Acta Palaeobotanica 52(1): 139–146, 2012

Debarya glyptosperma (De Bary) Wittrock 1872 (Zygnemataceae, Chlorophyta) as a possible airborne alga – a contribution to its palaeoecological interpretation

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Received 12 October 2011; accepted for publication 21 May 2012

ABSTRACT. This paper reports the finding of *Debarya glyptosperma* zygospores in xeric grasslands far from the natural habitat of algal species. This fact suggests that this species is an airborne alga and this has not been reported before. What is more the discoidal shape of the zygospores may dispose this taxon among the Zygnemataceae family towards air dispersion.

This new information may assist in assessing it as an indicator of limnic conditions. However, the simple discovery of *Debarya* without any accompanying algal taxa and/or other water plants should not be conclusively interpreted as proof of the existence of water bodies because the zygospores might originate from distant transport.

KEYWORDS: *Debarya*, Zygnemataceae, airborne algae, palynological analysis, palaeoecology, non-pollen palynomorphs

INTRODUCTION

The genus *Debarya* was clarified by Wittrock in 1872 to classify more precisely the "*Mougeotia glyptosperma*" described by De Bary in 1858 (Transeau 1925). According to Transeau (1925) there are thirteen species, Kadłubowska (1972) has a count of 10 species, while contemporary sources specify 21 species (Guiry & Guiry 2012). Before this publication no source has instances of *Debarya glyptosperma*, or any other member of the *Debarya* genus as an airborne alga (van Overeem 1936, Gregory et al. 1955, Stevenson & Collier 1962, Schlichting 1964, Brown et al. 1964, Brown 1971, Mittal et al., 1979, Tiberg et al. 1983, Tiberg 1987, Broady 1996, Marshall & Chalmers 1997, Tormo et al. 2001, Sharma et al. 2006, 2007). Within the Zygnemataceae family only *Zygnema* sp. has been reported from aeroplankton in Polynesia (Brown 1971).

This paper presents data on the zygospores of *Debarya glyptosperma* in xeric grassland communities far from the natural habitat of the algal species. They were encountered during palynological research on surface samples. Their discovery provides new information about the ecology of this genus and its palaeobotanical interpretation.

MATERIAL AND METHODS

Material, at least 10 subsamples, was taken for analysis using a random pinch technique from 16 plots of 100 m^2 in size, located in xeric grasslands within Kraków. The subsamples were usually taken from mosses, soil surface and detritus, which were homogenized together in plastic bags in order to obtain a single amalgamated sample for palynological analyses (Adam & Mechringer 1975). A description of the surrounding vegetation was given according to the Braun-Blanquet (1965) method. The identification of plant communities was done using a special manual (Matuszkiewicz 2005). To check the potential source of *Debarya* zygospores surface and water samples from the fish pond in Mydlniki and from a place of temporal water stagnation in the nearest vicinity were collected in July/August 2010 (Fig. 1). Midsummer is considered to be an optimum period for the sporulation of *Debaria glyptosperma* (Ellis-Adam & van Geel 1978).

For palynological analysis samples of 1 cm^3 from every sample were acetolyzed using a modified Erdtman method (Faegri & Iversen 1989). To each sample one *Lycopodium* tablet with a known number of spores was added in order to evaluate the concentration of sporomorphs (Stockmarr 1971). In most of the samples more than 500 pollen grains of arboreal taxa were counted at a magnification of 400 and 1000. Pollen grains and spores were identified with the help of special keys and papers (Moore et al. 1991, Beug 2004) and the reference collection of the Władysław Szafer Institute of Botany, Polish Academy of Sciences. *Debarya* zygospores were determined on the basis of keys to the Zygnemataceae family (Transeau 1925, Kadłubowska 1972). Terrestrial plant pollen percentages were calculated as a ratio to the sum of AP (Arboreal Pollen) + NAP (Non Arboreal Pollen) as their source, while the percentages of *Debarya glyptosperma* were calculated on the basis of AP + NAP + *Debarya*. The calbulations were plotted using the POLPAL program (Nalepka & Walanus 2003). All photographs were taken at 400× magnification under a NIKON Eclipse 80 microscope with a NIKON Digital Sight DS-41 camera. Samples from the water and mud collected in places of water stagnation (site IV in Fig. 1b) and shoreline section of fish ponds (sites I, II, III in Fig. 1b) were laboratory treated in the same way as samples from the plots. A minimum number of 4 slides from each sample were scanned for the presence of *Debarya* zygospores.

RESULTS

One of the studied sites the Mydlniki quarry located in Kraków (230 m. a.s.l., 50°05′15.6″N 19°50′38.3″E), showed the occurrence of *Debarya* zygospores (Fig. 1). It was located on the slope with inclination of about 10% and south-eastern exposure, formerly used as cultivated field (see Karpińska-Kołaczek et al. 2010). Soil was identified as eutric cambisol (with reliable admixture of sand) on limestone as a parent material (W. Heise personal observation). The taxonomic content combined with percentage description of surface cover by particular taxa pointed to *Koelerio-Festucetum rupicolae* association as a type of vegetation in analysed plot. *Hieracium pilosella*, *Agrostis capillaris*, *Dianthus carthusianorum*, and *Trifolium arvense* were the main taxa growing in the plot (Fig. 1). The frequency of *Debarya* zygospores was calculated to be 0.4%, and their concentration was estimated to be about 1600 zygospores/cm^3. These values exceed those reached by pollen types of e.g. *Euphorbia* and *Galium* which were also present in the examined plot (Tab. 1, Fig. 2).

The identified zygospores were a lenticular to compressed ovoid, with a median wall marked by three parallel ridges and in polar view they were connected by radial lines; shorter axis 21–26 µm, longer 34–45 µm

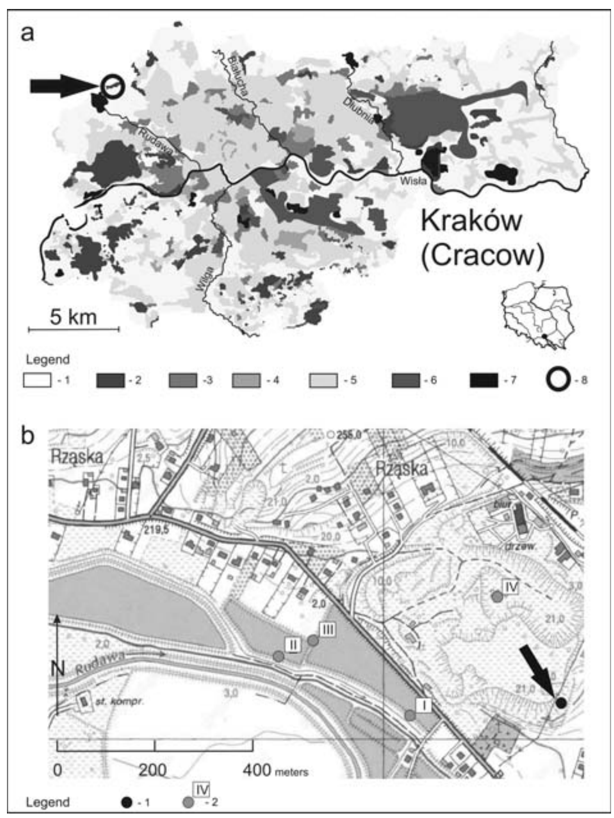

Fig. 1. The location of the site of *Debarya glyptosperma* in Kraków: **a** – map of vegetation in Kraków; based on the map – Xerothermic grasslands in Kraków (2009): **1** – meadows and arable fields, **2** – woods, **3** – gardens, **4** – parks, **5** – urban areas, **6** – industrial areas, **7** – rivers, water reservoirs, 8 – location of site where zygospores of *Debarya* where found; **b** – map of the area of Mydlniki quarry: **1** – location of site where zygospores of *Debarya* were found, **2** – location of the sites where additional samples were collected: **I**, **II**, **III** – fish ponds, **IV** – place of temporal water stagnation

Table 1. Taxonomic composition of the plot (10×10 m) where *Debarya* zygospores were detected. A description of releve follows Braun-Blanquet (1965)

Vegetation layer	Cover total (%)	
A Trees	0	
B Shrubs	0	
C Herbs	75	
D Mooses	10	
Species	Cover (Braun-Blanquet abundance scale)	Sociability scale
Hieracium pilosella	4	4
Agrostis capillaris	2	3
Dianthus carthusianorum	2	1
Trifolium arvense	2	2
Arrhenatherum elatius	1	1
Artemisia campestris	1	1
Galium verum	1	2
Phleum phleoides	1	3
Rumex acetosa	1	2
Sedum acre	1	2
Vicia grandiflora	1	1
Achillea millefolium	+	
Centaurea stoebe	+	
Coronilla varia	+	
Euphorbia cyparissias	+	
Euphrasia rostkoviana	+	
Melampyrum arvense	+	
Plantago lanceolata	+	
Potentilla arenaria	+	
Rhinanthus minor	+	
Sedum maximum	+	
Vicia cracca	+	
Equisetum arvense	r	
Erigeron acer	r	
Erigeron annuum	r	
Festuca rupicola	r	
Lotus corniculatus	r	
Scabiosa ochroleuca	r	
Trifolium pratense	r	
Veronica chamaedrys	r	
Vicia hirsuta	r	

(Fig. 3). These zygospores are from the *Debarya glyptosperma* species widely spread in Europe, Asia, Africa and both Americas (Kadłubowska 1972).

Unfortunately, an analysis of samples from the nearest potential habitats of *Debarya glyptosperma* shows no occurrence of this species. What is more, other members of the Zygnemataceae family were only detected as single zygospores in the fish pond, among them *Spirogyra* was found twice, and *Zygnema* only once.

DISCUSSION

The scarce information about the ecology of *Debarya glyptosperma* suggest that the main habitat of this species are natural or artificial water bodies of a medium or large size (sometimes covering several squre miles) which are shallow and on siliciferous soil (Frémy & Meslin 1927, Allorge & Allorge 1930), as well as river mouths (Kadłubowska 1972) and ditches (John 2002). However, the bulk of information about the ecology of this taxon comes from an analysis of fossil material.

Fossil (Holocene) zygospores of *D. glyptosperma* from Wietmarscher Moor in Western Germany are thought to be connected with the transitional phase between poor sandy subsoils and mesotrophic peat bog (Ellis-Adam & van Geel 1978). In another situation fossil zygospores were found during analysis of profiles from sandy soils in Kootwijk (The Netherlands) where they were probably related to temporarily inundated places in a heath rich in *Lycopodium* (Ellis-Adam & van Geel 1978). These indications are in accordance with the data of Allorge and Allorge (1930) and of Frémy and Meslin (1927) following Ellis-Adam and van Geel (1978) who collected this species from wet heaths in NW Spain and in Normandy, respectively. Generally, the presence of *Debarya* spp. zygospores in Holocene deposits in The Netherlands and Germany is interpreted as suggesting their accumulation in small temporary pools, perhaps in the early phases of sandy pool development and in periodically inundated soils (Ellis-Adam & van Geel 1978, van Geel et al. 1984, 1989).

On the other hand, microfossils called *Debarya* aff. *D. glyptosperma* recorded in Colombia in Quaternary lake sediments were interpreted as being associated with a cold páramo (high-mountain) to a cool subpáramo climate (van Geel & van der Hammen 1978, Head 1992). These observations were confirmed by Montoya et al. (2010) after analysis of modern surface samples collected in the altitudinal transect from the cloudy forest to superparámo in Sierra de Santo Domingo, in the northernmost part of the Venezuelan Andes. In this paper zygospores of *Debarya* were reported three times from soil samples once from the cloudy forest at the height of 2620 m a.s.l., once in the subpáramo or shrub páramo at a height of 2830 m a.s.l., and once in the proper páramo

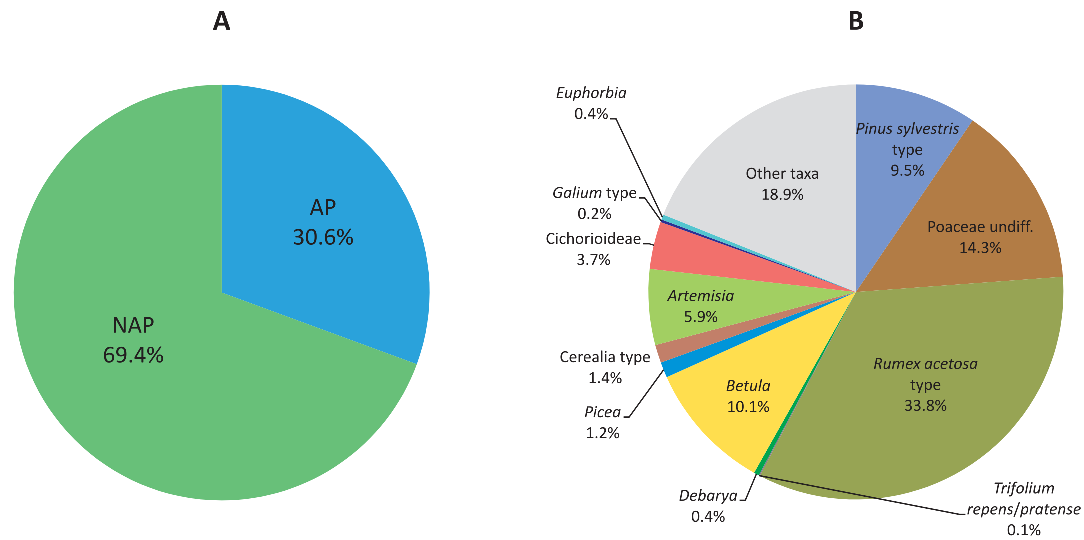

Fig. 2. Simplified percentage pollen diagrams (cyclograms) of sample from the plot where *Debarya glyptosperma* zygospores were found. A. Sum of arboreal pollen (AP) and non-arboreal pollen (NAP); B. *Debarya* and selected AP and NAP

at a height of 3940 m a.s.l.. This taxon was also found in a moss sample from the proper parámo at a height of 3140 m a.s.l. and in five samples collected from bogs or lakes (one from the proper parámo, four from the superparámo). Studies carried out in Chile revealed the occurrence of this taxon in shallow-water lake sediments in the northern part of the Lake District in Chile (Heusser 1984). *Debarya* is also known from other sites in Chile e.g. the intermittently muddy and poorly drained silty soil from a profile from Frutillar Bajo, a profile from the mire Fundo Llanquihue where they were widely distributed in lacustrine and peat sediments and from lacustrine sediments from the Fundo Liña Pantanosa and Mayol mires (Heusser et al 1999).

Debarya glyptosperma zygospores were also found in soils from the Snowy Mountain National Park, Australia by A. Martin in 1984, and were assigned to a hydro-terrestrial habitat (Grenfell 1995).

Moreover, the appearance of unidentified *Debarya* zygospores reported from the Tramandai Lagoon region in Brazil, together with other freshwater algae such as *Mougeotia* type, *Spirogyra* type, *Zygnema* type, and *Pediastrum* was attributed to the rapid freshening of the lagoon (Medeanic et al. 2003). Guiter et al. (2005) observed abundant *Debarya glyptosperma* zygospores in late Younger Dryas sediments and connected them with changes in the lacustrine environment in response to the improvement of the climate which began at the end of the Younger Dryas and continued during the Early Holocene. According to Carrión (2002) *Debarya* often behaves as a pioneer, but like most representatives of the Zygnemataceae

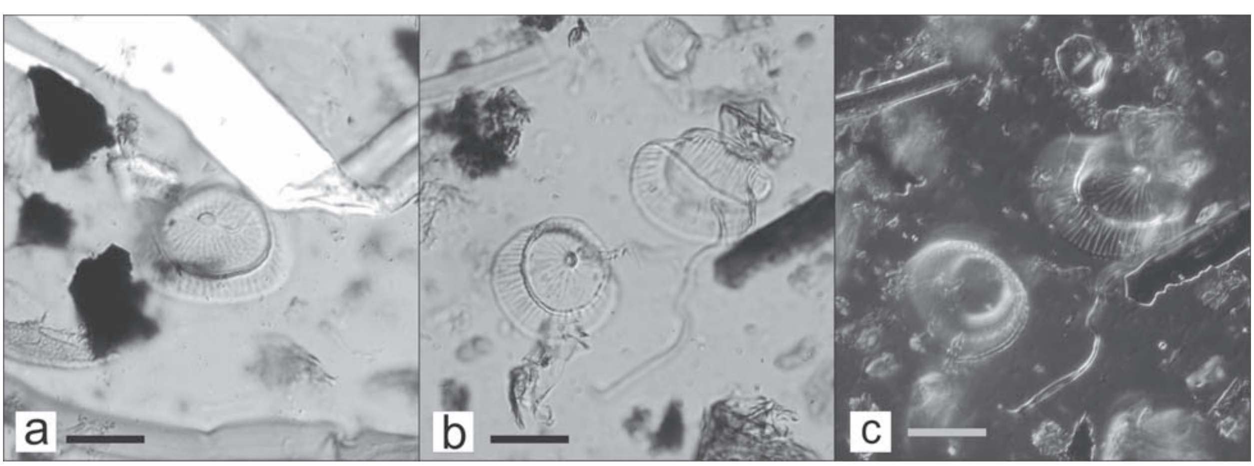

Fig. 3. Zygospores of *Debarya glyptosperma* found on xeric grasslands: **a–c** in light microscope (**c** – with dark field and Nomarski contrast). Scale bars – 20 µm. Phot. P. Kołaczek

it needs a relatively high water temperature to sporulate (Ellis-Adam & van Geel 1978, van Geel et al. 1989). The interesting facts about this alga brought analysis of soil samples from the stone mounds at Pouerua (Horrocks et al. 2002) and Puketona (Horrocks 2004) in New Zealand, where zygospores of *Debarya* together with *Lecaniella*, *Spirogyra* and *Schizosporis* were found. The scoria soils in those sites was porous and free-draining, so presence this taxa in that unhospitable habitat suggested Maori agricultural practises based on irrigation with wetland water (Horrocks 2004). The occurrence of *Debarya* was also reported from early Polynesian ditch systems on southern Aupouri Peninsula in New Zealand (Horrocs et al. 2007).

To sum up, although zygospores of *Debarya* have been also reported from terrestrial environments, they were always considered as indicators of humid conditions or temporal water stagnation. The fact that the dominant species of vascular plants found in the analysed plot according to Zarzycki et al. (2002) are indicators of dry soils excludes the probability of water stagnation within the analysed area; therefore this excludes the *in situ* occurrence of *Debarya glyptosperma*. What is more an inclination of the slope together with the permeable soil prevent from development of temporary pool in the plot and places located on higher altitude. This observation was made by W. Heise on numerous occasions during the winter and early spring thaw as well as after heavy rains. Thus the only possible local source of its zygospores may be fish ponds, a place of temporal water stagnation located about 300 m from the examined site and/or other water bodies. In most papers in which the occurrence of *Debarya* is mentioned, this taxon coexists with other algae from the Zygnemataceae family such as *Spirogyra*, *Mougeotia* or *Zygnema* and/or other Chlorophyta e.g. *Pediastrum* and/or *Botryococcus* (Elis-Adam 1978, van Geel & van der Hammen 1978, van Geel et al. 1984, 1989, Carrión & van Geel 1999, Heusser et. al. 1999, Carrión 2002, Medeanic et al. 2003, Guiter et al. 2005, Montoya et al. 2010). Nevertheless, *Debarya* zygospores were also detected separately (comp. Elis-Adam 1978, van Geel & van der Hammen 1978). No other genera such as *Spirogyra*, *Mougeotia*, *Zygnema*, *Pediastrum*, or *Botryococcus* were identified in the sample from the quarry in Mydlniki, which confirms a lack of proper conditions for the presence of these taxa. This fact points to the possibility of three ways for the dispersal of zygospores which led to the appearance of *Debarya* on the xeric grassland.

1. Agricultural activity (watering crops). Even though there had been cultivated field at that place until 1970's, the first possibility seems to be unreliable because watering crops was not practiced then at that place. It was also impossible due to topographic situation and because fish ponds were under national ownership and were fenced at that time, thus excluded from agricultural usage of private owners (W. Heise, personal research unpublished).

2. Zoological carriers. Several studies have shown that various species of water birds may be effective transporters of algae (e.g. Schlichting 1960, Proctor 1962, Maguire 1963, Atkinson 1972, Schlichting et al. 1978, Coesel et al. 1988, Kristiansen 1996). Algae may be transported in two ways: on the external parts of a bird e.g. feet, feathers or in digestive tracks. McAndrews and Turton (2010) detected similar transport in fossil material, in that case parasitic fungi which live on cereal leaves were relocated into the lake by geese which ate those leaves and defecated them during their occupation of the lake surface. So the occurrence of *Debarya* on the surface of xeric grassland could have been caused by geese or other species of water bird which may have eaten sporulating algal filaments and afterwards grass and other herbaceous vegetation (meanwhile producing feaces with *Debarya* spores) at the sampling site. Although this explanation seems to be logical, the xeric grasslands in Kraków are extremely rarely visited by water birds (personal observation of W. Heise in late summer and autumn 2007–2010, during phytosociological investigations of xeric grasslands). These plant associations are far less attractive for grazing than cultivated fields or mown meadows which are common in the vicinity and on the outskirts of Kraków. What is more, no other algae taxa e.g. *Mougeotia*, *Zygnema*, *Spirogyra*, *Pediastrum*, or *Botryococcus* were detected in the surface sample from the xeric grassland in Mydlniki. The lack of *Debarya* zygospores in the neighbouring water body also excludes the possibility of zygospore transfer by other hydro-terrestrial organisms

or by a researcher who may have done it accidentally during field work.

3. Wind. The conclusion that the occurrence of *Debarya* in xeric habitats is the effect of the air transport of zygospores seems to be the most probable. What is more the discoidal shape may dispose this taxon among the Zygnemataceae family towards air dispersion, so this could explain the lack of other members of this family in the sample where *Debarya* was detected.

Unfortunately, the aerobiological monitoring which is conducted in Kraków does not include airborne algae counting (D. Myszkowska pers. comm.).

Above mentioned data shed new light on the interpretation of the ecological role of *Debarya* in palynological profiles. The mere presence of its zygospores in xeric grassland does not conclusively indicate water bodies, because their occurrence is the effect of distant transport. It seems more probable that only if other water algae and/or limnophytes accompany their presence may they be considered palynomorphs indicative of limnic conditions.

CONCLUSION

The occurrence of *Debarya glyptosperma* zygospores on xeric grassland, an area where stagnation of water is not possible, points to the long distance transport of this species. Although it is not direct evidence, other possibilities such as the transport via water birds (e.g. ducks, geese) or hydro-terrestrial mammals are impossible because of the fact that this xeric grassland is hardly ever visited by these type of animals. What is more in the nearest water bodies this species was not detected, which further confirms that hydro-terrestrial mammals could not have been carriers of *Debarya* zygospors in this case. Finally, further detailed analysis of aerobiological and/or surface samples may contribute new information about the ecology of the dispersal of algae.

ACKNOWLEDGEMENTS

We wish to express our gratitude to the anonymous reviewers for useful comments, which helped us to improve the manuscript as well as the Society of PhD Students of the Jagiellonian University (Towarzystwo Doktorantów UJ) which financially supported language revision.

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