Variation of the tree form factor and taper in European larch of Polish provenances tested under conditions of the Beskid Sądecki mountain range (southern Poland)

J. Socha[1], M. Kulej[2]

[1]*Department of Forest Mensuration, Faculty of Forestry, Agricultural University of Cracow, Poland*

[2]*Department of Forest Tree Breeding, Faculty of Forestry, Agricultural University of Cracow, Poland*

ABSTRACT: The genetic variation in 20 provenances of European larch, growing under site conditions of the Beskid Sądecki mountain range (experimental area in Krynica), was investigated during a long-term study carried out within the 1967 Polish Provenance Experiment on Larch. Data consisted of diameter measurements taken outside bark on standing trees of the analyzed provenances. Results showed that there was no distinct variation in the tested larch populations in respect of stem form. Some differences between compared provenances in respect of stem taper and form factor were the result of differences in tree height and diameter.

Keywords: genotype; planting experiment; stem profile

The determination of the volume of trees and their parts by means of the basic characteristics such as dbh and height, recommended from the practical point of view, is burdened with errors resulting from variation of the stem form of trees. This variation is a result of differences in the rate of diameter increment at different heights of the stem and differences in the height increment of trees (Mitscherlich 1970). These differences may be caused by many factors including species variation, climatic factors, site quality, age of trees and stands, defoliation, and stand density (Muhairwe 1994). The taper of the upper stem section is also affected by the length of the crown (Kilkki, Varmola 1981; Larson 1963; Socha 2002). Within the crown, stem diameters at particular heights are generally smaller in comparison with trees of the same dimensions but shorter crowns. Also genetic factors may decide on the stem form. During the study aimed at the provenance variation of *Abies grandis* (Socha, Kulej 2005) it was found that the stem form variation was influenced by the provenance (genotype). Provenances the parent stands of which grew at higher elevations were characterized by greater stem volume than provenances from lower elevations, at the same values of dbh and height. In *Fagus sylvatica* Dudzińska (2003) found differences between mountain beech and lowland beech in respect of the stem form. Similar conclusions were drawn from studies on the stem form of *Picea abies* (Ciosmak 2002; Socha, Kubik 2004).

The knowledge of factors affecting the stem form of forest trees is the basis of correct determination of tree volume, not burdened with systematic errors. Stem tapering, affecting the quality of timber to a certain extent, may be one of the criteria of provenance selection.

The purpose of this study was to estimate the provenance variation of the tree form factor and taper of European larch on the basis of empirical data acquired by measurements of dendrometric characteristics of 20 larch provenances tested under the 1967 Polish Provenance Experiment on Larch. The study was carried out in the comparative experimental area established in Krynica (the Beskid Sądecki mountain range, southern Poland) and supervised by the Department of Forest Tree Breeding, Faculty of Forestry, Agricultural University of Cracow.

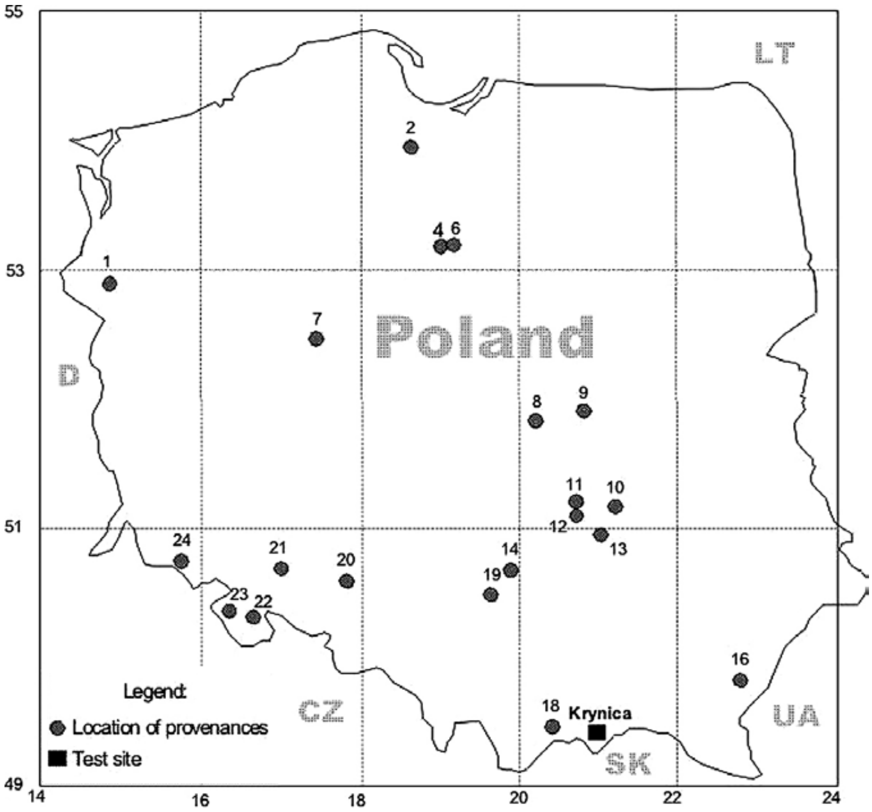

Fig. 1. Location of parental larch stands of provenances investigated on a test site at Krynica Experimental Forest Station

MATERIAL

This study was aimed at 20 provenances of larch from the entire territory of Poland (Fig. 1) tested in the experimental area in Krynica situated in the Carpathian Forest Region (sub-region of the Gorce and Beskid Sądecki mountain ranges). The experimental area is located in the Wojkowa forest section of the Forest Experimental Station in Krynica at 785 m above sea level, i.e. in the middle part of the lower mountain zone. Its site type was classified as the mountain forest site. Individual provenances were planted in five replications (plots 20 × 20 m each) and distributed following the rule of the "Latin rectangle". A detailed description of the study area may be found in the author's earlier paper (Kulej 2001). The study material consisted of dbh measurements of all trees, and height measurements of 5 trees in each plot, as well as diameter measurements of stem sections taken on 3 standing trees selected at random for each provenance in 5 replications (15 trees of each provenance). Measured trees were 39 years old. The section diameter measurements were taken at the base of the stem as well as 0.5 m, 1.3 m, 2.0 m above the ground level, and then every 2 m up to the tree top. The last measurement was taken about 2–3 m from the tree top. In total, section diameter measurements were taken on 300 trees. The Ledha GEO laser dendrometer was used.

METHODS

Because the parent stands of tested provenances of European larch were growing in various regions of Poland (Fig. 1), apart from the variation of the stem form, also the geographical variation was analyzed. For this purpose the provenances were included in five groups depending on the geographical location of parent stands:

I – provenances from northern Poland (1, 2, 4, 6);
II – provenances from central Poland (7, 8, 9);
III – provenances from the Świętokrzyskie Mountains (10, 11, 12, 13, 14, 19);
IV – provenances from the Sudetes (20, 21, 22, 23, 24);
V – provenances from the Carpathians (16, 18).

On the basis of section measurements taken on standing trees, diameters at 100 relative heights (0.00, 0.01, 0.02 … 0.99) were computed for each tree using interpolation according the 3rd degree Hermite's functions (Kosma 1999). An example of the curve computed by the interpolation method where diameters measured at different heights were joined is shown in Fig. 2.

Volumes of the stem as well as of merchantable timber of each tree were computed using a section method with section length equal to 0.01 of the tree length. Volumes were computed using Smilian's equation. Volumes computed from the sum of volumes of individual sections were accepted as real values in further analyses.

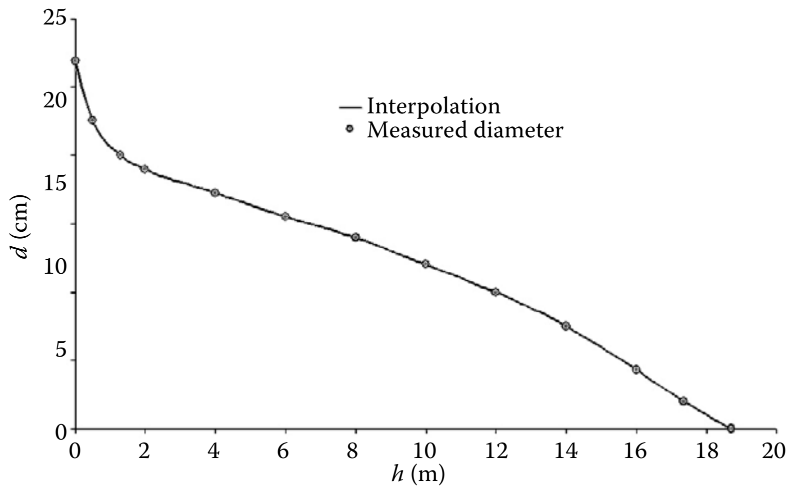

Fig. 2. Diameters measured on the stem and interpolation curve computed using Hermite's method (h = 18.7 m, dbh = 20.05 cm)

The estimation of variation of the tree form factor for all data within individual provenances was done in several stages. Since the values of the tree form factor most often depend on the tree size, a direct comparison of form factors of provenances differing in diameter and height may lead to erroneous conclusions (Allen 1993). In such a case possible differences in the values of the form factor may be a result of differences in the diameter and height of trees of individual provenances. To eliminate these differences a regression model was worked out for all data. This model described the form factor as an independent variable being explained by dependent variables. The model form factors computed from the regression equation were the mean values for given tree dimensions (dependent variables). To find whether a given provenance is characterized by higher or smaller form factor values, the real (computed on the basis of volume, diameter and height of the tree) and the model form factors were computed for each tree. Then the differences between model and real form factors were computed. The values of differences between these form factors provided information indicating whether a given provenance significantly differed in respect of this trait from the total population.

Analyses of differences between form factor values were carried out for the true ($f_{0.05}$) and breast height ($f_{1.3}$) stem form factors. For this purpose regression models describing the relationship between the form factors and the basic biometric characteristics of trees, such as height and diameter, were worked out in order to compare real values with model values of the form factor by computing the absolute (δf) (equation 1) and per cent ($\delta f_{\%}$) (equation 2) differences between model (f_{pred}) and real values (f_{obs}).

$$\delta f = f_{pred} - f_{obs} \tag{1}$$

$$\delta f_{\%} = \frac{f_{pred} - f_{obs}}{f_{obs}} \times 100\% \tag{2}$$

The determined errors assumed to be the basis of the comparison between the stem form factors of various provenances became the basis of the estimation of provenance diversification in respect of the stem form factor.

The estimation of the stem taper was done on the basis of the coefficient of tapering proposed by Krenn (1944) (equation 3).

$$z = \frac{d_{0.1} - d_{0.5}}{0.4h} \tag{3}$$

The coefficient of tapering determined in such a way is, however, dependent on tree dimensions, and differences in its value may result from differences in the rate of tree growth of individual provenances (Kulej 2001). To eliminate their influence the coefficient of tapering z_r was used. It was proposed to compute this coefficient on the basis of relative diameters (equation 4).

$$z_r = 2.5 \times (d_{r0.1} - d_{r0.5}) \tag{4}$$

A detailed analysis of the effect of provenances on the stem profile and taper of tree stems was carried out by the comparison of diameters from relative heights: 0.05, 0.10, 0.20, ... 0.90. The effects of the provenance and provenance region on the values of relative diameters were analyzed using the analysis of variance.

Stand density is one of the hypothetic factors that may affect the stem form of trees. This is why also the analyses determining the relationship between the variation of the stem form and stand density were carried out. The stand density index (SDI) proposed by Reineke (Woodall et al. 2002; Zeide 2005) was used. This index is a relative measure of density elaborated for even-aged stands, and it is determined on the basis of the number of trees per hectare (TPH) and the quadratic-mean dbh (d_q) (equation 5).

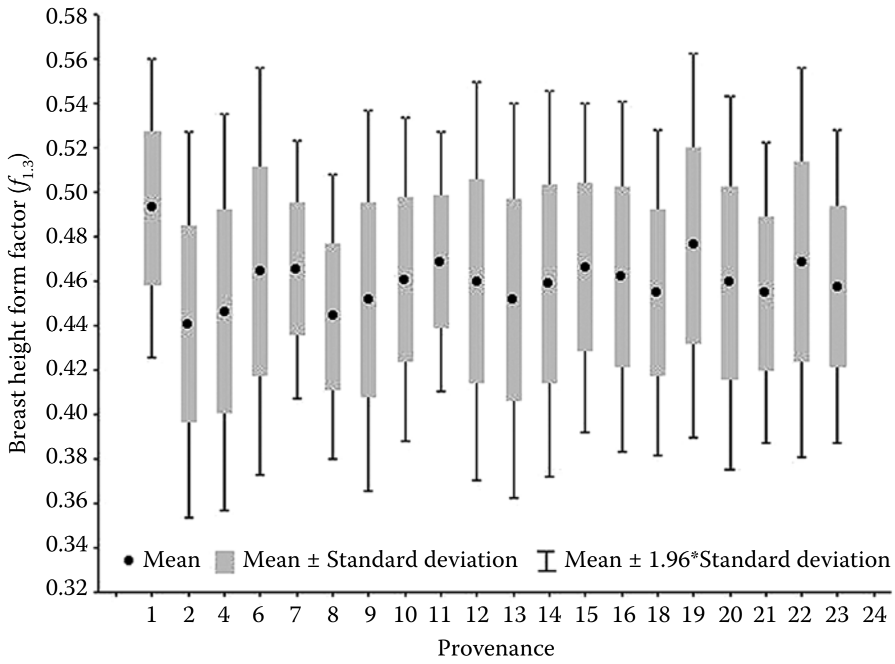

Fig. 3. Mean values of the breast height form factor of European larch of different provenances

$$SDI = TPH\left(\frac{dbh_q}{25}\right)^{1.6} \quad (5)$$

This index is based on the relationship between the mean dbh and the number of trees per unit area. In order to check whether the density index *SDI* significantly modifies the variation of the true form factor the method of multiple regression was used with the tested true form factor as a dependent variable and the stand density (*SDI*), height (*H*), and diameter from height 0.05h ($D_{0.05h}$) as independent variables.

RESULTS

Variation of breast height and true form factors

Breast height form factor

The breast height form factor of the analyzed provenances of European larch turned out to be independent of the values of the basic dendrometric characteristics of trees such as dbh, height or crown length (absolute and relative). Thus, when comparing the breast height form factors of different provenances there was no need to exclude the effect

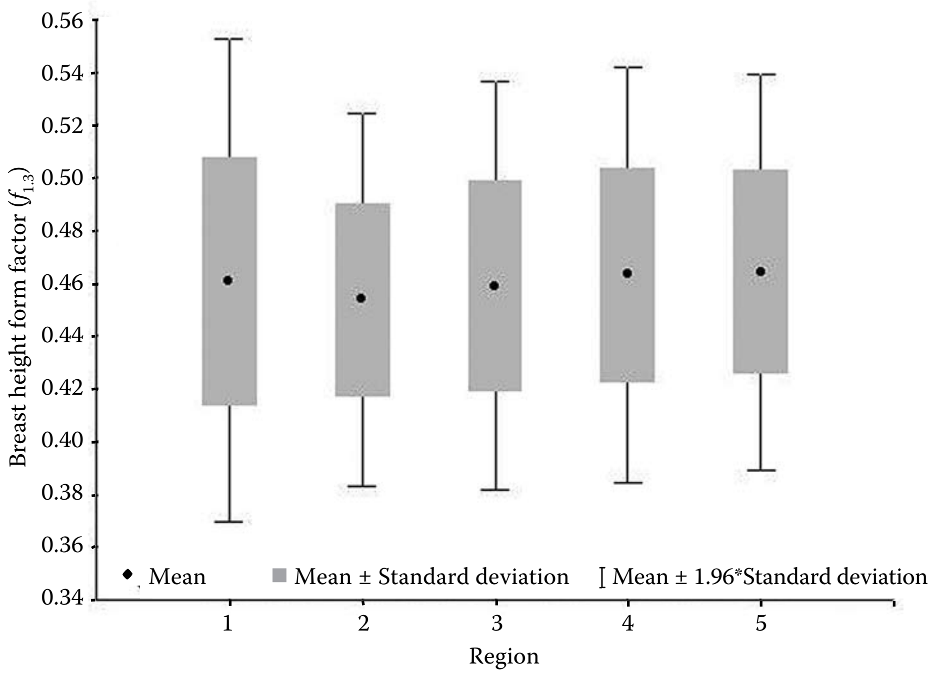

Fig. 4. Values of the breast height form factor ($f_{1.3}$) of European larch depending on the provenance region

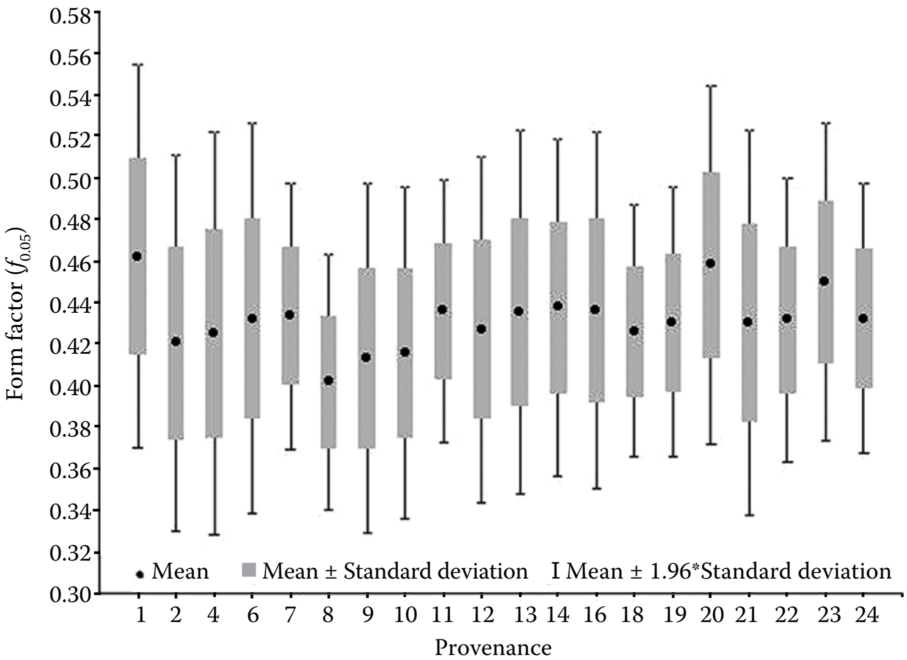

Fig. 5. Values of the true form factor ($f_{0.05}$) of European larch depending on the provenance region

of dendrometric characteristics on their variation. The tree form factors of partial populations of European larch under comparison ranged on average from 0.441 for provenance 2 (Pelplin) to 0.493 for provenance 1 (Myślibórz Północ) (Fig. 3). On the basis of the analysis of variance, with the previous test of homogeneity of variance, it was found that the observed differences in the mean values of the breast height form factor of tested provenances were statistically insignificant (α = 0.05).

No significant differences were found in the mean values of form factors determined for the different provenance regions of larch. The mean values of form factors for larches from the respective regions ranged from 0.454 for region 2 (central Poland) to 0.464 for region 5 (the Carpathians) (Fig. 4).

True form factor ($f_{0.05}$)

In the case of the true form factor $f_{0.05}$ the variation between individual provenances was considerably greater (Fig. 5). For two provenances, i.e. provenance 1 (Myślibórz Północ) and provenance 6 (Konstancjewo-Tomkowo), the difference was significant (α = 0.05).

The analysis at the region level also showed certain diversification of the true form factor (Fig. 6). The

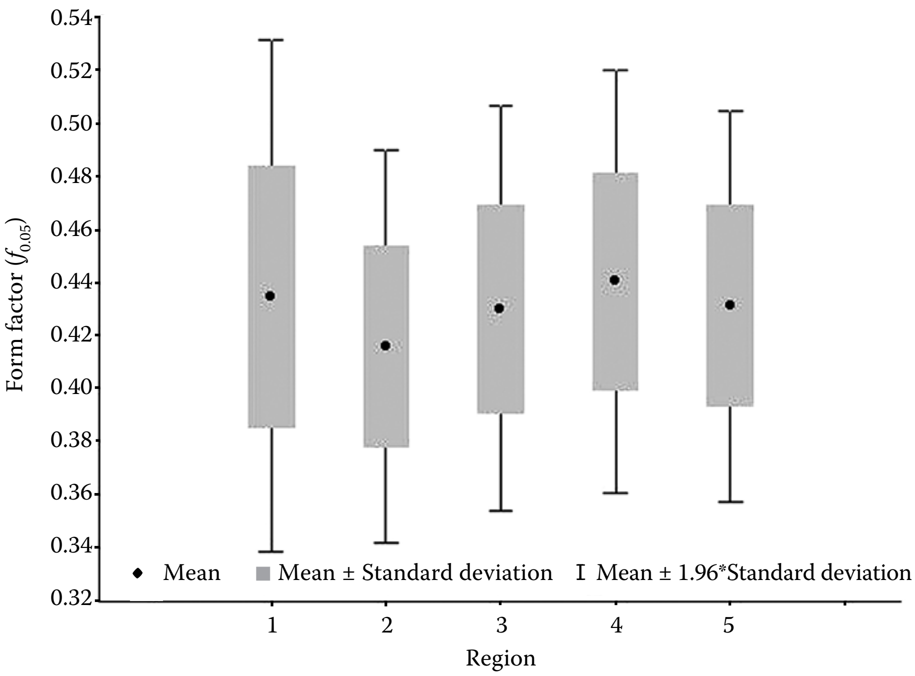

Fig. 6. Values of the true form factor ($f_{0.05}$) of European larch depending on the provenance

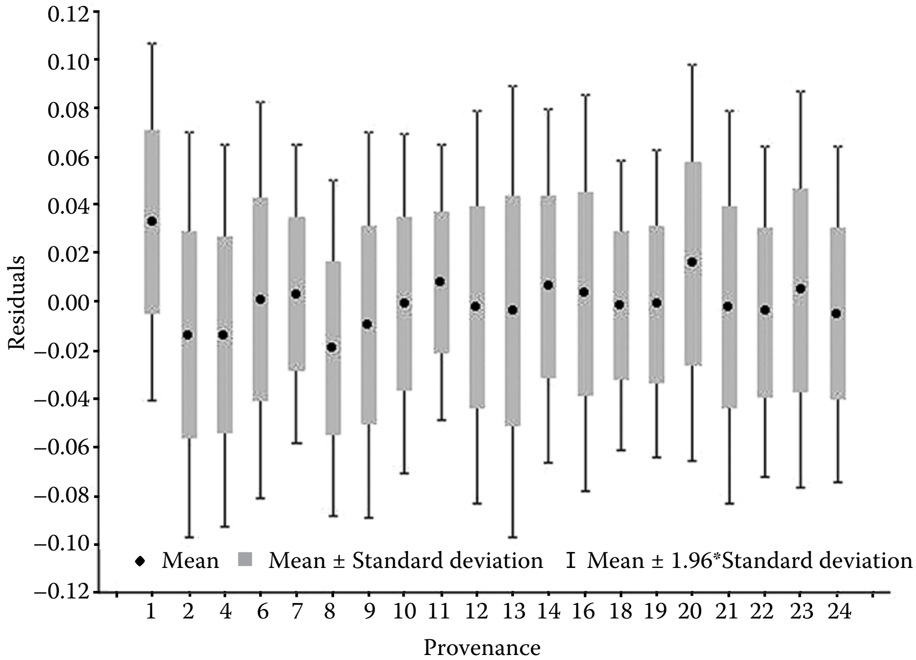

Fig. 7. Mean residual values of the equation of multiple regression used to determine the true form factor depending on the provenance

analysis of variance, carried out in order to compare the mean form factors of individual regions, indicated the existence of significant differences in form factor values between the different regions. On the basis of multiple comparisons by Tukey's test provenances from central Poland and from the Sudetes were found to significantly differ in the mean values of the form factor (regions 2 and 4).

Using the multiple regression analysis the values of the true form factor were found to depend on the diameter and height of trees. Therefore, the observed differences could result from provenance diversification in respect of tree diameter and height. For this reason a regression model describing the form factor by means of two independent variables, dbh and height, was used to compare the values of form factors of individual provenances. On the basis of the corrected coefficient of determination it was stated that a linear equation (equation 6) describing the relationship between the true form factor and the diameter $d_{0.05}$ and height explained about 14% of the form factor variation.

$$f_{0.05} = 0.3180 + 0.007657 \times h - 0.001846 \times d_{0.05} \quad (6)$$

The information on the provenance diversification of the true form factor was obtained by comparison of residual values of the regression model. For this purpose in each of 300 trees making up the study

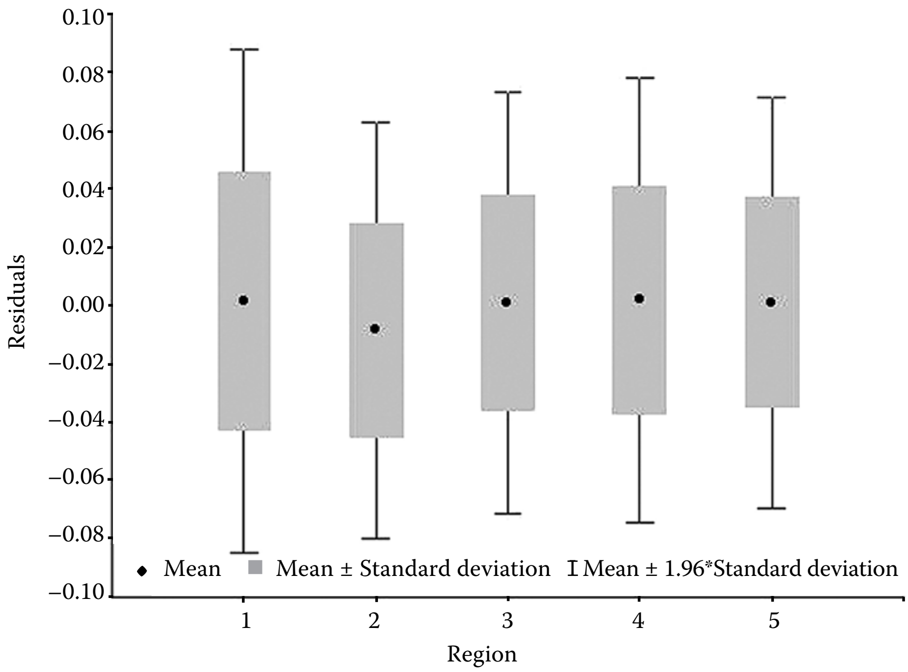

Fig. 8. Mean residual values of the equation of multiple regression used to determine the true form factor depending on the provenance region

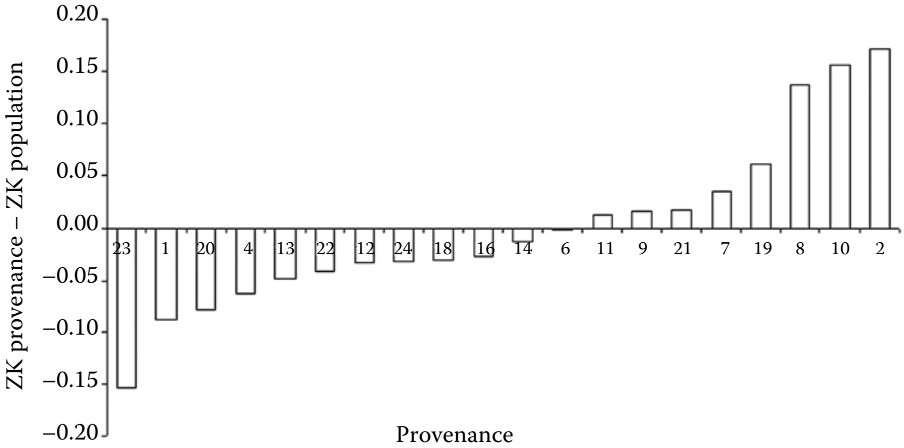

Fig. 9. Differences between the mean stem tapering of individual provenances determined according to Krenn (1944) and the mean stem tapering determined for all empirical data

material the model form factor was computed and compared with the real one in accordance with equation 1. The residual values of the equation for the form factor computed for individual provenances were similar. The analysis of variance showed that the residuals of the regression model for individual provenances ranging from –0.019 for provenance 8 (Rawa mazowiecka) to +0.033 for provenance 1 (Myślibórz Północ) did not differ significantly (Fig. 7).

Similar results were obtained when residual values for individual regions were compared (Fig. 8). In this case the elimination of the effect of tree diameter and height caused that differences in the values of the form factor observed for region 2 (provenances from central Poland) and region 4 (provenances from the Sudetes) turned out to be insignificant. No differences were found in residual values of the regression equation describing the form factor on the basis of dbh and height. Differences in the values of the true form factor found by the direct comparison were also caused by diversification of dimensional characteristics of trees in this case.

Stem tapering

The stem tapering determined according to Krenn's equation (equation 2) showed considerable provenance diversification. The mean value of taper varied from 0.67 cm/m for provenance 23 (Szczytna Śląska) to 1.00 cm/m for provenance 2 (Pelplin). The extreme differences between the mean stem taper of individual provenances and the mean taper of populations under investigations ranged from –0.15 (provenance 23 – Szczytna Śląska) to +0.17 (provenance 2 – Pelplin) (Fig. 9). The occurrence of groups significantly differing from one another was found on the basis of the analysis of variance.

The multiple regression analysis showed that stem tapering was strongly correlated with dbh and height of trees. The coefficient of multiple correlation for this relationship was 0.70. As it was shown by the value of the corrected coefficient of determination 49% of taper variation was explained by dbh and height of trees. Differences between individual provenances in respect of tapering values were therefore

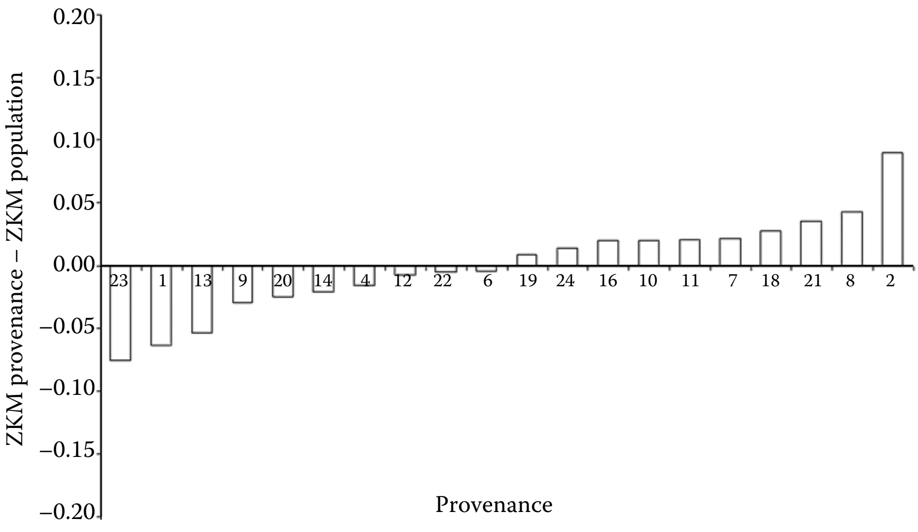

Fig. 10. Differences between the mean stem tapering of individual provenances determined according to Krenn's (1944) modified equation and the mean stem tapering determined for all empirical data

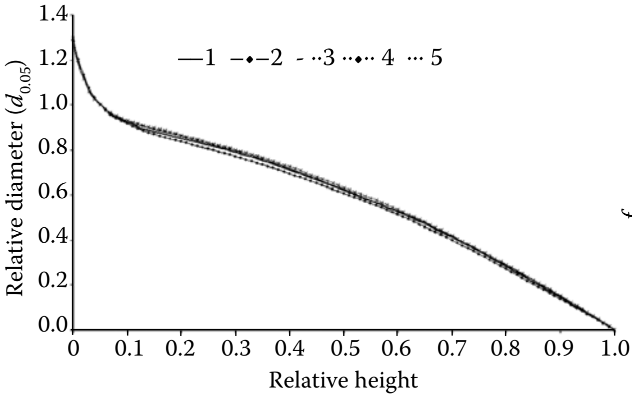

Fig. 11. Stem profiles of European larch from individual provenance regions

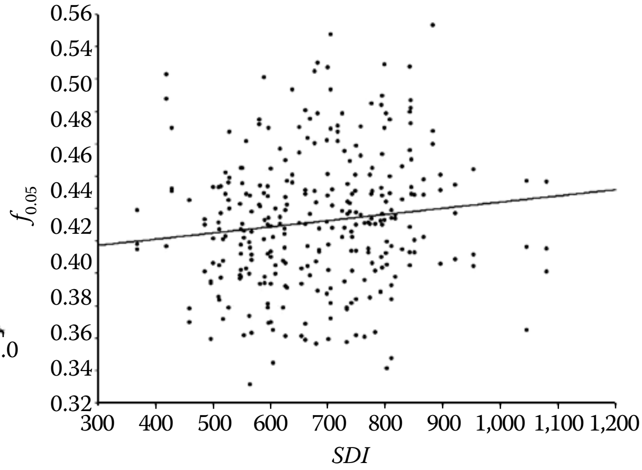

Fig. 12. Relationship between the true form factor and the stand density index (*SDI*)

caused to a great extent by differences in the rate of height and diameter growth.

The effect of dbh and height on variation of stem tapering was eliminated by computing the relative tapering (equation 4). In this case the range of taper variation distinctly decreased but the extreme mean values were still observed in provenance 23 (Szczytna Śląska) and provenance 2 (Pelplin) (Fig. 10). The comparison of means, using the analysis of variance, showed that when the effect of dbh and height was eliminated the mean values of tapering of individual partial populations did not differ significantly.

The stem profile variation

Individual provenance regions differed in respect of the range of variation of relative diameters $d_{0.05}$ at individual heights of the stem. However, on the basis of a direct comparison of the trait under analysis it was observed that the different regions were characterized by similar mean values of relative diameters at individual stem heights (Fig. 11). The differences in mean relative diameters at individual heights were not larger than 0.02. A little greater diversification of average stem profiles occurred between individual provenances.

The one-way analysis of variance did not show any differences in the values of mean relative diameters $d_{w0.05}$ from the particular heights which would have been caused by the provenance or by the provenance region. This was confirmed by results of the analysis of the tree form factors and tapering.

Relationship between stand density and variation of the stem profile

Using simple linear regression a slight, although statistically significant ($\alpha = 0.05$) effect of stand density index (*SDI*) on variation of the true form factor $f_{0.05}$ was found (Fig. 12). The coefficient of correlation, and in consequence the proportion of explained variation, was however relatively small since the value of the coefficient of determination (R^2) was only 0.015.

After using the model of multiple regression in which apart from the index *SDI* also the relative diameter at height 0.05h ($d_{w0.05}$) and the tree height were independent variables, in the description of variation of the true form factor ($f_{0.05}$) it turned out that the index of stand density *SDI* was an insignificant variable. The proportion of variance being ex-

Table 1. Parameters of a multiple regression model describing the true stem form factor $f_{0.05}$ on the basis of the stand density index (*SDI*), height (*H*) and relative diameter $d_{w0.05}$, and estimation of their significance

Variables	Parameters of a multiple regression equation and estimation of their significance			
	parameter ß	standard error of parameter ß	*t*-statistics value	probability level
Free term	0.30652	0.01906	16.08178	0.00000
SDI	0.00002[a]	0.00002	1.24408	0.21446
H	0.00741	0.00122	6.09091	0.00000
$d_{w0.05}$	–0.00175	0.00062	–2.84490	0.00475

[a]Parameter insignificant at $\alpha < 0.2145$

plained by this trait did not differ significantly from zero (Table 1).

DISCUSSION

The analyses of the stem form of European larch, described by means of the tree form factor, or directly expressed by means of the taper or diameters at individual heights of the stem, did not show the influence of the provenance on its variation. Taking into account the dimension traits of trees, the proportion of variance explained by provenances did not differ significantly from zero. Results of this study differ from results of the study on *Abies grandis* (Socha, Kulej 2005) which showed that the stem form of that tree species was a trait determined by the genotype. Similar results were also expected on the basis of studies aimed at the stem form of mountain and lowland *Fagus sylvatica* (Dudzińska 2003), as well as studies concerning *Picea abies* stands which showed differences between mountain and lowland stands in respect of the stem form (Ciosmak 2002). At the present state of investigations it is difficult to make comprehensive hypotheses on the observed regularities in variation of the stem form of the studied larch partial populations. The authors of the present study are of the opinion that their results permit to formulate the hypothesis about specific properties of larch as a species the tree form factor and tapering of which are determined by growth conditions to a greater extent than by the provenance (genotype). However, growth conditions in this case should be understood as conditions on a macro scale. Specific growth conditions on a micro scale, occurring in individual experimental plots of the provenance experiment and determined on the basis of the *SDI* index, did not significantly affect the form of tree stems.

CONCLUSIONS

Differences in the values of the stem form and taper, observed on the basis of a direct comparison, resulted from differences in the growth rate of the analyzed larch provenances causing a significant diversification of diameter and height of trees. The values of the breast height form factor ranged on average from 0.441 (Pelplin) to 0.493 (Myślibórz Północ). However, the differences between provenances were not statistically significant.

In the case of the true stem form factor ($f_{0.05}$) significant differences in absolute values of this trait were found between provenances from Myślibórz Północ and Konstancjewo-Tomkowo. However, these differences resulted from the relationship between the true form factor and diameter and height of trees. The elimination of the effect of diameter and height made these differences statistically insignificant ($\alpha = 0.05$).

More detailed information on the stem form of larch was obtained on the basis of the analysis of relative diameters at different heights of the stem. In this case, irrespective of assumed diameter in respect of which relative diameters at individual stem heights were computed, and in spite of a certain diversification of mean stem profiles of individual partial populations, no significant effect of the genotype (provenance) on their variation was found. The variation of the stem form was not significantly affected by the provenance region, either. The observed differences in mean diameters from individual stem heights were statistically insignificant.

The results of the analysis of the relationship between the stem form of larch of the tested provenances and the index of stand density, obtained during this study, were not expected. Although there was a slightly positive correlation between the true form factor and the stand density index, it was however, as proved by detailed analyses, the result of differences caused by dendrometric traits of the analyzed provenances. Their elimination showed that the stand density index had no influence on variation of the true stem form factor.

The results obtained during this study indicated specific growth properties of European larch of the tested partial populations which cause that the form factor and taper of the stem do not depend on the provenance. It should be pointed out, however, that this study concerned only one of the so called parallel experimental areas of the 1967 Polish Provenance Experiment on Larch, i.e. the Krynica experimental area situated in the Beskid Sądecki mountain range. Therefore, results of this study need to be confirmed by similar studies carrield out in other experimental areas of different growth conditions.

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Změny stromové výtvarnice a sbíhavosti kmene u modřínu opadavého polských proveniencí ověřované v podmínkách horského pásma Beskyd Sądecki (jižní Polsko)

ABSTRAKT: V dlouhodobé studii, která se uskutečnila v rámci Polského provenienčního pokusu s modřínem 1967, jsme sledovali genetickou proměnlivost u 20 proveniencí modřínu opadavého, který se nachází ve stanovištních podmínkách horského pásma Beskyd Sądecki (na pokusné ploše v Krynici). Údaje pocházely z měření tloušťky kmene s kůrou na stojících stromech sledovaných proveniencí. Získané výsledky nenaznačily u sledovaných populací modřínu žádné zřetelné změny ve tvaru kmene. Některé rozdíly mezi srovnávanými proveniencemi ve sbíhavosti kmene a stromové výtvarnici vyplynuly z rozdílů ve stromové výšce a tloušťce.

Klíčová slova: genotyp; provenienční pokus; profil kmene

Corresponding author:

Dr. Jarosław Socha, Agricultural University of Cracow, Faculty of Forestry, Department of Forest Mensuration, Al. 29 Listopada 46, 31-425 Cracow, Poland
tel.: + 48 12 662 5011, fax: + 48 12 411 9715, e-mail: rlsocha@cyf-kr.edu.pl