 8.0). The quality of extracted DNA was analyzed by means of agarose gel electrophoresis (0.8%), followed by ethidium bromide staining.

2.3. Fourier transform Raman spectroscopy

The FT-Raman spectra were recorded in backscattering geometry (180°) with a Bruker FRA 106/S Raman accessory equipped with an InGaAs detector and attached to the conventional Bruker Equinox 55 FT-IR spectrometer. The 1064 nm Nd:YAG laser was used as excitation source, and the laser power was set to 400 mW. 500 scans were accumulated and averaged for each spectrum. All samples were maintained at room temperature (21°C). Spectra acquisition was performed using Bruker OPUS version 4.0 spectroscopy software. Measurements on the DNA samples were followed by the background signal measurement at identical experimental settings, in order to determine the spectral contribution from the buffer solution and the quartz recipient, which was then subtracted from each DNA sample spectrum.

3. Results and discussion

FT-Raman spectral profiles in the region 500–1800 cm^{-1} of the eight genomic DNAs extracted from sword fern, chrysanthemum, redwood, orchids, common sundew, potato and scopolia leaves, respectively, are presented in Figs 1–8. Labels indicate wavenumber values for the more prominent bands in

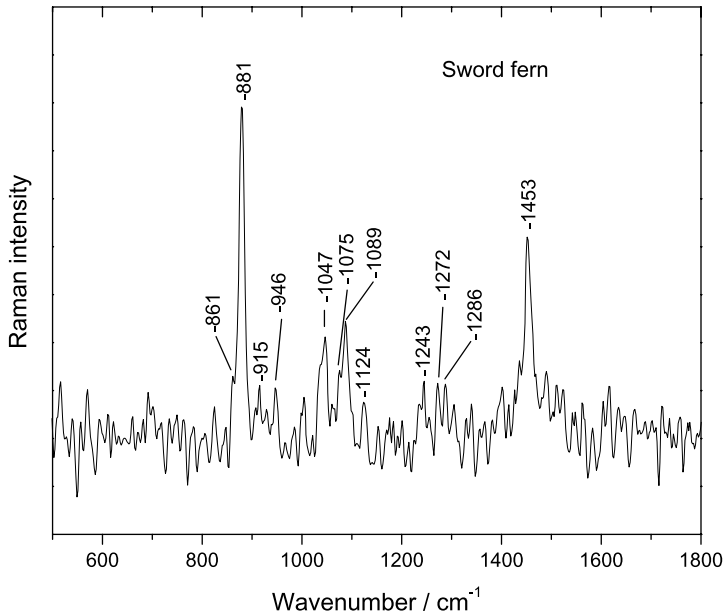

Fig. 1. FT-Raman spectrum of genomic DNA extracted from sword fern leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

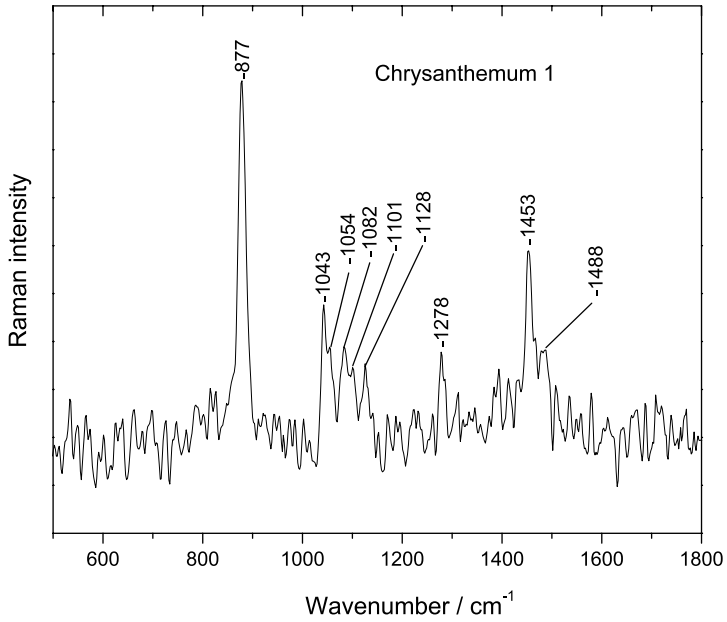

Fig. 2. FT-Raman spectrum of genomic DNA extracted from chrysanthemum leaves (extraction 1) in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

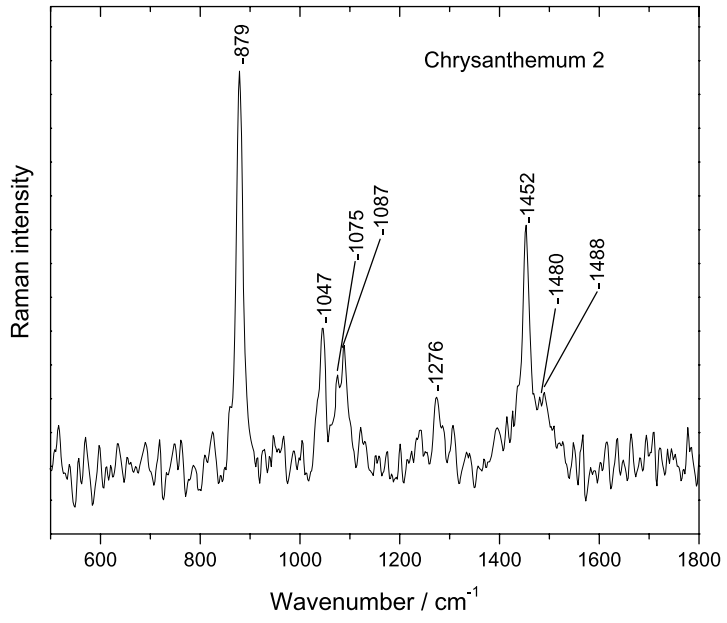

Fig. 3. FT-Raman spectrum of genomic DNA extracted from chrysanthemum leaves (extraction 2) in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

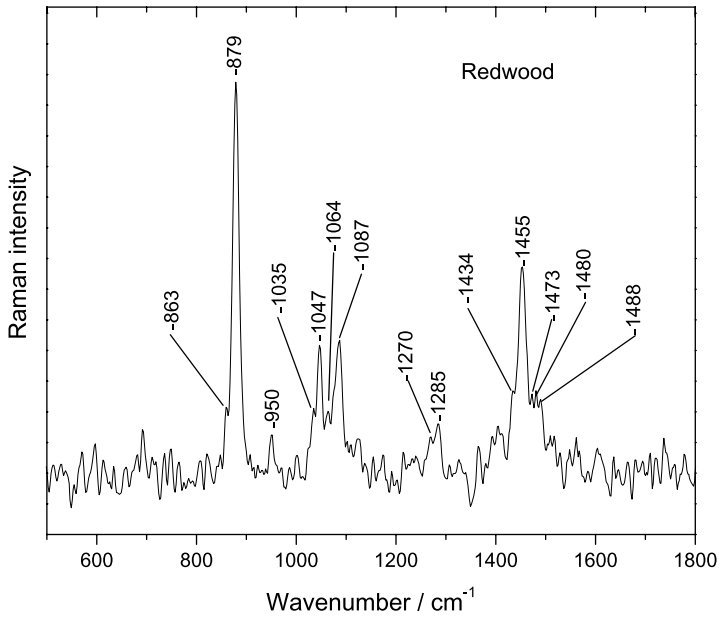

Fig. 4. FT-Raman spectrum of genomic DNA extracted from redwood leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

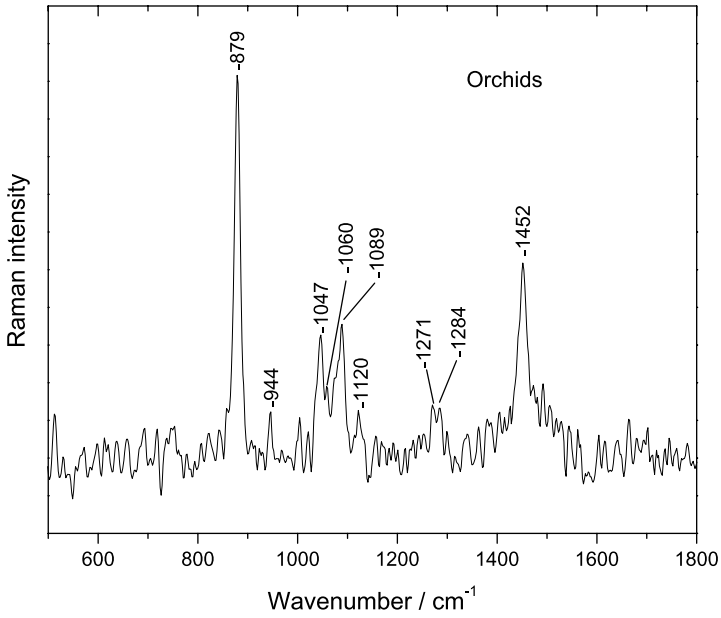

Fig. 5. FT-Raman spectrum of genomic DNA extracted from orchids leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

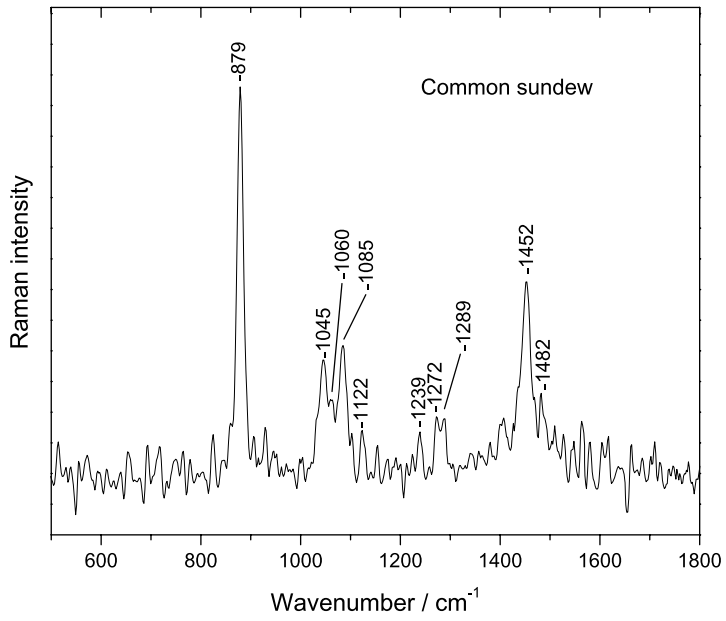

Fig. 6. FT-Raman spectrum of genomic DNA extracted from common sundew leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

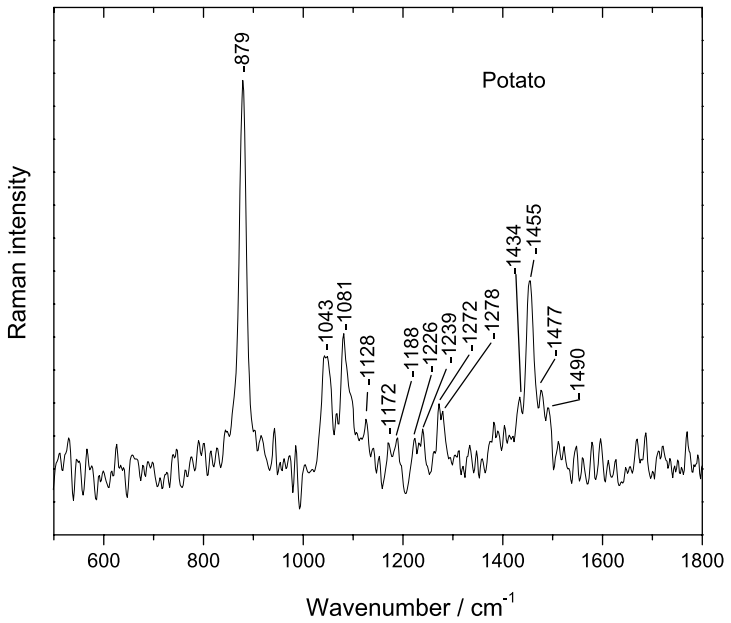

Fig. 7. FT-Raman spectrum of genomic DNA extracted from potato leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

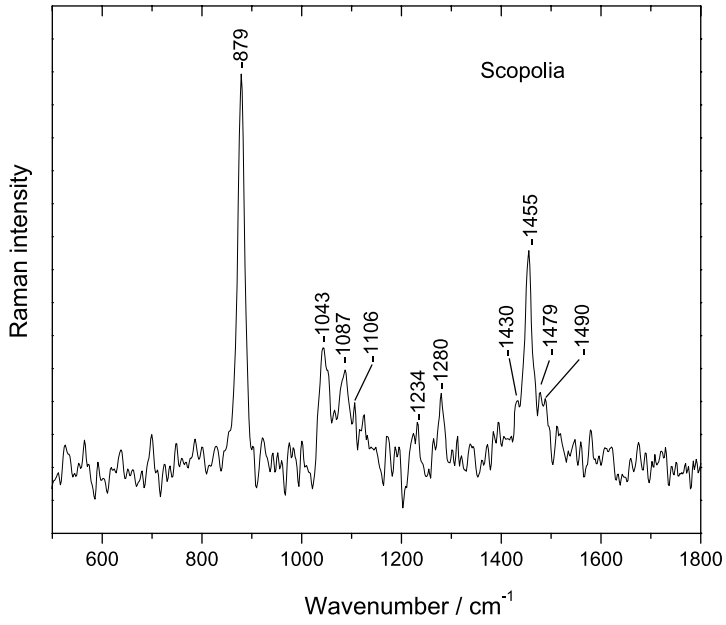

Fig. 8. FT-Raman spectrum of genomic DNA extracted from scopolia leaves in the 500–1800 cm^{-1} spectral region. The Raman signal contribution of the buffer solution was subtracted. Scans number: 500; laser power 400 mW.

each spectrum (cm^{-1} units). Two DNA samples, independently extracted from chrysanthemum leaves, have been investigated (Figs 2–3). In the following we will refer to the source of these extractions as chrysanthemum 1 and chrysanthemum 2.

A poor FT-Raman spectrum was obtained for genomic DNA extracted from carnation leaves (data not shown).

Raman wavenumbers and tentative assignments of genomic DNA extracted from potato leaves are given in Table 1.

A detailed comparative analysis of the FT-Raman signatures of the eight genomic DNAs is presented in Table 2. Proposed Raman band assignments found in the literature for similar compounds are also included. In some cases, assignments are described in terms of a specific DNA atom or functional group, which makes the related Raman band very useful for recognition of specific DNA–ligand interactions [14].

A shoulder was observed at 861 cm^{-1} in the FT-Raman spectrum of DNA extracted from sword fern leaves, and at 863 cm^{-1} in the FT-Raman spectrum of DNA from redwood. These bands can be assigned to DNA backbone vibrations [1].

A strong band was found at 879 cm^{-1} for genomic DNAs extracted from chrysanthemum 2, redwood, orchids, common sundew, potato and scopolia leaves, respectively (Figs 3–8). This band, originating from the stretching vibration of the deoxyribose ring [2,14,15], phosphodiester mode (875 cm^{-1}, indicative of the C form) [15,16] and ring vibration of adenine [17], appeared at 881 cm^{-1} in the FT-Raman spectrum of DNA from sword fern and at 877 cm^{-1} for the chrysanthemum 1 leaves. Disruption of hydrogen bonding between water molecules and polar groups of the sugar–phosphate backbone, as a consequence of either elevating the solution temperature, lowering the solution pH, or lowering the relative humidity in fibers ([15] and references therein), may produce a band at 872 cm^{-1} which accompanies the B-to-C structure transformation of calf thymus DNA fibers ([15] and references therein).

Table 1
Raman wavenumbers and tentative assignments of genomic DNA from potato leaves

Raman wavenumbers (cm^{-1})	Tentative assignment
879	Stretching vibration of the deoxyribose ring [2,14,15], phosphodiester mode (875 cm^{-1}, indicative of the C form) [15,16], ring vibration of adenine [17]
1043	CO stretching of the phosphodiester network (C–O–P–O–C) [15,18] ring vibration of guanine [17]
1081	P–O symmetric stretching of the phosphodioxy group (PO_2^-) [2–4,14–16,18–22]
1128	Ring vibration of adenine [17]
1172	Ring vibrations of cytosine, guanine [14]
1188	Ring vibrations of guanine [17], thymine, cytosine [15]
1226	P–O asymmetric stretching of the phosphodioxy group (PO_2^-) [18], cytosine [1,14]
1239	Ring vibrations of thymine [1–4,15,19,20] cytosine [1–4,14,19,20,22], guanine [17]
1272	Ring vibrations of cytosine, guanine, thymine [17]
1278	Ring vibration of cytosine [1,17]
1434 sh[a]	Ring vibration of thymine [17]
1455	CH_2 scissor of deoxyribose [2,14,21], ring vibrations of adenine [14,17], cytosine [17], thymine [17]
1477 sh	Ring vibration of guanine [17], adenine [17]
1490 sh	Ring mode (guanine, adenine) [2,14]

Abbreviations: [a]sh – shoulder.

The band near 915 cm^{-1}, which was observed in the FT-Raman spectrum of DNA from sword fern, is assigned to the deoxyribose and to DNA backbone [15].

The sugar residues of DNA are expected to be major contributors to the weak Raman band observed near 950 cm^{-1} in the case of DNA extraction from redwood leaves ([1] and references therein). This band, assigned to a vibration localized in the deoxyribose moiety, was detected at 946 cm^{-1} in the case of genomic DNA extracted from sword fern and at 944 cm^{-1} for orchids (Figs 1 and 5).

A shoulder near 1035 cm^{-1} in the FT-Raman spectrum of genomic DNA extracted from redwood leaves is probably due to dA and dG residues [17].

A band appeared also at 1047 cm^{-1} for DNAs from sword fern, chrysanthemum (extraction 2), redwood, and orchids, respectively. This marker band, due to a complex vibrational mode involving the CO stretching of the phosphodiester network (C–O–P–O–C) [15,18] and the ring vibration of guanine [17], was noticed at 1045 cm^{-1} in the case of DNA sample from common sundew and at 1043 cm^{-1} for genomic DNAs from chrysanthemum (extraction 1), potato and scopolia, respectively.

A band near 1054 cm^{-1}, originating in DNA backbone (sugar C–O stretching mode) [15] is indicated in connection with the Raman spectral changes accompanying the melting of DNA [15]. A shoulder appeared at this wavenumber in the FT-Raman spectrum of genomic DNA extracted from chrysanthemum 1. This band was observed at 1064 cm^{-1} in the case of DNA from redwood and at 1060 cm^{-1} in the case of DNAs from orchids and common sundew, respectively.

A strong band appeared at 1089 cm^{-1} in the FT-Raman spectra of genomic DNA extracted from sword fern and orchids, respectively, which is due to the symmetric stretching vibration of the phosphodioxy (PO_2^-) moiety [2–4,14–16,18–22]. This band was detected at wavenumbers values between 1081–1089 cm^{-1} for genomic DNAs from different leaf tissues (see Table 2). This marker band was found at 1100 cm^{-1} in A-DNA and RNA (PO_2^- symmetric stretch) [1,2,7]. A vibration originating mainly in the deoxyribose appeared also in our spectra at 1101 cm^{-1}, in the case of DNA extracted from chrysanthemum 1 and at 1106 cm^{-1}, in the case of genomic DNA extracted from scopolia.

Table 2
Raman wavenumbers (cm^{-1}) and tentative assignments of genomic DNA from different leaf tissues

Sword fern	Chrysan-themum 1	Chrysan-themum 2	Redwood	Orchids	Common sundew	Potato	Scopolia	Tentative assignment[a]
861 sh[b]			863 sh					Sugar-phosphate backbone
881	877	879	879	879	879	879	879	Deoxyribose, phosphodiester, dA
915								Deoxyribose, backbone
946			950	944				Deoxyribose
			1035 sh					dA, dG
1047	1043	1047	1047	1047	1045	1043	1043	CO stretching (C–O–P–O–C), dG
	1054 sh		1064 sh	1060 sh	1060 sh			Backbone (stretching CO)
1089	1082	1087	1087	1089	1085	1081	1087	P–O sym. stretching of (PO_2^-)
	1101						1106	Deoxyribose, PO_2^- sym. stretch[c]
1124	1128			1120	1122	1128		dA
						1172		dC, dG
						1188		dG, dT, dC
						1226		P-O asym. stretching (PO_2^-), dC
1243					1239	1239	1234	dT, dC, dG
1272			1270	1271	1272	1272		dC, dG, dT
1286	1278	1276	1285	1284	1289	1278	1280	dC
			1434 sh			1434 sh	1430 sh	dT
1453	1453	1452	1455	1452	1452	1455	1455	Deoxyribose, dA, dC, dT
			1473 sh					dA
		1480 sh	1480 sh			1477 sh	1479 sh	dG, dA (N7)
	1488	1488 sh	1488 sh		1482	1490 sh	1490 sh	dG (N7), dA

[a]*Abbreviations*: dA – deoxyadenosine; dG – deoxyguanosine; dC – deoxycytidine; dT – thymidine.

[b]sh – shoulder.

[c]Indicator of A-DNA.

Raman spectrum of DNA contains many overlapping bands in the region 1100–1600 cm^{-1}, which originate primarily from in-plane vibrations of base residues ([1] and references therein). Previous studies ([1] and references therein) showed that these bands cannot be assigned unambiguously because of the peaks overlap and also because the intensity of the bands in this spectral range is in general sensitive to the base-stacking interactions (Raman hypochromism).

The 1128 cm^{-1} band in the spectra of DNA from chrysanthemum 1 and potato, respectively, might be attributed to the ring vibration of adenine [17]. This vibration was observed at 1124 cm^{-1} in the case of DNA extracted from sword fern, at 1120 cm^{-1} for DNA from orchids and at 1122 cm^{-1} for genomic DNA extracted from common sundew.

The peak at 1172 cm^{-1} in the FT-Raman spectrum of genomic DNA extracted from potato leaves is due to the ring vibrations of cytosine and guanine [14].

The band centered near 1188 cm^{-1} for the case of DNA extracted from potato leaves, contains a major contribution from cytosine residues at 1178 cm^{-1}, and only a minor contribution from thymine residues at 1190 cm^{-1} ([1] and references therein). This band might be due also to the guanine residues, as indicated by some authors [17], whereas others exclude guanine as a contributor [1].

The 1226 cm^{-1} band of genomic DNA extracted from potato leaves might be due to the P–O asymmetric stretching of the phosphodioxy group (PO_2^-) [18] and to the cytosine residues [1,14].

The peak at 1239 cm^{-1} in the FT-Raman spectra of DNA from common sundew and potato leaves are mostly due to the ring vibrations of thymine [1–4,15,19,20] and cytosine [1–4,14,19,20,22]. Other authors indicate also the guanine [17] as a contributor to the band. This Raman marker appears near 1243 cm^{-1} for DNA from sword fern and at 1234 cm^{-1} for DNA from scopolia.

The band near 1272 cm^{-1} present in the FT-Raman spectra of genomic DNAs extracted from sword fern, common sundew and potato leaves, arise from the ring vibrations of cytosine [1,17], guanine [17], and thymine [17]. Some authors exclude the contribution of thymine residues to this line [1]. This band was found at 1270 cm^{-1} for DNA extracted from redwood leaves and at 1271 cm^{-1} for genomic DNA from orchids.

The FT-Raman band appearing in the wavenumber range 1276–1289 cm^{-1} for genomic DNA from different leaf tissues (see Table 2) can be attributed to the ring vibration of cytosine [1,17].

A shoulder at 1434 cm^{-1} in the case of DNA from redwood and potato, respectively, might be due to a ring vibration of thymine [17]. This shoulder appears at 1430 cm^{-1} in the case of genomic DNA extracted from scopolia (see Table 2).

A prominent band appeared at 1455 cm^{-1} in the Raman spectra of genomic DNAs extracted from redwood, potato and scopolia leaves, respectively and is attributed to the CH_2 scissor of deoxyribose [2, 14,21], ring vibrations of adenine [14,17], cytosine [17] and thymine [17]. This band was detected at 1453 cm^{-1} in the case of DNA from sword fern and chrysanthemum 1 and at 1452 cm^{-1} for genomic DNA extracted from chrysanthemum 2, orchids and common sundew, respectively.

The shoulder at 1473 cm^{-1} in the spectrum of DNA extracted from redwood leaves is probably due to contributions from aromatic stretching modes, largely adenine ([14] and references therein).

The Raman shoulder near 1480 cm^{-1}, attributed to DNA extracted from chrysanthemum 2 and redwood leaves, is due primarily to a vibration localized in the guanine imidazolium ring ([23] and references therein). An adenine contribution is also expected [1,14,17]. N7 of adenine might be implied in this vibration [14]. This band was found at 1477 cm^{-1} and at 1479 cm^{-1} in the case of DNAs from potato and scopolia leaves, respectively.

The guanine (N7) band near 1488 cm^{-1} might be also due to dA residues [2,14]. This vibration appeared at this wavenumber for genomic DNAs extracted from chrysanthemum 1, chrysanthemum 2 and redwood leaves, respectively, and was observed at 1482 cm^{-1} for common sundew DNA and at 1490 cm^{-1} in the case of potato and scopolia DNAs, respectively. It has been shown that the band near 1488 cm^{-1} shifts to lower wavenumbers with thermal denaturation, an effect which can be attributed to stronger hydrogen bonding of solvent with the guanine N7 site in denatured DNA [15]. The 1488 cm^{-1} vibration also shows an increase in intensity with DNA melting [3,15]. These features might suggest that DNA extracted from common sundew leaves is partially melted.

Spectral differences among the two genomic DNAs, independently extracted from chrysanthemum leaves, are to be observed in the region 1000–1200 cm^{-1} (see Figs 2, 3 and Table 2). Besides, similarities of the FT-Raman spectra of genomic DNAs from potato and scopolia leaves, respectively, have been found (Figs 7, 8 and Table 2). This might be explained by their belonging to the same family (Solanaceae). Other spectral differences among genomic plant DNAs have also been observed (see Figs 1–8 and Table 2). It is proposed that GC or AT basepairs amount in the genomic DNAs is an important factor in determining their Raman signature [1].

The present findings demonstrate that Raman spectroscopy may be exploited to distinguish different plant genomic DNAs.

4. Conclusions

FT-Raman spectra of eight genomic DNAs from sword fern (*Nephrolepis exaltata* L.), chrysanthemum (*Dendranthema grandiflora* Ramat.), redwood (*Sequoia sempervirens* D. Don. Endl.), orchids (*Cymbidium* × *hybrida*), common sundew (*Drosera rotundifolia* L.), potato (*Solanum tuberosum* L.) and scopolia (*Scopolia carniolica* Jacq.) have been discussed in the wavenumber range 500–1800 cm^{-1}.

A detailed comparative analysis of Raman signatures of the seven DNA species is given. Two extractions of DNA from chrysanthemum are considered. Raman wavenumbers (in cm^{-1}) are given for all types of vibrations for plant genomic DNAs, including bands assigned to localized vibrations of the purine and pyrimidine residues, localized vibrations of the deoxyribose-phosphate moiety, etc. [1]. Bands near 861 cm^{-1} (backbone), 879 cm^{-1} (deoxyribose, dA), 915 cm^{-1} (deoxyribose, backbone), 950 cm^{-1} (deoxyribose), 1035 cm^{-1} (dA, dG), 1047 cm^{-1} (CO stretching C–O–P–O–C, dG), 1054 cm^{-1} (backbone, stretching CO), 1089 cm^{-1} (P–O symmetric stretching of PO_2^-), 1101 cm^{-1} (deoxyribose, PO_2^- symmetric stretch), 1128 cm^{-1} (dA), 1172 cm^{-1} (dC, dG), 1188 cm^{-1}, (dG, dT, dC), 1226 cm^{-1} (P–O asymmetric stretching PO_2^-, dC), 1239 cm^{-1} (dT, dC, dG), 1272 cm^{-1} (dC, dG, dT), 1276 cm^{-1} (dC), 1434 cm^{-1} (dT), 1455 cm^{-1} (deoxyribose, dA, dC, dT), 1473 cm^{-1} (dA), 1480 cm^{-1} (dG, dA) and 1488 cm^{-1} (dG, dA), characteristic to genomic DNAs from different leaf tissues are presented in detail.

We have found that common sundew DNA might be in a partially melted state, judging from its band near 1482 cm^{-1}.

Spectral differences among the two genomic DNAs, independently extracted from chrysanthemum leaves, are to be observed in the wavenumber range 1000–1200 cm^{-1}. Besides, similarities of the FT-Raman spectra of genomic DNAs from potato and scopolia leaves, respectively, have been found. This might be explained by their belonging to the same family (Solanaceae). Other spectral differences among genomic plant DNAs have also been observed (see Table 2).

The present findings demonstrate that Raman spectroscopy may be exploited to distinguish different plant genomic DNAs. It is proposed that GC or AT basepairs amount in the genomic DNAs is an important factor in determining the Raman signature [1].

This study provides a basis for future use of Raman spectroscopy to analyze specific plant DNA-ligand interactions or DNA structural changes induced by plants' stress conditions associated with their natural environment.

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