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VARIABILITY OF QUALITATIVE FEATURES OF *PLAGIOTHECIUM NEMORALE* IN CENTRAL AND EASTERN EUROPE

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Abstract

The most frequently indicated taxonomically significant features among species of the genus *Plagiothecium* are qualitative features. However, there are no articles in the literature which describe the analysis of variability or provide the statistical analysis of these features. The material for this research came from Central and Eastern Europe, from the largest Herbaria in: Hungary, the Czech Republic, Slovakia, Poland, Lithuania, Latvia, and Estonia and Ukraine. 2 107 specimens described as *P. nemorale* sensu lato were revised, out of which 140 specimens were selected for detailed research. They were tested for 11 qualitative features and statistically analysed. The analyses show that the studied features to a different extent co-exist with each other and among the tested specimens two groups can be distinguished. In addition, we can indicate that four features make it possible to distinguish specimens belonging to particular groups: the shape (SHA), the serrations of the leaf apex (SEA), and the shape of the cells from the top and middle part of the leaf (SC1, SC2).

Key words: Intraspecies variability, Bryophytes, *Plagiothecium* genus, Europe.

Introduction

The Plagiotheciaceae M. Fleisch. and *Plagiothecium* Schimp. are widespread around the world. This genus has been the subject of quite detailed research so far (Jedlička, 1947 b, 1948, 1950; Ireland, 1969, 1986, 1992; Iwatsuki, 1970; Lefebvre, 1970 a, b; Lewinsky, 1974; Newton, 1983; Szweykowski & Zieliński, 1983; Inoue & Iwatsuki, 1987; Hofman, 1988; Buck & Ireland, 1989; Ireland & Buck, 1994; Ignatov & Ochyra, 1995; Arikawa & Higuchi, 1999; Pedersen & Hedenäs, 2001 a, b; Hedenäs, & Pedersen, 2002; Ochyra *et al*., 2000; Ochyra, 2002;; Ochyra, & Buck, 2002; Ochyra *et al*., 2008; Wolski, 2017 a, 2018), but these articles have concerned different issues.

Despite many studies, authors of revisions and taxonomic papers state that all species of this genus are highly variable. Additionally, they suggest that among species of this genus the greatest taxonomic problems are caused by species belonging to the section *Orthophyllum* Jedl., and some authors even considered it to be a complex (Iwatsuki, 1970; Lewinsky, 1974; Hemerik, 1989).

In most articles concerning the revision and taxonomy of this group of plants, authors focus on the analysis of several, described already in the literature, features, without checking the taxonomic value of other traits, sometimes not described so far (Jedlička, 1947 b, 1948, 1950; Ireland, 1969, 1986, 1992; Iwatsuki, 1970; Lewinsky, 1974; Hemerik, 1989). Most of these studies provide different and often very divergent results concerning not only the ranges of variability of individual characteristics but also indicating different traits as taxonomically important for the described species (Wolski, 2018). Additionally, Wolski (2018) indicates that in the description of species from this group of plants qualitative features dominate, while quantitative features are much less frequently indicated.

Various indicated taxonomically significant traits, different ranges of variability of the studied characteristics and the dominance of qualitative features lead to the situation when the proposed features are excluded or the ranges of variability of these characteristics for each species overlap. This leads to misunderstandings and makes it difficult to provide clear revisions of studied specimens (Wolski, 2018).

Differences in the variability of the traits and the absence of detailed research on this subject were the reasons for starting research on the intraspecific variability of the European range of *P. nemorale*. The results concerning the variability of qualitative features will be presented in this article.

Materials and Methods

The study is based on specimens of the *P. nemorale* sensu lato collected from the largest Herbaria from Central and Eastern Europe: the Czech Republic (BRNU, PL, PR, PRC), Slovakia (BRA, SLO), Poland (IBL, KRAM B, LBL, LOD, POZG-B, SOSN), Lithuania (BILAS), Latvia (Silava), and Estonia (TAA, TALL, TAM, TU). Specimens from Hungary come from the Herbarium BRNU and the Herbarium H, while data from Ukraine come from the Herbarium BRNU. A part of material from Estonia comes also from the Herbarium H. 2 107 specimens described as *P. nemorale* were revised. From the revised material, 140 specimens were randomly selected for the further analysis (Appendix). Each of them was characterised on the basis of 11 qualitative characteristics (Table 1). The entire methodology of research and the location of characteristic features on the plant were described in detail in Wolski's (2017 a) article.

For each of the examined leaves, the shape (SHL), concavity (COL), symmetry of the leaves (SYL) were evaluated. Additionally, the shape (SHA), curvature (CLA), and serrations of the leaf apex (SEA) were observed. Next, the shape of five randomly selected cells from the top (SC1), middle (SC2) and lower part of the leaf (SC3) was evaluated. The fact whether leaf cells create regular transverse rows (RTR), along with the shape of decurrent cells (SDC), was noted.

Appendix

Czech Republic 1. Bohemia, Novohradské Hory, leg., det. Vacínová, PRC 66. 2. Šumava, leg., det. Loskotová, PRC 245. 3. Bohemia, Česká Lípa, leg., det. Bašková, PRC. 4. Bohemia, Novohradské Hory, leg., det. Vacínová, PRC 69. 5. Bohemia, Šumava, leg., det. Kučera, PRC. 6. Bohemia, Šumava, leg., det. Kučera, PRC. 7. Bohemia, Šumava, leg., det. Kučera, PRC 198. 8. Bohemia, Novohradské Hory, leg., det. Vacínová, PRC 366. 9. Morava, Drahanska Vrchovina, leg., det. Doležal, SNM 162. 10. Morava, Brno, leg., det. Doležal, SNM 226. 11. Ceskomoravska Vrchovina, leg., det. Doležal, SNM 150. 12. Ceskomoravska Mezihoři, leg., det. Doležal, SNM 150. 13. Rýmařov, Valšovský Žleb, leg., det. Doležal, SNM 161. 14. Morava, Brno, leg., det. Doležal, SNM 226. 15. Ceskomoravska Vrchovina, leg., det. Doležal, SNM 217. 16. Doupovské Vrchy, leg., det. Vondráček, PL 169/760. 17. Doupovské Vrchy, Oslovice, leg., det. Vondráček, PL 169/759. 18. Doupovské Vrchy, Dubina, leg., det. Vondráček, PL 169/769. 19. Doupovské Vrchy, Kyselka, leg., det. Vondráček, PL 169/757. 20. Šumava, Zelená Lhota, leg., det. Sofron, PL 169/479. 21. Šumava, Král, leg., det. Vondráček, PL 169/679. 22. Šumava, Zilená Lhota, leg., det. Vondráček, PL 169/586. 23. Doupovská Pahorkatina, Oslovice, leg., det. Vondráček, PL 169/763. 24. Plze, Ždírec, leg., det. Vondráček, PL 169/382. *Slovakia* 25. Mony, Malá Fatra, leg., det. Pilous, BRNU 343116. 26. Mony, Malá Fatra, leg., det. Pilous, PR. 27. Mony, Malá Fatra, leg., det. Pilous, PR. 28. Little Carpathians, Bratislava, leg., det. Peciat, SLO. 29. Little Carpathians, Zachora Chata, leg., det. Janovicová, SLO. 30. Slovenské Rudohorie, Hladomorna Dolina, leg., det. Peciat, SLO. 31. Little Carpathians, Bratislava, leg., det. Janovicová, SLO. 32. Little Carpathians, Sräty Jur, leg., det. Janovicová, SLO. 33. Slovensky Raj, Stratena u Dobšinsjé, leg., det. Pilous, SNM 229. 34. Little Farta, Stankovany Rezervace Slatiny, leg., det. Pilous, SNM 228. 35. Slovensky Raj, Čingov Sokolia Dolina, leg., det. Pilous, SNM 229. *Hungary* 36. Borsod, Supra Vallem Felsősebes, Ómassa, leg., det. Boros, Hasoka, BRNU 0648207. 37. Borsod, Vallis Leány-Völgy, leg., det. Boros, Hasoka, BRNU 0648210. 38. Borsod, Udvarko, Prope Lillafüred, leg., det. Boros, Hasoka, BRNU 294. 39. Komárom, Vallis Bodony-Völgy, leg., det. Boros, Hasoka, BRNU 169. 40. Komárom, In Valle Rivi Fekete-Ér Prope Oroszlány, leg., det. Boros, Hasoka, BRNU 0648212. 41. Komárom, Rivi Mocsár-Berek, leg., det. Boros, Hasoka, BRNU 165. 42. Esztergom, Vallis Nyir-Völgg, leg., det. Boros, Hasoka, BRNU 0648203. 43. Comit Pest, Inárcsi Szőlőtelep, BRNU 0648202. 44. Pest, Vallis Rivi Bükköspatak, BRNU 0648199. 45. Comit Vas In Silvis Vallis Vogelsang, leg., det. Boros, Hasoka, BRNU 275. 46. Vas Vallis, Hárompatakvölgy, leg., det. Boros, Hasoka, BRNU 276. 47. Heves, Prope Parád, leg., det. Boros, Hasoka, BRNU 380. 48. Heves, Montis Háromkő, leg., det. Boros, Hasoka, BRNU 295. 49. Somogy, Prope Őrtilos, leg., det. Vajda, BRNU 0648201. 51. Zala, Prope Kisrada, leg., det. Boros, Hasoka, BRNU 629. 53. Komárom, Oroszlány, leg., det. Vajda, H 3112603. 54. Veszprém, Márkó, leg., det. Vajda, H 3237546. 55. Nógrád, Királyháza, leg., det. Vajda, H 3113607. 56. Fejér, Oroszlány, leg., det. Vajda, H 3113604. *Ukraine* 50. Máramaros, Trebusafejérpatak, leg., det. Boros, Hasoka, BRNU 80. 52. Bereg Prope Kisanna, leg., det. Boros, Hasoka, BRNU 278. *Poland* 57. Rozpuda nature reserve, leg. Sokołowski, det. Karczmarz, IBL 8314. 58. Wigierski landscaped park, leg. Sokołowski, det. Karczmarz, IBL 7507. 59. Knyszyńska primary forest, Kozłowy nature reserve, leg. Sokołowski, det. Karczmarz, IBL 8076. 60. Augustowska forest, leg., det. Gocławska, IBL 1437. 61. Białystok, Antoniuk forest, leg. Sokołowski, det. Karczmarz, IBL 8671. 62. Szypliszki, leg. Sokołowski, det. Karczmarz, IBL 8326. 63. Kąty, leg. Bocheński, det. Lisowski, POZG-B 7126. 64. Poznań, Wola, near Bogdanka, leg., det. Bocheński, POZG-B 2739. 65. Wielkopolski National Park, by the lake Góreckim, leg., det. Machałowska, POZG-B 19095. 66. West Pomerania, Bukowa forestnear Szczecin, Bukowe Zdroje nature reserve, leg., det. Rusińska, POZG-B 8268. 67. Poznań, Olszak forest, near Maltańskie lake, leg., det. Rusińska, POZG-B 7630. 68. West Pomerania, Upiłki, leg., det. Lisowski, Szafrański, Tobolewski, POZG-B 61683. 69. West Pomerania, Cieszonko, projected Staniszewskie Zdroje nature reserve, leg., det. Rusińska, POZG-B 1256. 70. West Pomerania, Rąbino, on the soil and the stump, leg. Rusińska, Urbański, det. Rusińska, POZG-B 165. 71. West Pomerania, Charzykowy, leg., det. Lisowski, Szafrański, Tobolewski, POZG-B 61880. 72. West Pomerania, Sośnica nature reserve, leg., det. Rusińska, POZG-B 7951. 73. West Pomerania, Pustkowo, leg., Lisowski, det. Lisowski, Rusińska, POZG-B 11980. 74. Bory Tucholskie National Park, leg., det. Lisowski, POZG-B 12818. 75. West Pomerania, Brętowo, near Strzyżą river, leg., det. Rusińska, POZG-B 3846. 76. West Pomerania, Diabelski Skok nature reserve, leg. Rusińska, Urbański, det. Rusińska, POZG-B 22. 77. West

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Pomerania, Drawa nature reserve, leg. Rusińska, Urbański, det. Rusińska, POZG-B 411. 78. Żarnowica, near Dębki village, leg., det. Lisowski, POZG-B 97209. 79. West Pomerania, Głodzino, leg. Rusińska, Urbański, det. Rusińska, POZG-B 212. 80. West Pomerania, Wieleń, leg., det. Rusińska, POZG-B 8564. 81. Carpathians, Western Beskid Mts., Beskid Śląski Mts., Wisła nature reserve, leg., det. Stebel, SOSN 42215. 82. Western Beskid Mts., Beskid Śląski Mts. Szyndzielnia Mts., leg., det. Stebel, SOSN 31290. 83. Western Beskid Mts., Beskid Maly Mts., Leskowiec, leg. Roksana Krause, det. Stebel, SOSN 45274. 84. Western Beskid Mts., Silesian Beskid Mts., Szyndzielnia Mts., leg., det. Stebel, SOSN 34993. 85. Western Beskid Mts., Beskid Maly Mts., Wielka Puszcza, leg., det. Stebel, SOSN 57336. 86. Western Beskid Mts., Beskid Maly Mts., Zasolnica nature reserve, leg., det. Stebel, SOSN 47248. 87. Western Beskid Mts., Beskid Śląski Mts., Bielsko-Biała Wapienica, leg., det. Stebel, SOSN 40562. 88. Western Beskid Mts., Beskid Śląski Mts., Szczyrk, Salmopol Solisko, leg., det. Stebel, SOSN 47981. 89. Western Beskid, Silesian Beskid, Ustroń Polana, leg., det. Stebel, SOSN 34732. 90. Western Beskid Mts., Beskid Maly Mts., Kocierz Górny, leg. Stebel & Stebel, det. Stebel, SOSN 23652. 91. Western Beskid Mts., Silesian Beskid Mts., Czantoria nature reaserve, leg., det. Stebel, SOSN 37025. 92. Bieszczadzki National Park, leg. Żarnowiec, Szymocha, det. Żarnowiec, SOSN 16122. 93. Western Bieszczady, leg. Ambroży, det. Żarnowiec, SOSN 16598. 94. Bieszczadzki National Park, leg. Żarnowiec, Szymocha, det. Żarnowiec, SOSN 16119. 95. Western Bieszczady, leg. Ambroży, det. Żarnowiec, SOSN 16870. 96. Central Poland, Bolimów Landscaped Park, Kowiesy, leg., det. Łuczak, Filipiak, LOD 7327. 97. Central Poland, Jabłeczniknature reaserve, leg., det. Mańkowska, Czarna, LOD 7229. 98. Central Poland, Dąbrowa Łącka nature reserve, leg., det. Król, Szpnor, LOD 12395. 99. Central Poland, Stróża, Rząśnia, leg., det. Filipiak, LOD 7239. 100. Central Poland, Dębowiec nature reserve, Żytno, leg., det. Urbanek, LOD 7163. 101. Central Poland, Modlica nature reserve, Tuszyn, leg., det. Chmielewski, LOD 7156. 102. Central Poland, Walewice forest, Sulmierzyce, leg., det. Filipiak, LOD 7281. 103. Central Poland, Jodły Łaskie nature reserve, leg., det. Wolski, LOD 14552. 104. Central Poland Jodły Łaskie nature reaserve, Sędziejowice, leg., det. Sęczkowska, LOD 12457. 105. Central Poland, Radziwiłłów, Puszcza Mariańska, leg. Olaczek, det. Mickiewicz, LOD 7271. 106. Sandomierska basin, Brzoza Królewska, leg. Gromadzka, LBL. 107. Sandomierska basin, Witoldówka near from Sieniawa, leg. Moisiąg, LBL. 108. Lubelszczyzna district, Lubartów district, near Nowy Staw village, leg. Karczmarz, Łuczycka, LBL. 109. Białowieża forest, Zwierzyniec, leg., det. Bloch, LBL. 110. Sandomierska basin, Krzywe near from Sieniawa, leg., det. Misiąg, LBL. 111. Sandomierska basin, Wierzchosławice forest , near from Stradowski pond, leg., det. Krzak, LBL. 112. Świętokrzyski National Park, leg., det. Paciorek, KRAM B 223982. 113. West Pomerania, Buczyna Wąwozy nature reserve, leg., det. Fudali, KRAM B 129290. 114. West Pomerania, Kołowskie Parowy nature reserve, leg., det. Fudali, KRAM B 129365. *Estonia* 115.Viljandimaa, Viljandi, Heimtali, leg. Leis, det. Vellak TAA 5004954. 116. Tartu, Siniküla, leg., det. Vellak TAA 5004961. 117. Pärnu, Kiigemäe, leg., det. Vellak TAA 303. 118. Ida-Viru, Tudu, leg., det. Leis TU 151281. 119. Saare county, Abruka Island, leg., det. Ehrlich TAM B874:42. 120. Saare county, Abruka Island, leg. Tuomikuaski, H 3230093. 121. Saare county, Abruka Island, leg. Tuomikuaski, H 3113593. *Lithuania* 122. Marjampolės, leg. Marozas, det. Tumosienė, BILASB9346. 123. Marjampolės, Buktos miško, leg. Balsevičienė, det. Tumosienė, BILAS B1742. 124. Kalvarijos, Mockų, leg. Katilius, det. Tumosienė, BILAS B8742. 125. Vilkaviškio, Paržerių, Uosijos forest; leg. Čiuplys, det. Tumosienė, BILAS B6418. 126. Vilkaviškio, Bartininkų, Budavonės forest, leg. Balsevičius, det. Tumosienė, BILAS B8754. 127. Varėnos, Mikalauciškės, leg. Skirpastas, det. Tumosienė, BILAS B6427. 128. Vilkaviškio, Pajevonio, Vištytgirio forest, leg. Balsevičius, det. Tumosienė, BILAS B3695. 129. Biržų, leg. Jukonienė, Radzevičūtė, BILAS 10621. 130. Alytaus, Vizgiris, leg. Kuzas, det. Radzevičūtė, BILAS 5016. 131. Alytaus, Seirijų, Girukės forest, leg. Valatkevičius, det. Tumosienė, BILAS B1758. 132. Jonavos, Žiemių forest leg. Ferencaitė, det. Tumosienė, BILAS B7510. 133. Jonavos, leg. Balsevičius, det. Tumosienė, B7508. 134. Vilkaviškis region, Vištytgiris forest, leg., det. Jukonienė, BILAS 6869. 135. Lazdijų, Širvinto forest, leg., det. Jukonienė, BILAS 5722. 136. Lazdijų, Seirijų, Rinkotų forest, leg. Balsevičius, det. Tumosienė, BILAS B1726. 137. Radviliško, Radvilonių forest, leg., det. Liepinaitytė, BILAS 4122. 138. Kaišiadorių, Rumšiškių, Upelio park, leg., det. BILASPipinys, 5125. *Latvia* 139. Salacgriva, Vecsalaca forest, leg., det. Âbolina 4576. 140. Limbaži, Liepupes forest, leg., det. Bambe 24360.

Table 1. All the measured characteristics and their symbols.

Characteristic	Symbol
1. The shape of the leaf	SHL
2. The concavity of the leaf	COL
3. The symmetry of the leaf	SYL
4. The shape of the leaf apex	SHA
5. The curvature of the leaf apex	CLA
6. The serrations of the leaf apex	SEA
7. The shape of the cells from the top of the leaf	SC1
8. The shape of the cells from the middle part of the leaf	SC2
9. The shape of the cells from the lower part of the leaf	SC3
10. The creation of regular transverse rows by leaf cells	RTR
11. The shape of the decurrent cells	SDC

Each of the features was evaluated in two categories. SHL – ovate or lanceolate; COL – complanate or concave leaf; SYL – symmetrical or asymmetrical leaf; CLA – straight or curved apex; SEA – denticulate or entire apex, RTR – leaf cells forming regular transverse rows or not. SHL, SHA, SC1, SC2 and SC3 were estimated on the basis of glossary from Smith (2001). In the case of the leaf cell shape (SC1, SC2 and SC3), the following categories were added: narrowly hexagonal and elongated hexagonal.

The collected data were subjected to statistical analysis which included CA (correspondence analysis), HCA (hierarchical cluster analysis) – Ward's metod, and UPGMA (unweighted pair-group method using arithmetic averages) which examines the relationships between nominal variables.

Results

In terms of the shape of the leaf (SHL), those with ovate leaves (113 specimens – 81% of all the examined specimens) dominate. Fewer specimens are reported with the lanceolate shape of the leaf (27–19%). Among all the examined specimens, in terms of the concavity of the leaf (COL), specimens with concave leaves dominate (79 specimens – 56%), fewer specimens are recorded with complanate leaves (61 specimens –44%). In terms of the symmetry of the leaf (SYL), among all the examined specimens, those with symmetric leaves (121 specimens – 86% of all) are dominant, the others (19–14%) are characterised by slightly asymmetric leaves (Fig. 1). In terms of the shape of the leaf apex (SHA), 70 specimens were recorded with the acuminate, acute and apiculate apex. In terms of the curvature of the leaf apex (CLA), most of the tested specimens (94–67%) were characterised by the straight apex, while 46 (33%) specimens had the gently curved apex. In terms of the serrations of the leaf apex (SEA), most of the tested specimens (101–72%) had the entire apex, while only 39 (28%) specimens had the serrated apex.

The shape of the leaf cells is variable. In terms of the shape of the cells, narrowly hexagonal cells (72–51% of all the examined specimens) and elongated hexagonal cells (68 specimens – 49%) co-dominate in the upper part of the leaf (SC1). In the middle part of the leaf (SC2), elongated hexagonal cells (98 specimens – 70%) dominate, while specimens with narrowly hexagonal cells (42–30%) are fewer. In terms of the shape of the cells from the lower part of the leaf (SC3), in all the tested specimens, elongated hexagonal cells are present (Fig. 2). In terms of the creation of regular transverse rows (RTR) by leaf cells, it can be clearly stated that cells of all of the tested specimens always create regular transverse rows (Fig. 2). The shape of the decurrent cells (SDC) was not very variable, in most of the tested specimens (133–95% of all the examined specimens), rectangular cells dominated, much less often (7–5%) rectangular and square cells were noted (Fig. 3).

Fig. 1. The shape (SHL), the concavity (COL) and the symmetry of the leaf (SYL) of *P. nemorale*. From the left: No. 68 and 38, these numbers refer to the specimen numbers from the appendix.

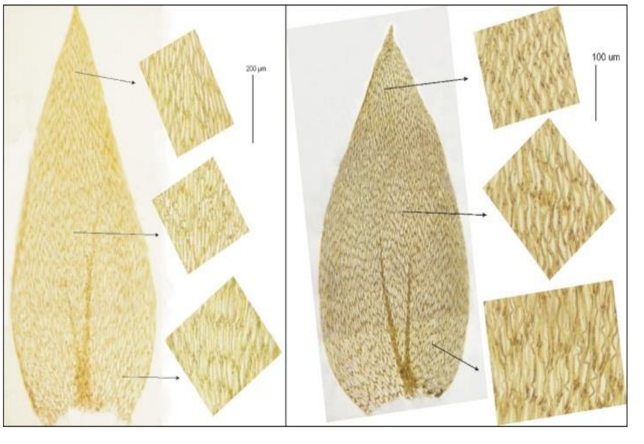

Fig. 2. The shape (SC1, SC2, SC3) of the cells from the each part of the leaf. From the left: No. 57 and 40, these numbers refer to the specimen numbers from the appendix.

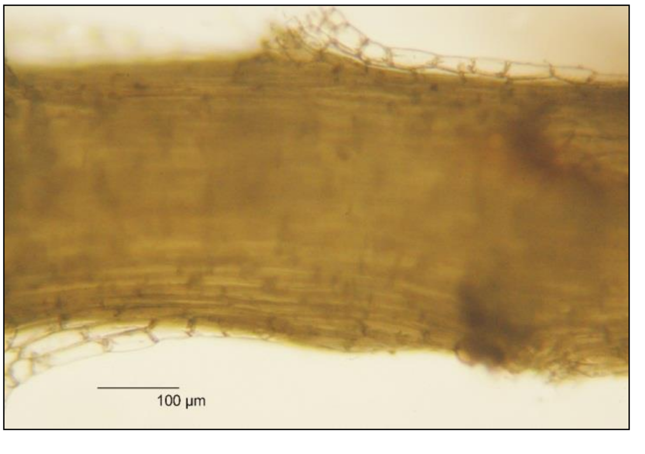

Fig. 3. The decurrent cells of *P. nemorale* on the stem (No. 41 – these numbers refer to the specimen numbers from the appendix).

Due to the fact that the RTR do not show any variability, and SC3 almost not show any variability, they were omitted in the further statistical analyses. Finally, nine characteristics were taken into account. The correspondence analysis indicates a small percentage of explained volatility (Axis 1–25%, Axis 2–13%), nevertheless, this analysis shows groups of features that co-exist with each other. The most numerous group is group A, which includes seven co-existing leaf features. The second (least numerous) is the group B, which represents four characteristics. The third, located between the previous two is group C. Additionally analysis shows, that the one feature (SDC: r-q) clearly does not group with other (Fig. 4).

Hierarchical cluster analysis of the studied features shows two large groups (Fig. 5). Group A is represented by 8 features and almost completely confirms the results of the previous analysis. However, the group B is represented by nine features. Again dendrogram shows that the SDC feature: r-q is the most different from other features (Fig. 5).

The UPGMA method carried agglomeration separates the examined specimens into two groups (Fig. 6). Analysing the obtained results, we can notice that there are features which are common for these groups. In both groups, specimens with symmetrical (group 1 – 70 specimens, which is 86% of all the specimens from this group, and group 2 – 51, 86%), ovate (1–56, 69%, 2–57, 97%), and concave leaf (1–42, 52%, 2–37, 63%) dominated.

Despite partial similarities, the analysis conducted reveals a number of features differentiating individuals belonging to particular groups. In group 1, the following specimens dominated: with the entire (47 specimens, 58% of all the specimens from this group), acuminate leaf apex (63, 77%) and with elongated hexagonal leaf cells (SC1 64, 79%, SC2 74, 91%). This group includes the following specimens: 1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 14, 15, 16, 17, 19, 21, 22, 23, 25, 26, 27, 29, 30, 31, 32, 33, 35, 38, 47, 52, 54, 55, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 70, 72, 73, 75, 76, 78, 79, 80, 81, 84, 85, 86, 87, 88, 90, 92, 94, 97, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 113, 115, 116, 121, 124, 125, 127, 128, 129, 131, 133, 140 (the numbers provided in accordance with the information in the appendix).

In group 2, the following specimens dominate: with the denticulate (23, 54%), acute and apiculate leaf apex (52 specimens, 88% of all the specimens from this group), and with narrowly hexagonal leaf cells (SC1 55, 93%, SC2 36, 66%) (Table 2). The following specimens belong to this group : 3, 5, 13, 18, 20, 24, 28, 34, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 48, 49, 50, 51, 53, 56, 57, 67, 69, 71, 74, 77, 82, 83, 89, 91, 93, 95, 96, 98, 99, 112, 114, 117, 118, 119, 120, 122, 123, 126, 130, 132, 134, 135, 136, 137, 138, 139, (the numbers provided in accordance with the information in the appendix).

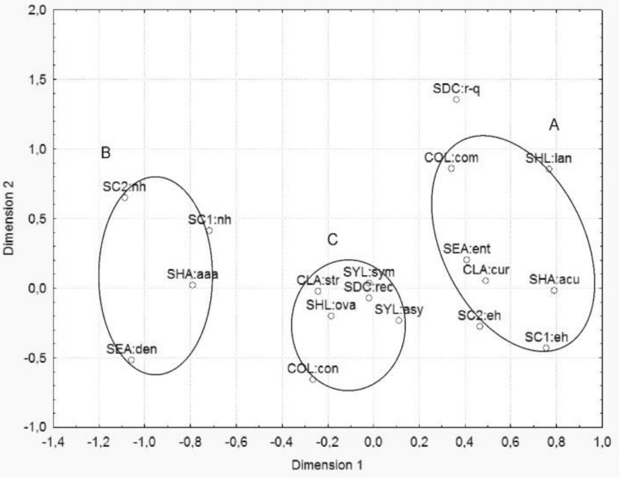

Fig. 4. The correspondence analysis of qualitative features. Explanation: COL: com – complanate, COL: con – concave; SHL: lan – lanceolate, SHL: ova – ovate; SYL: asy – asymmetrical, SYL: sym – symmetrical leaf; CLA: cur – curved, CLA: str – straight; SEA: ent – entire, SEA: den – denticulate; SHA: acu – acuminate, SHA: aaa – acute and apiculate apex; SC1: nh, SC2:eh – narrowly hexagonal, SC1: eh, SC2: nh – elongated hexagonal shape of the leaf cell; SDC: rec – rectangular, SDC: r-q – rectangular and square decurrent cells.

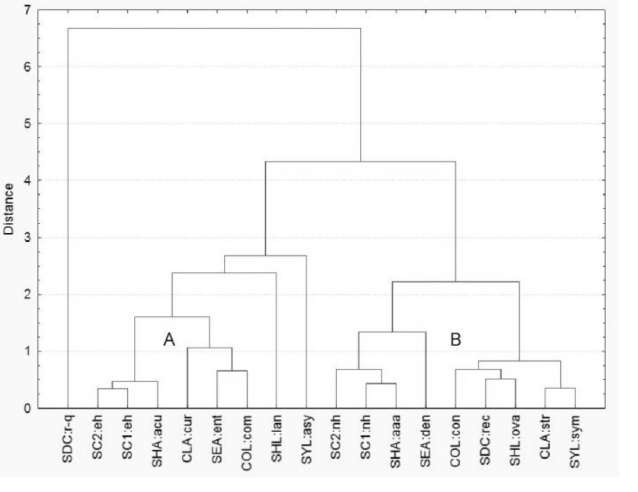

Fig. 5. Dendrogram of the investigated characteristics. Explanation: the same as in case Fig. 4.

Table 2. Qualitative features of specimens representing particular groups. The dominant features from particular groups are marked in bold. Explanation: eh – elongated hexagonal, nh – narrowly hexagonal leaf cells, other features are explained in Table 1.

Feature	SYL	SHL	COL	SEA	SHA	CLA	SC1	SC2
Group 1 ∑ 81	**symmetrical 70**	**ovate56**	**concave 42**	**entire 47**	**acuminate 63**	**curved 50**	**eh 64**	**eh 74**
	asymmetrical 11	lanceolate 25	complanate 39	denticulate 34	acute and apiculate 18	straight 31	nh 17	nh 7
Group 2 ∑ 59	**symmetrical 51**	**ovate 57**	**concave 37**	entire 27	acuminate 7	**curved 44**	eh 4	eh 23
	asymmetrical 8	lanceolate 2	complanate 22	**denticulate 32**	**acute and apiculate 52**	straight 15	**nh 55**	**nh 36**

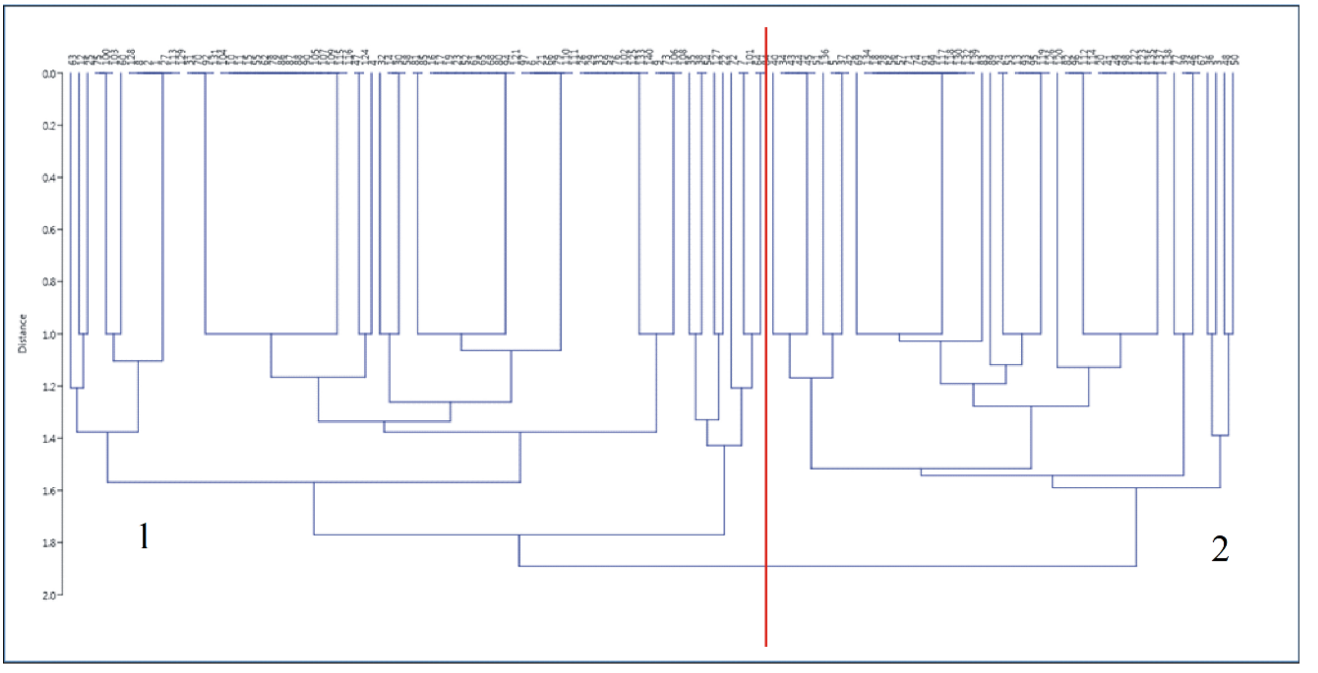

Fig. 6. Agglomeration of UPGMA tested specimens.

Discussion

In species from the section *Orthophyllum* of the genus *Plagiothecium*, among taxonomically significant features, qualitative features dominate over quantitative ones (Wolski, 2018). Qualitative features are mainly related to the size, colour and lustre of the plant as well as leaf cells and decurrent cells. Despite the great importance given to these features, few articles have drawn attention to the variability of these traits (Wolski, 2018).

Among the examined specimens, in terms of the shape of the leaf (SHL), specimens with ovate leaves dominate, while specimens with lanceolate leaves are recorded less often. This is confirmed by the literature data, where this species has mainly ovate (Greene, 1957; Nyholm, 1965; Iwatsuki, 1970; Lewinsky, 1974; Noguchi, 1994; Smith, 2001, Wolski, 2018) or ovate-lanceolate leaves (Jedlička, 1948, 1950). Additionally, ovate leaves are diagnostic features of *P. nemorale* (Greene, 1957; Lewinsky, 1974). Recorded in the study group, and noted by Jedlička (1948, 1950), specimens with lanceolate leaves also indicate the variability within this feature.

In terms of the concavity of the leaf (COL), among all the examined specimens, specimens with concave leaves are dominant, while complanate leaves are recorded less often. These results do not overlap completely with the observations of other authors, as they point out that leaves of this species are complanate (Jedlička, 1948, 1950; Nyholm, 1965; Iwatsuki, 1970; Lewinsky, 1974; Noguchi, 1994; Smith, 2001), more or less concave (Iwatsuki, 1970), or concave (Nyholm, 1965; Noguchi, 1994). Not many authors describe concave leaves for this species. Additionally, opinions about the taxonomic value of this feature differ, Lewinsky (1974) describes that *P. nemorale* has complanate leaves, while Iwatsuki (1970) observes that the leaves of this taxon are more or less concave. Even though these data are mutually exclusive, the two authors treat this feature as taxonomically important to distinguish *P. nemorale* from other species of this genus.

Among all the examined specimens, in terms of the symmetry of the leaf (SYL), specimens with symmetric leaves dominate. Most researchers describe that *P. nemorale* leaves are symmetric (Jedlička, 1948, 1950; Greene, 1957; Nyholm, 1965; Iwatsuki, 1970; Lewinsky, 1974) or almost symmetric (Nyholm, 1965; Iwatsuki, 1970; Noguchi, 1994; Smith, 2001). However, they also indicate that the leaves of this species can be slightly asymmetric (Jedlička, 1948, 1950; Greene, 1957; Iwatsuki, 1970; Lewinsky, 1974) or asymmetric (Noguchi, 1994). The cited articles confirm the described results of this study which indicates that the leaves of this species are mostly symmetrical. Iwatsuki (1970), Lewinsky (1974) and Smith (2001) indicate symmetrical leaves as a taxonomically important trait to distinguish this species from others. Iwatsuki (1970) and Lewinsky (1974), however, suggest that leaves can also be slightly asymmetric. The conducted research as well as the cited literature indicate that leaf symmetry is not a good taxonomic feature to distinguish this species, despite the fact that it is one of the most taxonomically important features for all species of the genus *Plagiothecium*.

In terms of the shape of the leaf apex (SHA), 70 specimens were recorded with the acuminate, acute and apiculate apex. Until now, the leaf apex had been given as acute (Greene, 1957; Noguchi, 1994; Smith, 2001) to acuminate (Smith, 2001). Nobody noticed before that the leaf apex of some specimens might be acute and apiculate. In addition conducted research demonstrate are that, this feature is important to dividing examined specimens into two groups. Smith (2001) also describes that the acute leaf apex is a diagnostic feature for this species. However the literature review indicate that it is this trait very variable (Wolski, 2018).

In terms of the serrations of the leaf apex (SEA), most of the tested specimens were with the entire apex, fewer specimens had the serrated apex. But, this feature is also helpful in separating the examined specimens into two groups. This confirms the opinions given by other researchers that the *P. nemorale* apex is entire (Iwatsuki, 1970; Lewinsky, 1974; Smith, 2001, Wolski, 2018), mostly entire (Nyholm, 1965) or denticulate (Jedlička, 1948, 1950; Iwatsuki, 1970; Lewinsky, 1974; Smith, 2001; Wolski, 2017 a, 2018). Which confirms that it is quite a variable feature (Wolski, 2018).

In terms of the creation of regular transverse rows (RTR) by leaf cells, it can be clearly stated that cells of all the tested specimens always create regular transverse rows. Greene (1957) and Smith (2001) also confirm that cells of this species create regular transverse rows. Smith (2001) describes that this feature is taxonomically important for *P. nemorale*. In my opinion, however, this requires more detailed research especially compared to other species from section *Orthophyllum*.

The conducted research shows that in the middle part of the leaf elongated hexagonal and narrowly hexagonal cells are observed. Elongated hexagonal cells dominate (in SC1, SC2 and SC3), and fewer specimens with narrowly hexagonal cells are recorded. In addition conducted research demonstrate are that the cell shape is important to dividing examined specimens into two groups. Iwatsuki (1970) and Noguchi (1994) also indicates that the cell shape is a taxonomically important feature for this species. The variability of this feature is confirmed by other researchers who write that median cells of this species are hexagonal (Greene, 1957; Iwatsuki, 1970), elongate-hexagonal (Nyholm, 1965; Iwatsuki, 1970; Noguchi, 1994) or narrowly hexagonal (Smith, 2001). Other authors even suggest that median cells of this species are: hexagono-rhomboidal (Jedlička, 1948, 1950; Noguchi, 1994), rhomboid (Nyholm, 1965; Iwatsuki, 1970), narrowly rhomboidal (Iwatsuki, 1970), elongate rhomboid-hexagonal or rectangular (Noguchi, 1994). The conducted research does not confirm the last item of data. Iwatsuki (1970) additionally describes that cells of this species are never linear or flexuose.

In terms of the shape of the decurrent cells (SDC), specimens with rectangular decurrent cells dominate, much less often rectangular and square cells are noted. Researchers report that the decurrent cells are from rectangular (Greene, 1957; Nyholm, 1965; Iwatsuki, 1970; Lewinsky, 1974; Smith, 2001; Wolski, 2017 a), elongate-rectangular (Noguchi, 1994), to elongate (Jedlička, 1948, 1950), or even sublinear (Noguchi, 1994), linear (Nyholm, 1965; Iwatsuki, 1970), enlarged (Smith, 2001), quadratic (Wolski, 2017 a), but never rounded (Noguchi, 1994; Smith, 2001). Lewinsky (1974) and Smith (2001) indicate rectangular cells as a taxonomically significant feature for this species. Noguchi (1994) and Smith (2001) claim that a taxonomic feature is also the fact that angular cells are not rounded. This last feature is often overlooked, though it is very important as it helps to distinguish easily *P. nemorale* from *P. denticulatum*, and these two species are often mistaken for each other.

The CA, and HCA indicates that the some of the features co-exist with each other. UPGMA show that the features affect the distribution of examined specimens. In both cases important are of four features: the shape (SHA), the serrations of the leaf apex (SEA) and the shape of the cells from the top and middle part of the leaf (SC1, SC2). The obtained results confirm the research concerning the variability of quantitative traits and their statistical analysis performed for *P. nemorale* (Wolski, 2017 a, b), which indicate high heterogeneity of the studied species.

Many subspecies, varieties, forms and subforms of *P. nemorale* have been described so far (e.g.: Jedlička, 1947 a, 1948, Barkman, 1957, Iwatsuki, 1970). Most forms and subforms of this species described by Jedlička (1947 a, 1948, 1950) have a number of qualitative features which he considered to be taxonomically significant. Iwatsuki (1970) described *P. nemorale* and *P. nemorale* forma *japonicum* (Sak.) Iwats. Indicating that forma *japonicum*, is characterised by: metallic lustre, ovate and concave leaves, and narrowly hexagonal leaf cells. But currently in Europe none of them is recognised (Hill *et al.*, 2006).

The presented results as well as the studies concerning the variability of quantitative traits of this species (Wolski, 2017 a, b) suggest that the *P. nemorale* are not only highly heterogeneous but also too widely described, and two groups distinguished within the studied specimens we can indicate as separate taxa.

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