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Needle variability of *Pinus mugo* Turra in the West Tatra Mts.

Abstract: Two year-old needles were collected from 57 individuals from the Tatra Mts. between Grześ and Wołowiec summits. The needles were analysed in respect to 16 morphological and anatomical traits. Data obtained were subject of multivariate statistical analyses. The most stable traits appear to be needle thickness/width ratio, needle thickness and width, and width of epidermal cells. The most variable traits include the distance between vascular bundles and Marcet's coefficient. Intrapopulational variation is low.

Additional key words: mountain pine, Poland, morphology, anatomy, statistical analysis

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Introduction

In the Tatra Mountains *Pinus mugo* Turra grows above the montane forest zone, forming a subalpine zone of the bush community *Pinetum mughi carpaticum* (Gostyńska-Jakuszewska, Zieliński 1976, Medwecka-Kornaś 1977) at altitudes of 1550–1850 m above sea level. However, isolated patches of this community or single, very low bushes can be found much higher, for example on Wielki Wierch up to 2140 m (Pawłowski 1956, 1972). Sometimes it also occurs at low altitudes, especially on limestone outcrops, in gullies and on peatland. The lowest localities of this species have been found by Kotula (1889–1890) at the mouth of the Żdziarska Valley at 769 m (it is uncertain if they still exist), and by Hantz (1979) in three other valleys: Dolina Strążyska, Dolina Białego and Dolina Olczyska at about 940 m in altitude.

The variability of *P. mugo* needles has been studied for a long time. Most of the papers published so far have been concerned not only with needle variability but also with taxonomic differences between *P. mugo, P. sylvestris* and their hybrids (Holubičková 1965, Marcet 1967, Szweykowski 1969, Staszkiewicz, Tyszkiewicz 1972, Szweykowski et al. 1976a, Szweykowski et al. 1976b, Szweykowski, Bobowicz 1977, Bobowicz et al. 1983a, Bobowicz et al. 1983b, Christensen 1987a, Minghetti 1997, Boratyńska, Pashkevich 2001).

The morphological and anatomical variability of *P. mugo* needles in the Tatra Mts. has been analysed recently by Bobowicz and Krzakowa (1986, 1988), who studied several populations of this species in both the Eastern and the Western Tatras.

The objective of the study presented here was to investigate the variability of needles in one *P. mugo* population in the Western Tatras and to compare it with results published earlier.

Material and methods

Material for this study was collected in November 1999 on the northern slope of a ridge between two summits, Grześ and Wołowiec, in the Western Tatras at altitudes of 1600–1650 m. Two-year-old needles collected from 57 individuals (10 dwarf shoots per individual) were analysed in respect of 5 morphological and 7 anatomical traits, as well as 4 traits resulting from mathematical calculations (Table 1). Detailed descriptions of the methods of collection and mea-

Table 1. Characteristics of needle traits of *Pinus mugo* (average values for 57 individuals, based on measurements of 10 needles/individual)

Traits	Arithmetic mean	Minimum	Maximum	Variance	Standard deviation	Variability coefficient
1. Needle length (mm)	44.50	28.70	60.20	31.92	5.64	12.69
2. Number of stomatal rows on convex (abaxial) side of needle	9.78	6.50	13.10	2.20	1.48	15.16
3. Number of stomatal rows on flat (adaxial) side of needle	7.26	5.50	10.70	1.10	1.05	14.49
4. Number of stomata on 2 mm long section of needle, on convex (abaxial) side of needle	18.69	15.56	22.86	3.04	1.74	9.33
5. Number of stomata on 2 mm long section of needle, on flat (adaxial) side of needle	18.43	14.89	22.59	3.03	1.74	9.44
6. Number of resin canals	4.21	2.20	5.80	0.60	0.77	18.44
7. Needle width (m)	1490.22	1294.12	1791.37	11013.25	104.94	7.04
8. Needle thickness (m)	849.10	752.25	986.00	2915.53	53.99	6.35
9. Distance between vascular bundles (m)	113.63	54.94	179.15	874.28	29.56	26.02
10. Width of epidermal cells (m)	14.15	12.21	16.48	1.04	1.02	7.21
11. Thickness of epidermal cells (m)	27.45	20.98	33.13	7.00	2.64	9.64
12. Thickness of hypodermal cells (m)	9.96	6.99	12.98	1.80	1.34	13.48
13. Marcet's coefficient (= traits 9*7/8)	200.39	96.33	306.54	2862.45	53.50	26.69
14. Stomatal rows ratio (=traits 2/3)	1.37	1.132	1.66	0.01	0.13	9.22
15. Needle thickness/width ratio (=traits 8/7)	0.57	0.52	0.63	0.00	0.02	4.01
16. Width/thickness ratio of epidermal cells (traits 11/10)	0.52	0.41	0.63	0.00	0.05	9.14

surement of the traits can be found in earlier works (Boratyńska, Bobowicz 2000, Boratyńska, Bobowicz 2001, Boratyńska, Pashkevich 2001).

The results of measurements were analysed statistically by Statistica PL Software for Windows 5.1. Arithmetic means, minimum and maximum values, standard deviation, variance, and coefficient of variation were calculated (Ferguson, Takane 2000). The coefficient of variation reflects the variability of individual traits very well. Pearson's correlation coefficient and coefficient of determination (correlation coefficient squared and multiplied by 100%) were also assessed. A discriminant function analysis was applied to determine the major discriminant traits. As a result of this analysis, the distribution of the studied individuals could be viewed in the space of the first, two and three discriminant traits. Moreover, dendrograms were constructed on the basis of Euclidean distances by the nearest neighbourhood method (single bonds) to analyse the similarity between individuals (Moczko et al. 1998, Zar 1999).

Results

Statistical characteristics of the 16 analysed traits, based on average values of each individual, are presented in Table 1. The most variable was the distance between vascular bundles (trait 9) and Marcet's coefficient (trait 13). Their absolute minimum and maximum values (considering all data, not only average values of individuals) were: 26.64 m and 209.79 m for trait 9, and 41.96 m and 412.92 m for trait 13. Variation coefficients for these two traits were high and exceeded 26% (Fig. 1). Highly variable was also the number of resin canals (trait 6), which ranged from 1 canal to as many as 8 canals.

A surprisingly low variation coefficient of 4.01% was recorded for the ratio of needle thickness to width in cross-section (trait 15). The mean value of this trait indicates that the studied needles are rather flat. However, some needles were very convex in cross-section, so that the value of trait 15 reached to 0.97, but this was very rare. The coefficient of variation did not exceed 10% also for needle thickness and width (traits 7 and 8), epidermal cell width and height and their ratio (traits 10, 11 and 16), numbers of stomata on both sides of the needle (traits 4 and 5), and the ratio of the number of stomatal rows on the

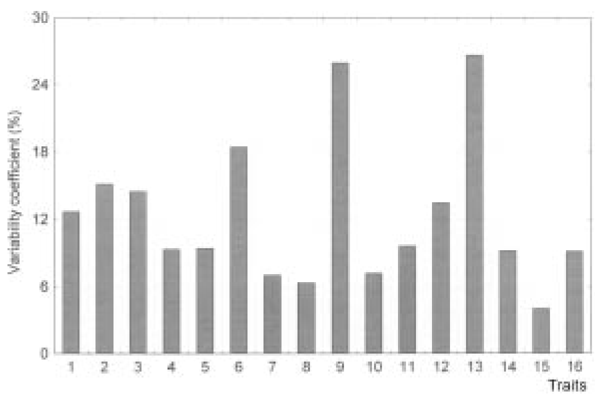

Fig. 1. Variability coefficients for 57 individuals of *Pinus mugo*

abaxial (convex) side of the needle to that on the adaxial (flat) side (trait 14).

Correlations between the traits were analysed on the basis of Pearson's coefficient of linear correlation. Its value is the highest for numbers of stomata on both sides of the needle (traits 4 and 5) and amounts to 0.96 (Fig. 2). The coefficient of determination for those traits is also high and amounts to 92%. This means that for the two traits only 8% of regression is due to non-linear effects. Strongly correlated are also needle width and thickness (traits 7 and 8), as their correlation coefficient is 0.83 and determination coefficient is 70%. Similar values (0.82 and 67%, respectively) were recorded for numbers of stomatal rows on the adaxial and the abaxial side of the needle (traits 3 and 2).

The discriminant function analysis indicates that needle length is the major trait discriminating between individuals, as its Wilk's lambda component is 0.142494. Quite important for discrimination between the studied individuals are also traits 6 (number of resin canals), 7 (neddle width), 15 (needle thickness/width ratio), 12 (thickness of hypodermal cells), 4 (number of stomata on 2 mm long section of needles on convex side of needle) and 5 (number of stomata on 2 mm long section of needle on flat side of needle), while the other traits proved to be rather unimportant.

A graphic representation of the intrapopulational variation is the diagram of distribution of the studied individuals in the space of the first three variables, based on the 16 analysed traits (Fig. 3). Determination coefficients between the first three variables and needle traits suggest that the obtained image (Table 2) is determined mainly by needle length in the case

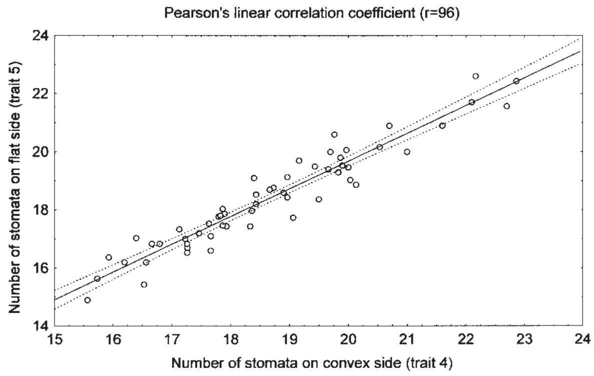

Fig. 2. Correlation between numbers of stomata on the abaxial and the adaxial side of the needle

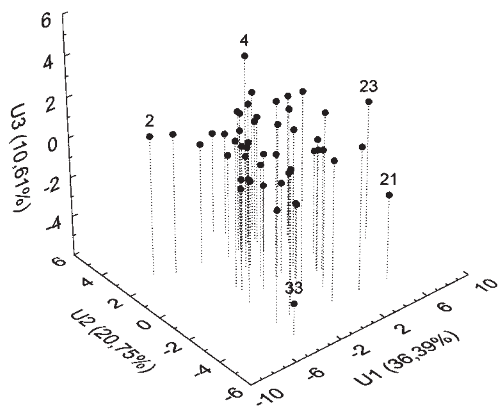

Fig. 3. Result of the discriminant analysis for 57 individuals of *Pinus mugo* in the space of the first three discriminant variables U_1, U_2 and U_3

Tabela 2. The determination coefficients between discriminant variables U_1, U_2, U_3 and 16 traits of needles of *Pinus mugo*

Traits	U_1 (36.39%)	U_2 (20.75%)	U_3 (10.61%)
1. Needle length (mm)	22.5089	6.6554	0.0136
2. Number of stomatal rows on convex (abaxial) side of the needle	3.6672	2.0797	0.0056
3. Number of stomatal rows on flat (adaxial) side of the needle	1.7007	1.6291	0.4514
4. Number of stomata on 2 mm long section of the needle, on convex (abaxial) side of the needle	0.0341	1.0880	4.8879
5. Number of stomata on 2 mm long section of the needle, on flat (adaxial) side of the needle	0.0268	1.5225	4.4142
6. Number of resin canals	0.4588	0.5467	0.0304
7. Width of the needle (m)	2.1849	3.6208	0.3682
8. Thickness of the needle (m)	3.3839	2.3802	0.1600
9. Distance between vascular bundles (m)	0.9498	2.9074	0.9793
10. Width of epidermis cells (m)	0.0382	0.0348	0.0180
11. Thickness of epidermis cells (m)	0.0877	0.1464	0.0666
12. Thickness of hypodermal cells (m)	0.0019	0.0467	0.0147
13. Marcet's coefficient (=traits 9*7/8)	0.6777	2.7664	0.5473
14. Stomatal rows ratio (=traits 2/3)	0.0543	0.0061	0.2272
15. Needle thickness/width ratio (=traits 8/7)	0.0000	0.2293	0.0601
16. Width/thickness ratio of epidermal cells (traits 11/10)	0.1236	0.0122	0.0000

of discriminant variables U_1 and U_2. Variable U_1 is responsible for about 36% and variable U_2 for about 21% of the observed variation. Moreover, U_1 is affected by numbers of stomatal rows on both sides of the needle (traits 2 and 3), and by needle thickness and width (traits 7 and 8). The last two traits and the distance between vascular bundles (trait 9), Marcet's coefficient (trait 13) and all traits concerned with stomata (traits 2–5) also exert a substantial impact on variable U_2. The third variable, U_3, accounts for only about 10% of the variation and is conditioned primarily by numbers of stomata on both sides of the needle (traits 4 and 5).

Fig. 3 shows that several individuals (including those marked with numbers 33, 21, 23 and 4) deviate markedly from all the other analysed members of the population. Individual 33 is distinguished by unusually thick and wide needles (means of the two traits: 1791.38 m and 964.75 m) and small numbers of stomata on both sides of the needle (mean: 16.2 in each of the two traits). Individual 4 is characterized by large numbers of stomata on both sides of the needle (means: 22.16 and 22.6), a large distance between vascular bundles (mean: 161.18 m) and long needles (mean: 48.5 mm). Individual 21 has the shortest needles (mean: 28.7 mm), with a short distance between vascular bundles (mean: 62.27 m). Individual 23 has small needles in respect of all dimensions: length (29 mm), width (1330.25 m) and thickness (784.13 m); and has many stomata on both sides of the needle (20.7 on adaxial and 20.9 on abaxial). An extreme position in the space of variables is occupied also by individual 2, with the longest needles (60.2 mm) and relatively narrow epidermal cells (12.71 m).

The dendrogram constructed on the basis of Euclidean distances with the use of the nearest neighbourhood method for 12 measurable traits generally confirms the relatively low variation within this population (Fig. 4). However, two distinct groups can be noticed: the first composed of individuals 35 and 33, and the other of individuals 53, 40 and 30. Grouping based on all 16 traits suggests that the group of distinct individuals includes also individuals 16 and 4.

Discussion

Interesting comparative data on *P. mugo* variation in the Tatras can be found mainly in works by Bobowicz and Krzakowa (1986, 1988). Mean values of all the analysed traits are similar in all the studied populations (except needle length and thickness of hypodermal cells, as those traits are missing in those works). Only numbers of stomata on both sides are slightly higher in needles measured in those works.

The majority of the analysed traits proved to be more variable in the population near Wołowiec than in the populations studied by Bobowicz and Krzakowa (1986, 1988). Coefficients of variation of indi-

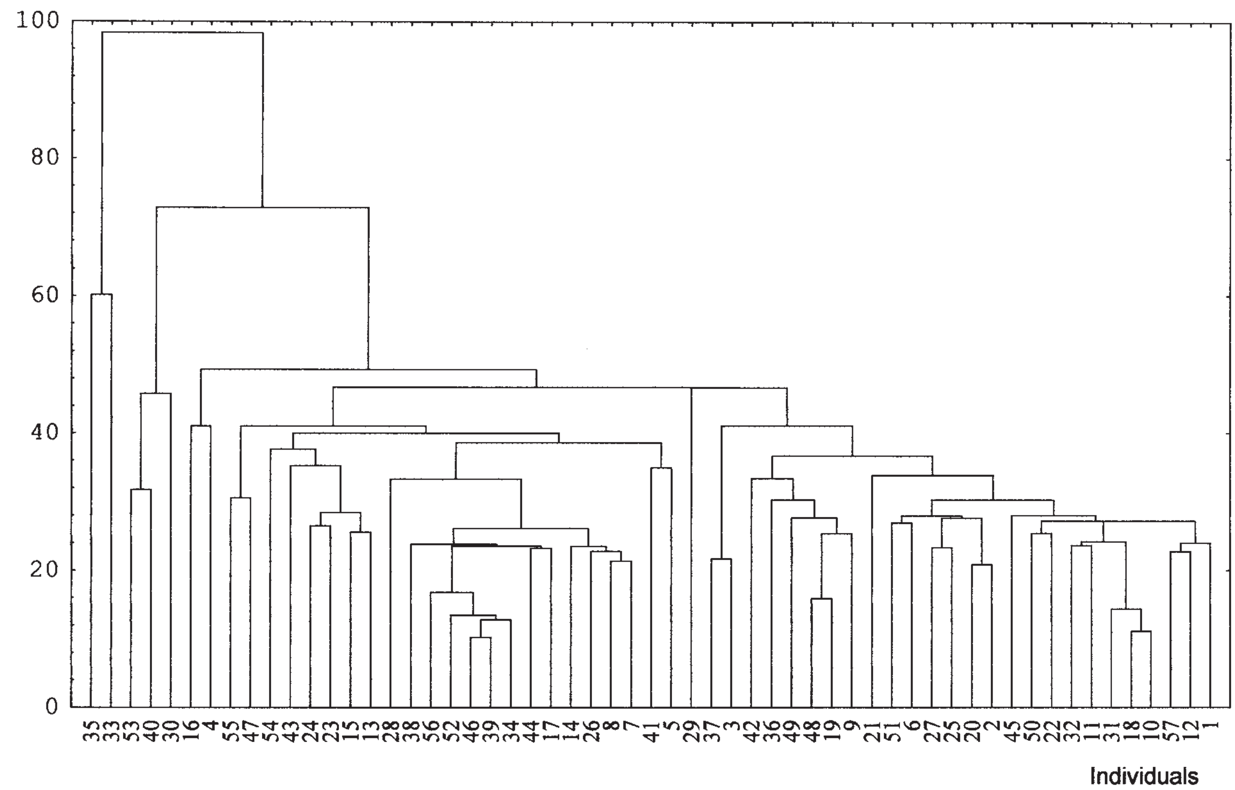

Fig. 4. Dendrogram of 57 individuals of *Pinus mugo* based on 12 measurable needle traits

vidual features differ particularly in the case of numbers of stomata and stomatal rows on both sides of the needle, width of epidermal cells, distance between vascular bundles, and Marcet's coefficient. Only the number of resin canals was less variable in this study than in the populations analysed earlier.

Conclusions

1. The least variable traits of *P. mugo* needles in the Tatra Mts. include: needle thickness/width ratio, needle thickness and width, and width of epidermal cells.
2. The most variable traits include the distance between vascular bundles and Marcet's coefficient.
3. The most strongly correlated are numbers of stomata on the adaxial and abaxial side of the needle, needle width and thickness, and numbers of stomatal rows on both sides of the needle.
4. Intrapopulational variation is rather low and individuals differ from one another mainly in needle length, but also in the number of resin canals, needle width, numbers of stomata on both sides of the needle, thickness of hypodermal cells, and needle thickness/width ratio.

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