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Revision of the genus *Solorina* (Lichenes) in Europe based on spore size variation

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The variation of the spore size and wall ornamentation in the European species of the lichen genus *Solorina* Ach. was studied. Sixty one samples were analyzed using statistical analyses (ANOVA, PCA). SEM micrographs of the taxa are provided. The results show that *Solorina monospora* Gyeln. is a distinct species and *S. bispora* Nyl. consists of ssp. *bispora* and ssp. *macrospora* (Harm.) Burgaz & Martínez *comb. nov.*

Key words: Europe, lichens, *Solorina*, spore, taxonomy

INTRODUCTION

The lichen genus *Solorina* Ach. was described by Acharius (1808: 228) to include terricolous lichens with a foliose thallus and ascoma impressed in the upper surface. The European taxa of this genus were studied by Hue (1911) and Gilbert (1975, 1992). Seven taxa were accepted: *S. bispora* Nyl. with three varieties (var. *bispora*, var. *macrospora* (Harm.) H. Olivier and var. *monospora* (Gyeln.) Frey), *S. crocea* (L.) Ach., *S. octospora* (Arnold) Arnold, *S. saccata* (L.) Ach. and *S. spongiosa* (Ach.) Anzi. They are rather homogeneous in their morphology, and the size and ornamentation of the spores are the main characters to distinguish them.

Nevertheless, some controversies related to spore ornamentation between European and American populations of *Solorina saccata* have been noted (Thomson & Thomson 1984, Krog & Swinscow 1986). In the course of our study on *Solorina* in connection with the Spanish project "Lichen Flora of the Iberian Peninsula" it was necessary to clarify if these characters have taxonomic value in the delimitation of the European taxa.

MATERIAL AND METHODS

The holotype of *Solorina bispora* was examined and further European material in the herbaria BCC, GDA, GZU, H, H-NYL, MA, MACB, as well as in the authors' personal herbaria.

Sixty one samples, mainly of European taxa, were studied (*see* Appendix). For each sample three characters were considered: (1) width, (2) length, and (3) wall ornamentation of the spores. In addition, the number of spores in the ascus and number of septa were included for the statistical analysis of the taxa included in *Solorina bispora*.

For each sample twenty mature and released spores were measured from handcut sections of apothecia using an Image Analysing Computer. Statistical analyses of the data were performed using Statistical Package Statgraphics (version 5.0) of the Statistical Graphics Corporation (1987). ANOVA analysis was employed to see if the data differed significantly. Bartlet's test was used to reveal the homogenous variance of the data. Principal Component Analysis

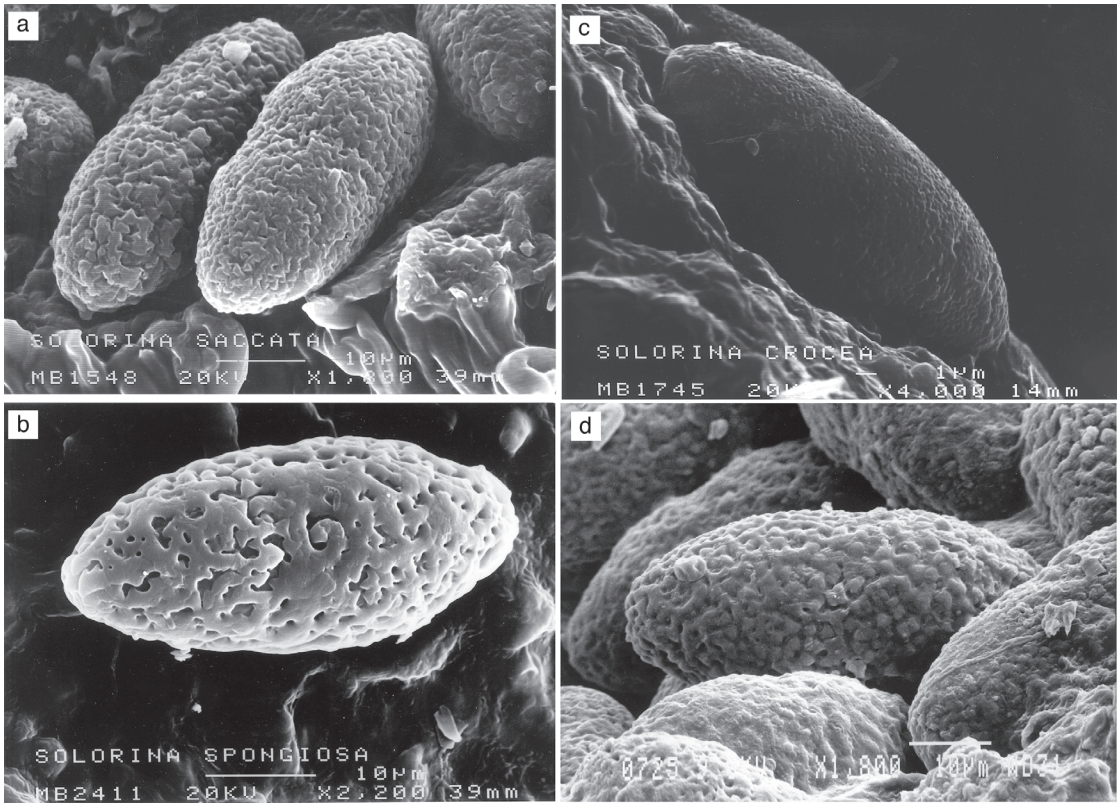

Fig. 1. *Solorina* spp. SEM micrographs of spore wall ornamentation. — a: *S. saccata* (L.) Ach. — b: *S. spongiosa* (Ach.) Anzi. — c: *S. crocea* (L.) Ach. — d: *S. octospora* (Arnold) Arnold.

(PCA) of the taxa included in *S. bispora* was carried out to determine the interrelationships between the measured variables and their grouping into complex gradients. Using this method of analysis the variables were standardized by the transformation: variable – mean/standard deviation.

The spore wall ornamentation was studied with a scanning electron microscope (SEM). The apothecia were vacuum-coated with gold-paladium.

RESULTS AND DISCUSSION

The results of the ANOVA analysis show significant differences in the width and length of the spores (Table 1). In general, mean spore sizes increase when the spore number in the ascus decreases. Thus, the spores of *Solorina octospora*

Table 1. *Solorina* spp. Mean ± standard deviation and ranges (in parentheses) of variables (in μm). *p* = significance level (tested with ANOVA).

Variable	Spore width	Spore length	Ornamentation
S. bispora var. *bispora*	32.9 ± 4.1 (22.7–44.2)	79.9 ± 9.6 (60.1–119.0)	deeper continuous reticulum
S. bispora var. *macrospora*	39.0 ± 7.2 (28.4–56.8)	110.7 ± 14.2 (82.9–154.0)	deeper continuous reticulum
S. bispora var. *monospora*	35.2 ± 4.8 (26.4–47.6)	121.2 ± 17.5 (92.9–161.5)	deeper continuous reticulum
S. crocea	11.0 ± 1.3 (8.4–21.2)	39.0 ± 4.8 (26.6–51.1)	rounded free papillae
S. octospora	13.3 ± 2.0 (10.4–33.3)	36.8 ± 3.3 (28.7–51.1)	rounded free papillae
S. saccata	20.0 ± 2.6 (13.6–27.5)	46.4 ± 5.6 (32.0–68.4)	isolate triangular structures
S. spongiosa	19.0 ± 2.0 (14.5–25.3)	44.6 ± 4.5 (29.0–57.5)	network with deep angular lacunae
p	< 0.001	< 0.001	

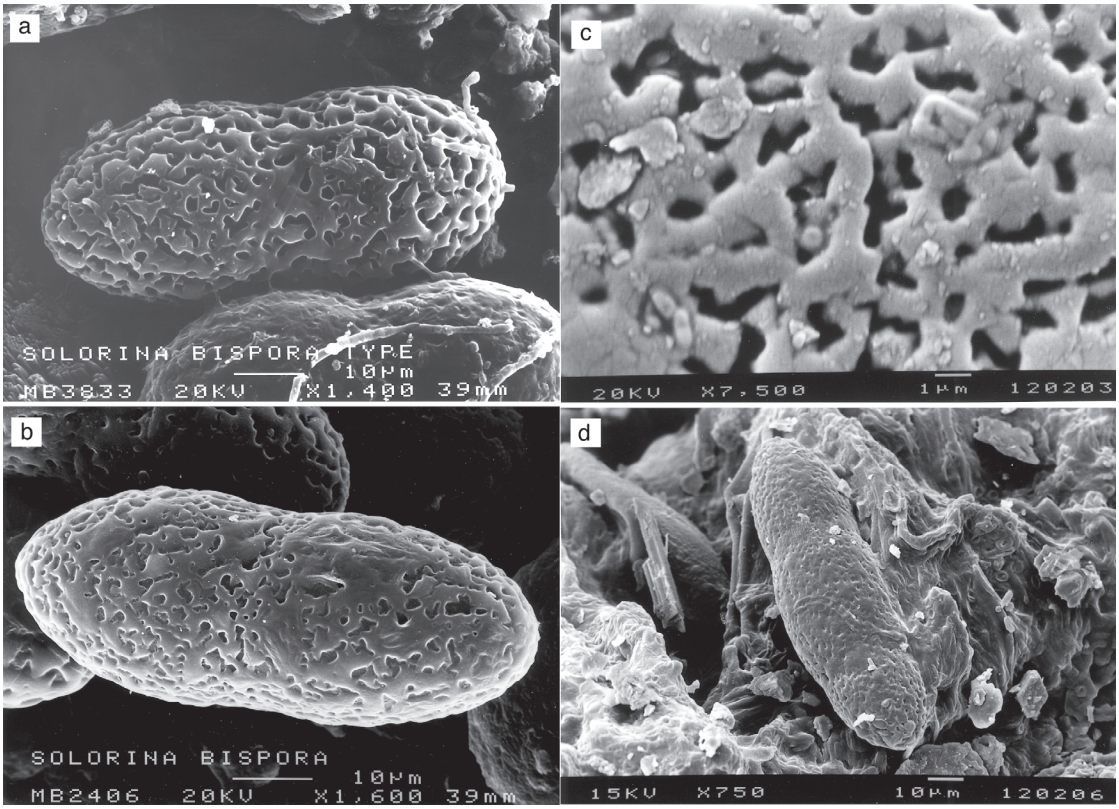

Fig. 2. *Solorina* spp. SEM micrographs of spore wall ornamentation. — a: *S. bispora* Nyl. var. *bispora*. — b: *S. bispora* var. *macrospora* (Harm.) Martínez & Burgaz. — c and d: *S. bispora* var. *monospora* (Gyeln.) Frey.

(eight spores in the ascus) were the smallest while those of *S. bispora* var. *monospora*, (one spore in the ascus), the biggest.

The wall ornamentation in the studied spores of *Solorina saccata* (isolated triangular structures, Fig. 1a) was similar to the Norwegian material studied by Krog and Swinscow (1986), but different from the North American material (irregular elongate ridges mixed with papillae) published by Thomson and Thomson (1984).

Solorina spongiosa had a network with deep angular lacunae in the spore wall (Fig. 1b). Although *S. saccata* and *S. spongiosa* had the same spore size, the ornamentation was clearly different (Fig. 1a and b) and this supports the recognition of *S. saccata* and *S. spongiosa* as two different species.

Solorina crocea and *S. octospora* were similar in spore size and had the same wall ornamentation of rounded free papillae (Fig. 1c and d). However, they were easily distinguished, since *S. crocea* had an orange medulla (solorinic acid).

The spore size differed significantly among the taxa recognized in *Solorina bispora*. However, they all had the same wall ornamentation of a continuous reticulum (Fig. 2). In this case, a Principal Component Analysis (PCA) was run within this group, adding the number of septa and number of spores in the ascus in order to elucidate the taxonomical status of the infraspecific taxa.

The first and second component accounted for 92% of the variation in the data set, therefore two groups could be found (Fig. 3). The first group consisted of *Solorina bispora* var. *monospora*, and the second group of *S. bispora* var. *bispora* and *S. bispora* var. *macrospora*.

According to this analysis, *Solorina bispora* var. *monospora* should be considered as a separate species, the correct name of which is *S. monospora* Gyeln. (Magyar Bot. Lapok 29: 29. 1939). It has very big spores ($121.2 \pm 17.5 \times 35.2 \pm 4.8$ µm) with two septa, and only one spore in

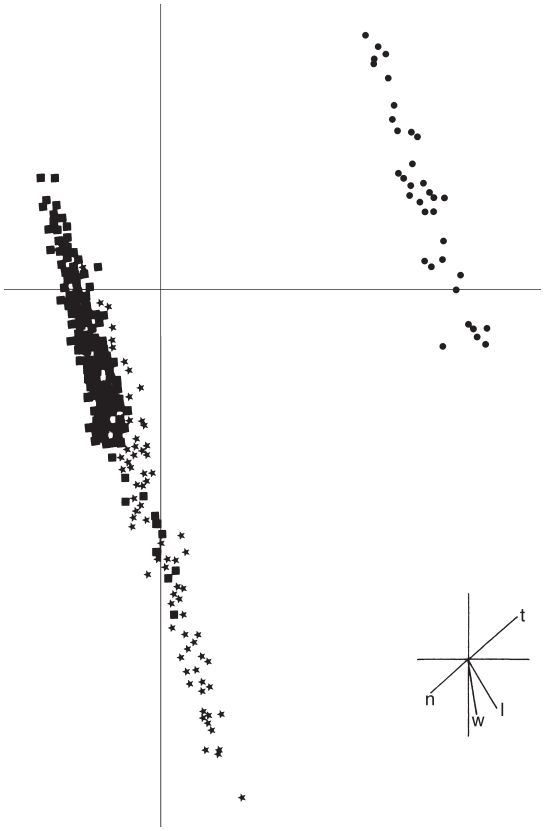

Fig. 3. *Solorina* spp. Plot of the first two principal components scores (PCA). ■ = *Solorina bispora* Nyl. var. *bispora*. ✶ = *S. bispora* var. *macrospora* (Harm.) Martínez & Burgaz. ● = *S. bispora* var. *monospora* (Gyeln.) Frey. — l: spore length, w: spore width, t: number of septa, n: number of spores in each ascus.

each ascus. In the second group, constituted by var. *bispora* and var. *macrospora*, there was an intrinsic gradient pattern indicating two taxa, but we could not see any clear gap between them. Since both have two spores in each ascus and have a single septa, spore length is the only character that separates them. Therefore, we suggest that the taxa should be recognized as two subspecies of which one is *S. bispora* ssp. *bispora* and the second requires the following new combination:

Solorina bispora Nyl. ssp. *macrospora* (Harm.) Burgaz & Martínez *comb. nov.*

Basionym: *Solorina macrospora* Harm., Lichens de France 4: 661. 1910 ("1909").

Following this analysis, a modification to the key of Clauzade and Roux (1985) to the European taxa of *Solorina* is proposed.

1. Lower surface of thallus orange ..... *S. crocea*
— Lower surface of thallus not orange 2
2. 4–8 spores in each ascus 3
— 1–2 spores in each ascus 4
3. 4 spores in each ascus 6
— 8 spores in each ascus ..... *S. octospora*
4. Asci 1-spored, spores 2-septate ..... *S. monospora*
— Asci 2-spored, spores 1-septate 5
5. Spores > 100 µm long .... *S. bispora* ssp. *macrospora*
— Spores < 90 µm long ..... *S. bispora* ssp. *bispora*
6. Spore ornamentation of isolated, triangular structures *S. saccata*
— Spore ornamentation of deep, angular lacunae .... *S. spongiosa*

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APPENDIX

Specimens examined

Solorina bispora ssp. *bispora*

France. Hautes Pyrénées, Barèges, 1600 m, *Nylander* (holotype, H-NYL 32893). **Iceland.** Valahnjúkur, W of the hospice in Langidalur, Thórsmörk, Rangárvallasysla, on humus among and over mosses, eks. NE, 300 m, *Svane*, dubl. 1187 (H). **Norway.** Gravin Smøreggen, 750–800 m, 1929, *Havaas*, Lich. exs. Norvegiae 586 (H). **Spain.** Albacete, Bienservida, Sierra de Alcaraz, La Pileta, 30SWH4062, 1500 m, in calcareous rock crevices, in *Pinus nigra* forests, 1995, *Álvarez & Herrero* (herb. Martínez 606); Asturias, Puerto de Ventana, 1600 m, in calcareous rock crevices, 1994, *Burgaz & Martínez* (MACB 53092); Teverga, Puerto de Ventana, on soil in *Fagus sylvatica* base, 1985, *Fuente* (MA 4089); Huesca, Biescas, Ibón de Piedrafita, 30TYN1630, 1600 m, in calcareous rock crevices, 1995, *Burgaz & Martínez* (MACB 53094); Panticosa, Campo de Troya, Corral de Mulas, 2150 m, in soil crevices, 1993, *Etayo & Gómez-Bolea* (MA 4253); Torla, barranco Lapazosa, 1995, *Aragón et al.* (herb. Martínez 995); Fanlo, Barranco de Goriz, 31TBH5527, 2200 m, on calcareous grassland, 1995, *Aragón et al.* (herb. Martínez 928); Lérida, Moixeró, Font Llebrera, 1985, *Hladún* (BCC 2363); León, Boca de Huérgano, Besande, alto de las Portillas, 30TUN4649, 1300 m, in calcareous rock crevices, in *Fagus sylvatica* forest, 1995, *Burgaz & Martínez* (herb. Martínez 792). **Sweden.** Jämtland, Undersåker, Välliste, 2.VII.1949, 1949, *Kjellmert* (H); Jämtland, Åre, Storlien, W slope of Mt. Skurdalshöjden, in rock crevices in mountain meadow, 800 m, 1975, *Vitikainen* 8582 (H); Lapponia tornensis, Björkliden, 1915, *Häyrén* (H); Lapponia tornensis, Björkliden, Nuolja, 1915, *Häyrén* (H).

Solorina bispora ssp. *macrospora*

Austria. Salzburg, Hohe Tauern, W of Krefelder Hütte above Kaprun, ridge of Kleiner Schmiedinger, N of Schmiedinger Scharte, calcareous schists, 2700 m, 1973, *Vitikainen* 7879 (H); Tirol, Stubaier Alpen, N-Hang des Blasers, Erdstufen in Firmeten über Dolomit, 2000–2200 m, 1958, *Steiner*, Plantae Graecenses, Lich. 285 (H). **Spain.** Huesca, San Juan de Plan, collado de Sahún, 31TBH81, 2200 m, in calcareous rock crevices, with *Pinus uncinata*, 1994, *Herrero* (MACB 53093). **Sweden.** Jämtland, Storlien, Skurdalshöjden, in terra, imprimis in fissuris rupium praeruptarum, 1913, *Malme,* Lich. Suecici Exs. 334b (H); Torne Lappmark, Jukkasjärvi, Apportjåkko, regio alpina, 1911, *Lång* (H). **Switzerland.** Ct. Bern, Simmeltal, St. Stephen, Rinderberg, Gandlouenegrat, LS3, 2080 m (oro-hemiarctic), calcareous soil in *Pinus mugo* stand, 1969, *Ahti* 26319 (H).

Solorina crocea

Andorra. Gracia (BCC 2323). **Austria.** Tirol, Ötztaler Alpen, beim Itlsee, nordwestl. von Obergurgl, 2700 m, 1959, *Steiner* (MA 314). **Bulgaria.** Borovetz, subida al pico Mussala, 2500 m, in grasslands, 1993, *Burgaz* (herb. Martínez 996). **Spain.** Asturias, Peña Trevinca, 2000 m, on slates, 1983, (SANT 138); León, San Emiliano, Riolagos, pico Penouta, 29TQH4055, 1950 m, on soil with *Vaccinium uliginosum*, 1995, *Álvarez & García* (herb. Martínez 799); Lérida, Espot, Pallars, Vall d'Amitges, 31TCH31, 2500 m, in granitic rock crevices, 1981, *Ninot & Carrillo* (BCC 2324); Barruera, collada de Delui, 31TCH3212, 2576 m, 1994, *Martínez et al.* (MACB 53102); Espot, collada de Saburó, 31TCH3710, 2700 m, 1994, *Martínez et al.* (MACB 53103); Segovia, Riofrío de Riaza, cancho de la Pedrosa, 30TVL6663, 1720 m, on soil with heathland, 1995, *Burgaz & Martínez* (herb. Martínez 633); Zaragoza, Moncayo, in acid rock crevices, (1984), *Burgaz* (MACB 11853).

Solorina monospora

Austria. Steiermark, Seetaler Alpen, Zirbitzkogel-Massiv SW von Judenburg, im E-exponierten Kar zwischen dem Kreiskogel und der Schusterleiten, knapp unter dem Grat, ca. 2150 m, über Marmor in erdigen Spalten, 1990, *Hafellner & Obermayer 25133* (GZU). **China.** S of Taxkorgan, W of KKH, 37°03´N/75°27´E, alt. 4730 m, open cushions in the alpine belt, Iter Karakorumense II-1991, 1991, *Miehe 5882a* (GZU). **Pakistan.** Khunjerab-Pass (30°50´N, 75°25´E), alt. 4660 m, open cushions in the alpine belt, Iter Karakorumense I-1990, 1990, *Miehe 2389* (GZU); Ibídem, alt. 4740 m, 1990, *Miehe 2295* (GZU).

Solorina octospora

Austria. Tirol, Stubaier Alpen, Gschnitztal, W of the Padasterjochhütte, 2300 m, calcareous slates, in crevices, 1973, *Vitikainen 8867* (H); Salzburg, Hohe Tauern, W of Krefelder Hütte above Kaprun, ridge of Kleiner Schmiedinger, N of Schmiedinger Scharte, calcareous schists, 2700 m, 1973, *Vitikainen 7882* (H). **Finland.** Lapponia enontekiensis, Enontekiö, Kilpisjärvi, E-Saana, 850–900 m, in fissuribus rupis calcarae in complubobus locis, 1958, *Huuskonen* (H); Lapponia enontekiensis, Kilpisjärvi, S-Saana, ad rupem praeruptam, 1961, *Huuskonen* (H). **France.** Montes Alpium, Le Lautaret, prope Monêtier-les-Bains, in latere septent. montis Butte de serre-Orel, 2100 m, ad terram humosam in rupibus siliceo-calcareis, 1980, *Rondon* (H). **Switzerland.** Graubünden, vallis Fenga, in ascensu montis "Heidelberger Hütte", 2280 m, in saxosis siliceo-calcareis, supra terram humosan, 1967, *Ammann & Vezda* 631 (H).

Solorina saccata

Spain. Asturias, Covadonga, lagos de Enol, 1992, *Bujan & Cremades* (SANT 8402); Puerto de Ventana, 1600 m, in calcareous rock crevices, 1994, *Burgaz & Martínez* (MACB 53097); Burgos, Huidobro, calcareous rocks in *Fagus sylvatica*, 1988, *Reinoso* (SANT 2667); Valle de Tobalina, Montejo de Cebas-Frias, 30TUN7834, 520 m, 1990, *Izuzquiza* (MACB 42589); Cádiz, Sierra de Grazalema, in *Abies pinsapo* forest, 1976, *Horjales* (MACB 5271); Granada, Trevenque, 30SVG5704, 1600 m, 1981, *Casares* (GDA 604); Huesca, Biescas, Piedrafita de Jaca, ibón de Piedrafita, 30TYN1630, 1600 m, 1995, *Burgaz & Martínez* (MACB 53095); Lérida, Moixeró, la Cerdanya, DG08, 1600 m, in *Pinus uncinata* forest, 1983, *Hladún* (BCC 1865); Lugo, El Caurel, la Rogueira, 1979, *Horjales* (SANT 148); Segovia, Cedillo de la Torre, 1985, *Ventureira* (MACB 17096).

Solorina spongiosa

Austria. Tirol, Tuxer Voralpen, Steinach am Brenner, W-Hang des Kalvarienberges, 1060 m, 1965, *Steiner* (H, MA 827); Tirol, Stubaier Alpen, Gschnitztal, N slope of Kirchdachspitze, 2600 m, calcareous slates, in rock crevices, 1973, *Vitikainen 8918* (H). **Czech.** Moravia occid., Tisnov, in fissis rupium calcariarum collis Drásovsky kopecek, 350 m, 1957, *Vezda* (H); Moravia, Tisnov, in colle "Drásovsky kopecek", 350 m, in rupibus calcareis, ad terram humosam, 1966, *Clauzade, Lambinon & Vezda* (H). **Finland.** Regio aboensis, Parainen Ersby, ad terram arenosum humosamque in calcariis vetustis, 1912, *Linkola* (H); regio aboensis, Lohja, Storön, 1892, *Boldt* (H). **Norway.** Tromsö, in monte Flöjfjeldet, 1864, *Fries* (H). **Spain.** Lérida, Espot to St. Maurici, on soil, 1986, *Gómez-Bolea* (BCC 2769).