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STATISTICAL CHARACTERISTICS OF DOUBLE BARK THICKNESS AT BREAST HEIGHT BASED ON PINE (*PINUS SYLVESTRIS* L.), LARCH (*LARIX DECIDUA* MILL.) AND OAK (*QUERCUS ROBUR* L.)

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Summary

Tree bark may be considered as a natural protective coat. Its thickness depends on the tree species, while in trees of the same species - on age. Bark thickness changes also along the stem. It is a highly variable characteristic. The best known parameter is bark thickness at a height of 1.3 m. The aim of the study was to:

– determine the value and variation of double bark thickness at breast height based on analyzed pines, larches and oaks,

– determine the power of relationships of double bark thickness at breast height with selected biometric characteristics of analyzed trees,

– develop linear regression equations to estimate the value of double bark thickness at breast height depending on age and breast height diameter for analyzed tree species.

Experimental material includes results of measurements for selected biometric traits of mean sample trees of three species, i.e. 40 pines (So), 24 larches (Md) and 33 oaks (Db). Based on the collected material basic statistical characteristics were determined for each species. The goodness of fit of double bark thickness with normal distribution was verified in the analyzed tree species. The power of the relationship of double bark thickness at breast height with selected mensuration traits was determined in this study.

Key words and phrases: Scots pine, European larch, common oak, bark thickness, correlation coefficient, linear and multiple regression

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1. Introduction, aim and scope of study

Tree bark may be considered a natural protective coat. Its thickness depends on the tree species, while in trees of the same species - on age. Bark thickness changes also along the stem. It is a highly variable characteristic. Knowledge on thickness of tree bark is of significant economic importance. In the 20th century bark was considered as a waste product of woodworking. At present not only foresters, but also gardeners and heat engineers consider potential utilization of bark. Bark of some tree species is used by industry (e.g. spruce, oak). When determining tree volume on standing trees a certain percentage is deducted for bark in order to determine wood volume inside bark, wood being a desirable and valuable raw material for industry. The determination of bark thickness at breast height is of significant importance for the improvement of methods to determine stand volume and volume increment. The accuracy of determination in case of stand volume and volume increment is determined by the accuracy of the determined proportion of thickness in diameter outside bark measured at a height of 1.30 m.

Bark thickness may be determined as the difference between the diameter of a tree outside bark and diameter inside bark. In such a case we obtain double bark thickness. Usually diameters (inside and outside bark) are measured in two perpendicular directions and the mean difference is assumed to be double bark thickness. Bark thickness may also be measured using a bark gauge; however, we need to consider high variation of this characteristic at the circumference.

The best known parameter is bark thickness at a height of 1.3 m. It depends on breast height diameter of a tree, i.e. the diameter measured at a height of 1.3 m. Studies conducted to date on bark thickness and its relationships with other characteristics concern primarily the most important economic species, i.e. pine.

The aim of the study was to:

– Determine the value and variation of double bark thickness at breast height based on analyzed pines, larches and oaks,

– Determine the power of relationships of double bark thickness at breast height with selected biometric characteristics of analyzed trees,

– Develop linear regression equations to estimate the value of double bark thickness at breast height depending on age and breast height diameter for analyzed tree species.

2. Experimental material and methodology

Experimental material includes results of measurements for selected biometric traits of mean sample trees of three species, i.e. 40 pines (So), 24 larches (Md) and 33 oaks (Db). Pines were selected at random from 8 stands in the Zielonka Experimental Forest Division (5 from each stands). Oaks were selected from 11 stands in the Łopuchówko Forest Division following the principles of variant I of the Urich method (with 3 sample trees from each stand). Larches were selected according to the assumption of the Hartig method from 8 stands in the Babimost Forest Division (also 3 trees from each stand). Most important measurement data characterizing analyzed trees at the time of their felling are given in Table 1.

Age of each tree (w) was determined by calculating the number of annual rings at the tree base. Breast height diameters were measured outside bark (d_{zk}) and inside bark (d_{bk}) in two perpendicular directions N-S and E-W. Double bark thickness (k) in all trees was established as the difference of breast height diameter outside bark and breast height diameter inside bark. Tree height (h) was assumed as the total length measured after trees were felled. Volume of each tree (v) was calculated by sectional measurements. Breast height tree form factor ($f_{1.3}$) was calculated as a ratio of whole tree volume to the volume of a comparative cylinder with a diameter equal to the breast height diameter of a given tree and height equal to its height.

Based on the collected experimental material for each species basic statistical characteristics were determined (arithmetic mean, standard deviation and coefficient of variation, minimum and maximum values). Power was established for the relationship of double bark thickness at breast height with selected mensuration traits (age –w, breast height diameter outside bark – d_{zk}, breast height diameter inside bark – d_{bk}, height – h, whole tree volume determined by sections – v, breast height tree form factor – $f_{1,3}$ and stem slenderness – s).

Table 1. Characteristics of selected measurement traits of trees at the time of their felling

Traits of trees	N	$\bar{x}$	min	max	s_{dx}	V (%)
So						
w (age – years)	40	55	23	87	20.06	36.23
d_{zk} (breast height diameter outside bark – cm)		20.59	10.11	31.30	6.66	32.33
h (height – m)		21.03	12.73	28.05	4.70	22.34
v (volume – m^3)		0.37	0.05	0.86	0.26	71.63
$f_{1,3}$ (breast height tree form factor)		0.43	0.31	0.52	0.05	10.64
Md						
w (age – years)	24	52	15	82	25.09	48.53
d_{zk} (breast height diameter outside bark – cm)		26.35	8.35	49.35	10.58	40.15
h (height – m)		22.84	9.27	30.20	6.51	28.52
v (volume – m^3)		0.75	0.03	2.31	0.59	79.29
$f_{1,3}$ (breast height tree form factor)		0.48	0.39	0.54	0.05	9.91
Db						
w (age – years)	33	92	41	148	33.96	37.11
d_{zk} (breast height diameter outside bark – cm)		31.48	14.55	56.85	11.17	35.49
h (height – m)		24.83	18.30	34.30	5.04	20.29
v (volume – m^3)		1.11	0.18	3.81	0.93	83.43
$f_{1,3}$ (breast height tree form factor)		0.48	0.33	0.58	0.05	9.51

3. Results

Among analyzed tree species the biggest double bark thickness was found for pine, for which the arithmetic mean was 2.05 cm (tab. 2). This species is also characterized by the highest variation in analyzed traits, amounting to as much as 55.53%. Only a slightly lower mean double bark thickness was recorded for larch (2.01 cm), while the smallest was observed for oak (1.87 cm). The same order was also found for the variation of the analyzed trait. In larch it was 40.71 %, while in oak it was only 33.59% (tab. 2).

Table 2. Basic statistical characteristics of double bark thickness of analyzed tree species

Species	N	$\bar{x}$	min	max	s_{dx}	V (%)
So	40	2.05	0.60	4.90	1.14	55.53
Md	24	2.01	0.92	4.50	0.82	40.71
Db	33	1.87	0.90	3.40	0.63	33.59

The goodness of fit of double bark thickness with normal distribution was verified in the analyzed tree species. Goodness of fit of empirical distribution with the normal distribution was tested using the Kolmogorov-Smirnoff, Lilliefors and Shapiro-Wilk tests (tab. 3). Only in case of pine two of the applied tests (the Lilliefors and Shapiro-Wilk tests) indicated a deviation of the empirical distribution. In case of larch only the Shapiro-Wilk test found a basis for the rejection of the hypothesis on the goodness of fit for double bark thickness with normal distribution. However, due to the slight discrepancy it was assumed that empirical distributions of the analyzed trait in the investigated species are at least close to the normal distribution.

Table 3. Tests of goodness of fit of double bark thickness three species with normal distribution

Species	N	Kołmogorov-Smirnoff test	Lilliefors test	Shapiro-Wilk test
		p-value		
Db	33	$p > 0.20$	$p > 0.20$	$p=0.09$
Md	24	$p > 0.20$	$p > 0.20$	$p=0.04$
So	40	$p > 0.20$	$p < 0.05$	$p=0.01$

The power of relationships of double bark thickness with selected biometric characteristics was determined in this study. The following parameters were taken into consideration: age (*w*) of trees, breast height diameter outside bark (d_{zk}), breast height diameter inside bark (d_{bk}), breast height tree form factor ($f_{1.3}$), height (*h*), tree volume (*v*) and slenderness (*s*). Results are given in Table 4. All correlation coefficients were statistically significant. In each of the investigated tree species the correlation with breast height tree form factor and slenderness was negative, which means that double bark thickness increases with a decrease in tree slenderness and a decrease in tree form factor.

Table 4. Linear correlation coefficients between double bark thickness and selected biometric traits of trees for analyzed species

Species	w	d_{zk}	d_{bk}	$f_{1,3}$	h	v	s
Db	0.595	0.803	0.782	-0.676	0.550	0.691	-0.743
Md	0.598	0.748	0.711	-0.788	0.512	0.608	-0.754
So	0.657	0.795	0.717	-0.546	0.644	0.766	-0.804

Recorded results concerning the relationship between double bark thickness and their selected biometric traits were an impulse to develop linear regression equations to estimate double bark thickness at breast height for oak, larch and pine.

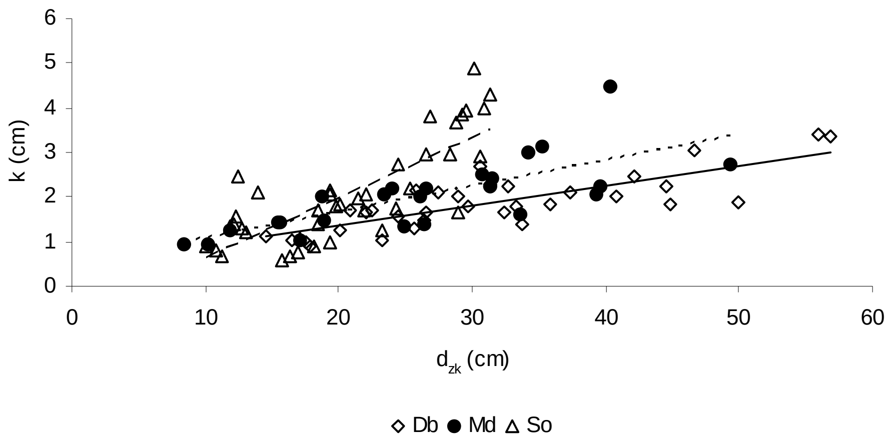

Fig. 1. Values of double bark thickness at a height of 1.30 m depending on breast height diameter in oak (Db), larch (Md) and pine (So)

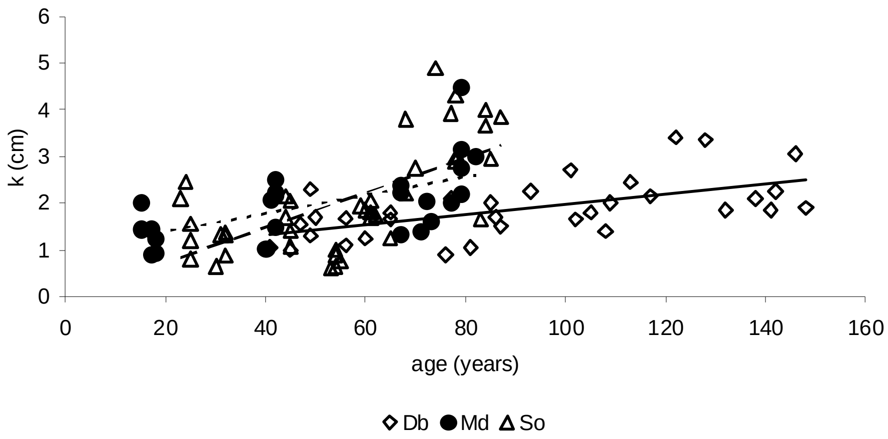

Fig. 2. Values of double bark thickness at a height of 1.30 m depending on age of trees in oak (Db), larch (Md) and pine (So)

As a result of estimation of regression equation parameters six equations were generated for the determination of double bark thickness at a height of 1.30 m. Linear equations to estimate double bark thickness depending on breast height diameter measured outside bark:

Db	$k = 0.0452 \cdot d_{zk} + 0.4487$	(3.1)
Md	$k = 0.0578 \cdot d_{zk} + 0.4847$	(3.2)
So	$k = 0.1362 \cdot d_{zk} - 0.7506$	(3.3)

Linear equations to estimate double bark thickness depending on age:

Db	$k = 0.0110 \cdot w + 0.8633$	(3.4)
Md	$k = 0.0195 \cdot w + 1.0011$	(3.5)
So	$k = 0.0373 \cdot w - 0.0148$	(3.6)

Variation in breast height diameter in oaks explains 64.5% variation in double bark thickness, in pine it is 63.2%, while in larches it is the least, i.e. 56%. Variation of tree age in analyzed species to a lesser extent explains variation in double bark thickness. This is most apparent in pine, where it amounts to

43.2%. In case of oaks and larches much lower coefficients of determination were recorded, exceeding only 35%.

Due to the course of linear dependences of double bark thickness with age (fig. 2) regression lines were compared for three analyzed species (pine, larch and oak). The aim of the comparison was to verify whether the course of the dependence in trees of all the analyzed species is similar in character or whether slopes of regression lines are different (Elandt 1964). Results of comparisons of three regression lines for this dependence (double bark thickness on age of trees) are given in table 5.

Table 5. Comparison of three regression lines for double bark thickness on age dependence

Variability	df	$\sum(x-\bar{x})^2$	$\sum(y-\bar{y})^2$	$\sum(x-\bar{x})(y-\bar{y})$	Regression coefficient	df	$\sum(y-Y)^2$
Db	32	36902.24	12.65	406.75	0.0110	31	8.17
Md	23	14480.96	15.38	282.20	0.0195	22	9.88
So	39	15699.38	50.66	586.09	0.0373	38	28.78
sum	94	67082.58	78.68	1275.04		91	46.82
Error	94	67082.58	78.68	1275.04	0.0190	93	54.45
Total	96	97927.55	79.30	1143.39	0.0117		
F_{calc} = 7.412489; F_{tab} = 3.096553							

On their basis it may be stated that not all lines have the same direction. i.e. they are not parallel. Figure 2 illustrating this dependence shows that the course of the dependence of double bark thickness on age for pine differs from the course of regression lines for the other two species, for which they are similar. The course of regression lines for larch and oak was compared. No statistically significant differences were found in the course of these regression lines (F_{calc} = 2.188844; F_{tab} = 4.023016811). Thus for these two species considered jointly (Db and Md), estimation was conducted for parameters of equations to estimate double bark thickness depending on the age of trees. The linear equation took the form:

$$k = 0.0084 \cdot w + 1.305 \tag{3.7}$$

Analogous comparisons for species were conducted for linear dependencies of double bark thickness on breast height diameter outside bark (fig. 1). Results are presented in table 6.

Also in this case it was found that lines were not parallel. Moreover. the course of regression lines was compared for larch and oak (F_{calc} = 1.17276; F_{tab} = 4.023016811). No statistically significant difference was found in the course of these lines. Parameters of the equation to estimate double bark thickness depending on breast height diameter were estimated for larch and oak considered jointly. The equation took the form:

$$k = 0,0461 \cdot d_{zk} + 0,5773 \tag{3.8}$$

Table 6. Comparison of three regression lines for double bark thickness on breast height diameter outside bark dependence

Variability	df	$\sum (x-\bar{x})^2$	$\sum (y-\bar{y})^2$	$\sum (x-\bar{x})(y-\bar{y})$	Regression coefficient	df	$\sum (y-Y)^2$
Db	32	3992.72	12.65	180.54	0.0452	31	4.49
Md	23	2574.90	15.38	148.91	0.0578	22	6.77
So	39	1727.55	50.66	235.22	0.1362	38	18.63
sum	94	8295.17	78.68	564.67		91	29.88
Error	94	8295.17	78.68	564.67	0.0681	93	40.25
Total	96	10452.17	79.30	529.70	0.0507		
F_{calc} = 15.7813; F_{tab} = 3.096553							

4. Discussion

Studies conducted to date on bark thickness and its relationships with other traits have been conducted mainly on pine. This is understandable, since it is a dominant species in Poland and a species of highest economic importance. Long-term studies on breast height bark thickness in pine and its relationship with breast height diameter outside bark and breast height tree form factors were conducted by Meixner (1964, 1965, 1967, 1970a, 1970b, 1971a, 1971b, 1972, 1973, 1977, 1978, 1986, 1988). Distinct relationships with breast height diameter outside bark were confirmed by studies by Bruchwald (1969, 1970), while papers by Rymer-Dudzińska (1962, 1965, 1969) consolidated knowledge on the dependence between bark thickness and breast height tree from factors in pine. Knowledge of bark thickness at breast height is used for the determination of stand basal area inside bark (Bruchwald 1970). According to the concept presented by Bruchwald (1971a, 1971b), for the determination of stand volume inside bark and its increment it is necessary to establish mean double bark thickness in diameter subclasses or diameter classes. Knowledge on this trait is also required for the estimation of periodical bark increment. which is used when determining stand volume increment outside bark using volume tables for standing trees by a single measurement at the end of the growing period (Šmelko 1964).

Meixner (1973) for bark thickness in pine overmature stands found the mean coefficient of variation to be 25.9%. In case of results presented here a higher variation was found in pines. as it amounted to as much as 55.53%. Meixner also observed a linear dependence of bark thickness with breast height diameter outside bark. Correlation coefficient ranged from 0.546 to 0.669, which showed an effect of variation in breast height diameter on the overall variation of bark thickness ranging from 29.8% to 44.8%. In this study the relationship of bark thickness outside bark was stronger, as correlation amounted to 0.795. Variation in breast height diameters of analyzed pines in 63.2% explains variation of the discussed trait.

5. Conclusions

1. Mean double bark thickness at breast height varies in different analyzed species. It is thickest in pines. followed by larches and finally oaks.

2. Bark thickness is characterized by a very high variation. For pine it was as much as 55.53 %, for larches it was 40.71 %, being the lowest for oaks, i.e. 33.59%.

3. Bark thickness increases with age of all analyzed tree species and with an increase in breast height diameter, height and volume. In case of breast height tree form factor and slenderness the correlation is negative.

4. The new linear regression equations to estimate double bark thickness depending on age and on breast height diameter measured outside bark for pine. oak and larch were developed.

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STATYSTYCZNA CHARAKTERYSTYKA PODWÓJNEJ GRUBOŚCI KORY DRZEW NA PIERŚNICY NA PRZYKŁADZIE SOSNY(*PINUS SYLVESTRIS* L.). MODRZEWIA (*LARIX DECIDUA* MILL.) I DĘBU (*QUERCUS ROBUR* L.)

Streszczenie

Korę drzew można nazwać naturalnym płaszczem ochronnym. Jej grubość zależy od gatunku drzewa. zaś u drzew tego samego gatunku od wieku. Grubość kory zmienia się też wzdłuż pnia. Jest cechą bardzo zmienną. Najlepiej poznana jest grubość kory na wysokości 1.3 m. Celem badań jest:

– określenie wielkości i zmienności podwójnej grubości kory na pierśnicy na przykładzie badanych sosen. modrzewi i dębów.

– ustalenie mocy związków podwójnej grubości kory na pierśnicy z wybranymi cechami biometrycznymi analizowanych drzew.

– opracowanie równań regresji liniowej do szacowania wielkości podwójnej grubości kory na pierśnicy w zależności od wieku i pierśnicy dla omawianych gatunków drzew.

Na podstawie zebranego materiału badawczego dla każdego gatunku określono podstawowe charakterystyki statystyczne. Sprawdzono zgodność rozkładów podwójnej grubości kory badanych gatunków drzew z rozkładem normalnym. Ustalono siłę związku podwójnej grubości kory na pierśnicy z wybranymi cechami dendrometrycznymi.

Słowa kluczowe: sosna zwyczajna, modrzew europejski, dąb szypułkowy, grubość kory, współczynnik korelacji, regresja liniowa

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