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ALINA HEJNOWICZ

A comparative study of the anatomical characters of wood of *Picea abies* Karst. and of *Larix polonica* Racib.

The microscopic structure of wood of larch and spruce is almost identical. This causes many difficulties in the identification of small or poorly conserved fragments of wood which it is not possible to place definitely in one genus or the other.

During 60 years of research (Burgerstein 1908, Brem 1934, Budkiewicz 1956 and 1961, Greguss 1955, Diannelidis 1953, Phillips 1941, Jay 1947, Moskalewa 1962, Huber 1951, Wichrow 1959, Hejnowicz 1964) it has not been possible to find wood characters of larch and spruce on the basis of which it would be possible to discriminate between the two species.

Among the diagnostic characters the following have been considered: 1) the type of transition from early to late wood in an annual ring, sudden in larch and gradual in spruce; 2) the distribution of bordered pits in an early wood tracheid, double in larch and single in spruce; 3) dentations on the inner surface of walls in the ray tracheids (they do not exist in larch and occur in spruce); 4) occurrence of terminal parenchyma in the wood of larch and the absence of this character in the wood of spruce; 5) location of the resin ducts in wood rays (in larch markedly eccentric and in spruce central); 6) number of cells lining the resin ducts (larger in larch and smaller in spruce). As has been shown by my earlier studies (Hejnowicz 1964, 1969) these are variable characters even within one tree. Some of them, it was found, are associated with juvenile type of wood and occur in the wood of both larch and spruce. For example the gradual transition from early to late wood within an annual ring, and the single bordered pits in tracheids of early wood occur in the juvenile wood of both larch and spruce. As a result none of the anatomical characters from 1 to 6 have any use for diagnostic purposes.

In order to answer the question whether it is possible to distinguish these two species in the basis of the microscopic characters of wood it was necessary to:

1. Analyse the intra-tree variation of individual characters at various levels of the stem and at various distances from the tree axis.
2. Determine the nature and range of variation of suitable characters

within a larger number of trees (inter-tree variation) belonging to the same species but coming from various stands in Poland.

3. Compare the wood of individuals representing both the studied species.

The problem of intra- and inter-tree variation of anatomical characters of wood of larch and spruce has already been studied (Hejnowicz 1964, 1969) and therefore the problems mentioned under points 1 and 2 are taken care of. The present paper is an attempt at summarizing the results as suggested in point 3 and at finding an answer to the basic question: whether and in what way is it possible to distinguish the wood of spruce from the wood of larch on the basis of anatomic characters.

METHODS AND RESULTS

As a basis for the present paper the detailed studies on the anatomy of larch (Hejnowicz 1964) and spruce (Hejnowicz 1969) have been used. In both these species the variability of several anatomical characters has been investigated in various growth rings, at various levels of the tree trunk, and in various trees from different parts of Poland.

For 23 studied characters of the wood anatomy analyses of variance have been perfored on the basis of which it was found that only in 7 characters there are significant differences between larch and spruce, namely:

1. Thickness of an early wood tracheid in radial measurement (x_1).
2. Area of transverse section of a tracheid.
3. Ratio of the two cross-section dimentions of early wood tracheids (x_2).
4. Number of tracheids on 1 mm² area of cross-section.
5. Diameter of a bordered pit in an early wood tracheid (x_3).
6. Height of one ray cell (x_4).
7. Width of one ray cell.

Four of these characters deserve special mention, since their ranges of distribution in the studied group of larches and spruces are basically different for the two species. Only occasionally did larches fall within the range of distribution for spruce and vice versa (figs. 1—4).

These differetiating characters are: 1) radial dimention of an early wood tracheid (x_1), 2) ratio of both the cross-section dimentions of early wood tracheis (x_2), 3) diameter of a bordered pit on an early wood tracheid (x_3) and 4) height of one ray cell (x_4).

In view of the fact that between the ranges of distribution for the selected characters it is not possible to draw a definite boundry between the two species it is not possible to use the values directly for discrimination between them. For this reason it was considered necessary to

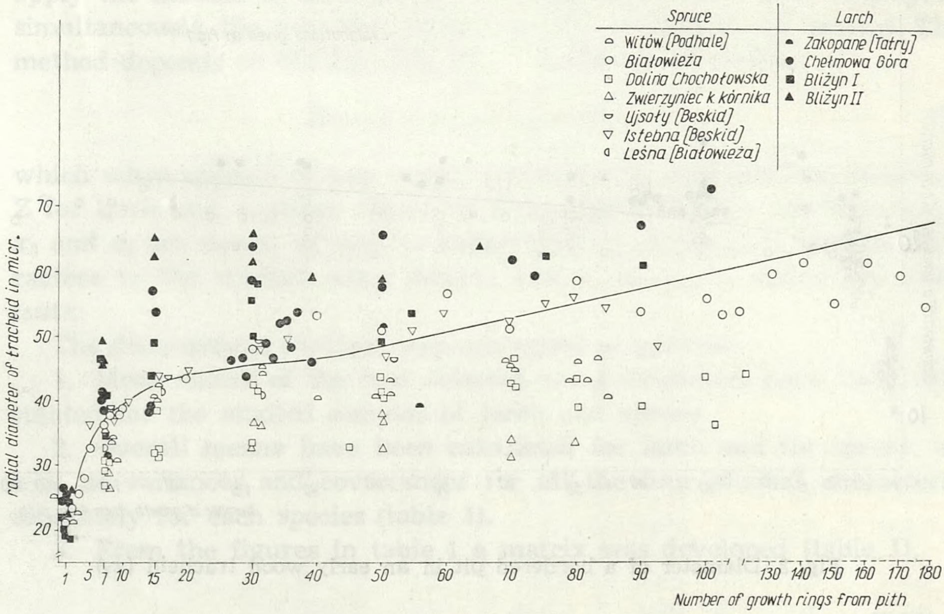

Fig. 1. Mean radial dimention of an early wood tracheid (x_1)

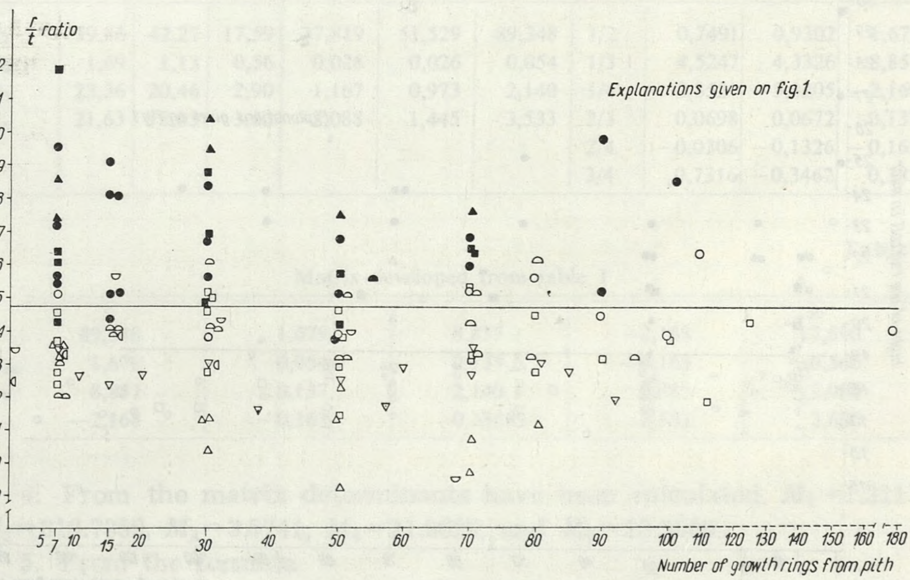

Fig. 2. Ratio of the two cross-section dimentions of an early wood tracheid (x_2)

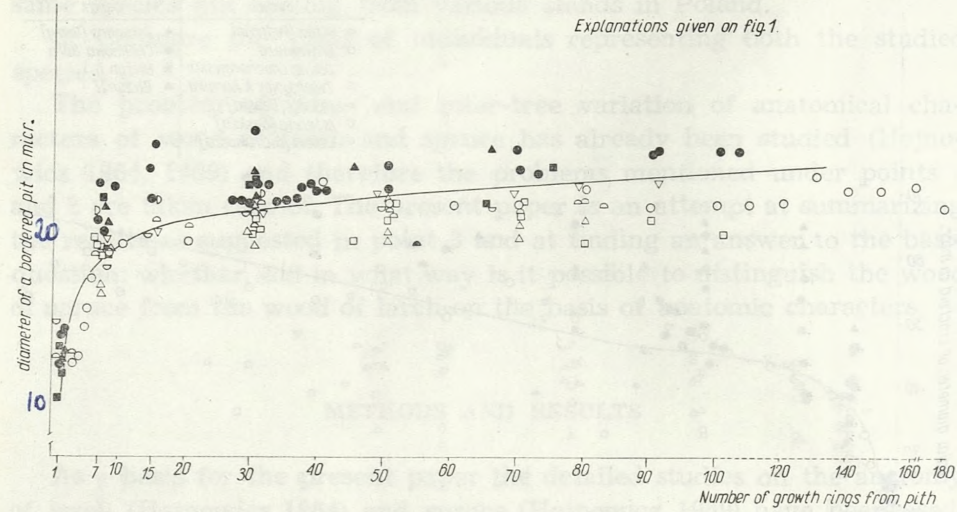

Fig. 3. Diameter of a bordered pit in an early wood tracheid (x_3)

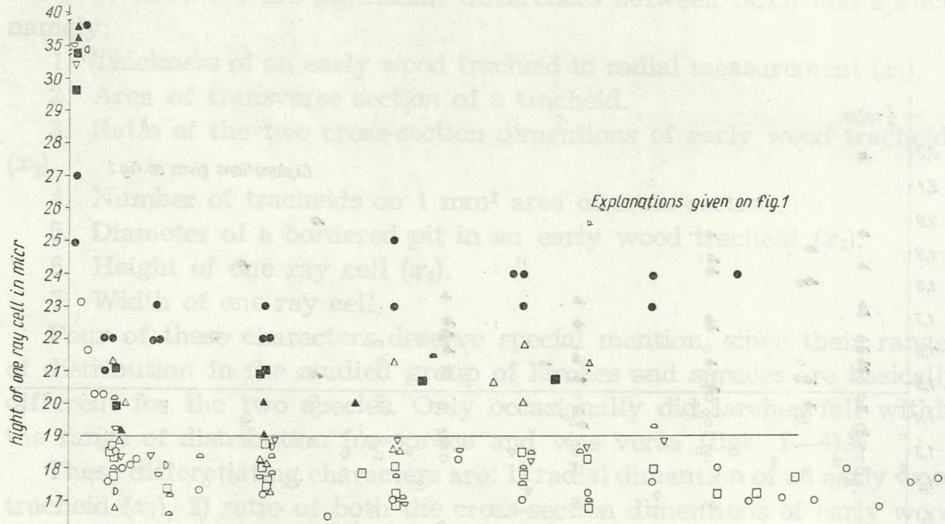

Fig. 4. Mean heigth of one ray cell (x_4)

apply the method of discrimination analysis (Perkal 1963) employing simultaneously the four characters best differentiating the species. The method depends on the building of a discriminant function:

$$Z = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + c \quad (1)$$

which when applied to any wood sample would give positive values of Z for larch and negative values of Z for spruce. In the function x_1, x_2, x_3 and x_4 are means of several measurements of the four selected characters in the studied wood sample and a_1, a_2, a_3, a_4 and c are constants.

The discriminant function was calculated as follows:

1. Mean values of the four selected wood characters have been calculated for the studied samples of larch and spruce.

2. Overall means have been calculated for larch and for spruce, as well as variances and covariances for all the four studied characters, separately for each species (table 1).

3. From the figures in table 1 a matrix was developed (table 1).

Table 1

Means, variances and covariances of characters 1, 2, 3, 4, for growth rings abowe the 15th

	Means			Variances			Covariances			
	larch	spruce	difference	larch	spruce	sum	characters	larch	spruce	sum
$\bar{x}_1$	59,86	42,27	17,59	37,819	51,529	89,348	1/2	0,7491	0,9302	1,6793
$\bar{x}_2$	1,69	1,13	0,56	0,028	0,026	0,054	1/3	4,5247	4,3326	8,8573
$\bar{x}_3$	23,36	20,46	2,90	1,167	0,973	2,140	1/4	2,8521	−5,0205	−2,1684
$\bar{x}_4$	21,63	18,03	3,60	2,088	1,445	3,533	2/3	0,0698	0,0672	0,1370
							2/4	−0,0306	−0,1326	−0,1632
							3/4	0,7316	−0,3462	0,3854

Table 2

Matrix developed from table 1

$M=$	89,348	1,679	8,857	−2,168	17,590
	1,679	0,054	0,137	−0,163	0,560
	8,857	0,137	2,140	0,385	2,900
	−2,168	−0,163	0,385	3,533	3,600

4. From the matrix determinants have been calculated. $M_1 = 1.3217$, $M_2 = 310.7359$, $M_3 = 3.5741$, $M_4 = 21.6628$, and $M_5 = 23.3089$.

5. From the formula

$$a_i = (-1)^i \frac{M_i}{M_5}$$

Table 3

A list of the mean values of wood characters (from various parts of the trunk) and the values of the discriminant functions for larch and spruce

Origin of wood sample	Mean values for characters				Values of the discriminant function	
	x_1	x_2	x_3	x_4	from 7th ring onwards z_2	from 15th ring onwards z_1
1	2	3	4	5	6	7
Larch						
Chełmowa Góra	64,0	1,81	25,8	23,2	2,9	8,0
	58,9	1,56	22,6	23,2	−0,8	4,5
	46,9	1,57	22,1	21,1	1,1	3,3
	65,5	2,01	22,0	20,3	0,2	6,7
	57,4	1,55	23,3	22,4	−0,1	3,8
	50,6	1,47	22,4	22,5	0	3,1
	61,9	1,66	23,9	23,3	0,1	6,0
	59,4	1,61	23,4	21,9	−0,1	4,1
	66,8	1,94	24,7	23,6	1,5	9,8
	60,5	1,50	24,2	21,4	−0,4	2,2
	72,1	1,92	24,8	22,8	0,4	8,5
	57,1	1,92	24,9	22,8	3,2	6,9
	54,2	1,81	21,7	22,7	0,9	7,5
	38,2	1,39	23,5	22,7	2,6	3,1
Bliżyn II	49,8	1,44	22,4	20,5	−0,1	0,9
	57,8	1,85	22,9	19,3	1,3	4,9
	53,4	1,58	21,5	20,6	−0,5	2,5
	62,3	1,63	22,7	20,8	−1,0	3,0
Bliżyn II	61,7	1,92	23,4	19,2	1,3	5,6
	65,5	1,68	23,9	24,0	−0,4	6,7
	58,9	1,72	23,5	20,1	0,7	3,9
	68,4	1,78	24,4	20,7	0,9	5,2
Tatry	31,4	1,58	18,3	21,5	1,4	4,1
Spruce						
Istebna (Beskid)	41,5	1,22	19,6	18,5	−1,9	−3,8
	45,5	1,29	20,3	18,5	−1,7	−3,0
	42,3	1,23	21,7	18,7	−0,5	−3,3
	46,7	1,26	21,2	18,3	−1,5	−3,6
	47,8	1,26	22,1	18,9	−1,0	−3,0
	45,0	1,19	20,9	18,9	−1,8	−3,9
Dolina Chochołowska	45,0	1,50	19,7	17,4	−0,7	−1,3
	42,4	1,47	19,6	17,9	−0,5	−1,1
	42,1	1,49	19,7	17,6	−0,5	−1,1
	33,7	1,26	20,2	18,8	0,3	−2,5
	43,6	1,38	18,1	16,9	−2,3	−3,6

Table 3 cont.

1	2	3	4	5	6	7
	41,7	1,46	21,1	18,0	0,6	−3,7
	40,2	1,31	20,3	17,2	−0,6	−0,9
	32,9	1,15	19,1	17,9	−1,0	−4,9
	46,2	1,54	20,9	17,1	0,1	−1,0
	42,8	1,29	20,7	18,5	−0,9	−3,5
	39,3	1,32	20,3	18,0	−0,3	−2,8
	39,1	1,25	19,0	18,3	−1,6	−5,5
	43,9	1,37	19,8	17,3	−1,3	−3,1
	35,2	1,19	19,8	17,2	−0,7	5,1
	43,7	1,40	20,9	17,8	−0,3	−2,0
Białowieża	48,1	1,38	21,1	17,1	−1,1	−3,2
	50,4	1,38	21,5	17,0	−1,2	−3,3
	56,5	1,49	21,6	18,3	−1,6	−0,9
	50,3	1,53	21,5	17,0	−0,3	−1,3
	53,4	1,45	21,1	17,6	−1,6	−2,1
	55,4	1,38	21,4	18,0	−2,2	−2,7
	53,4	1,49	21,9	17,1	−1,2	−1,9
	54,8	1,42	22,2	16,8	−1,3	−3,1
	53,2	1,38	21,1	17,7	−2,0	−2,9
Zwierzyniec k. Kórnika	36,2	1,12	21,4	17,1	−0,3	−5,9
	36,1	1,12	19,9	18,0	−1,2	5,2
	32,8	1,03	19,0	18,1	−1,8	−6,4
	37,7	1,21	21,8	18,5	0,3	−3,4
	36,3	1,12	19,9	18,5	−1,3	−4,8
	28,7	0,91	19,1	21,4	−1,6	−4,6
	34,0	1,06	20,1	20,1	−1,0	−4,0
	31,6	0,97	19,0	21,9	−1,9	−3 6
	33,4	1,10	20,6	21,3	−0,3	2,2
Witów (Podhale)	40,4	1,44	19,8	18,4	−0,2	−0,9
	44,8	1,43	21,8	17,8	0,3	−1,6
	40,5	1,33	21,2	17,9	0,1	−2,6
	42,8	1,31	20,9	17,1	−0,7	−3,8
	41,7	1,43	20,0	16,6	−0,4	−2,8
	46,5	1,40	21,9	19,4	−0,1	−0,5
	42,8	1,42	20,5	17,3	−0,3	−2,2
	44,8	1,41	21,4	17,8	−0,1	−1,9
	42,8	1,26	21,9	17,1	−0,3	−413
	45,3	1,36	21,4	18,0	−0,4	−2,4
	43,3	1,28	21,6	18,5	−0,4	−2,8
Leśna (Puszcza Białowieska)	41,3	1,38	21,5	17,8	0,5	−2,0
	37,4	1,23	21,9	18,7	0,6	−2,9
Ujsoły (Beskid)	42,6	1,54	18,9	17,1	−0,6	−1,1
	42,0	1,40	19,8	17,3	−0,7	−2,5
	40,7	1,36	20,4	16,8	−0,4	3,4
	28,6	0,96	19,8	18,5	−0,9	−6,5

constants of the discriminant function Z_1 have been calculated:

$$a_1 = -0.057,\ a_2 = 13.331,\ a_3 = 0.153,\ a_4 = 0.929,\ \text{and}\ c = -37.930.$$

(Constant c has been adjusted so as to obtain the maximum number of spruce samples with a negative value and larch samples with a positive value.)

6. Substituting in formula (1) for the discriminant function Z the values of the constants a_i and the means obtained directly from measurements for the individual characters ($\bar{x}_i$) the values of the function (Z_1) have been calculated (table 3, column 7). The values presented in this column have been calculated on the basis of a group of growth rings excluding growth ring 7, which was the nearest ring to the pith that was studied. The constants presented above refer to this group of growth rings. In column 6 of table 3 values of the discriminant function (Z_2) calculated for all the studied growth rings (7, 15, 30, 50 and further) are presented. When the function is calculated in this way the discrimination is not complete. Some larch samples have negative values and some spruce samples have positive values. In practice however it is not difficult to decide from which part of the tree trunk a wood sample comes, close to the pith or away from it. In samples close to the pith the rays converge at acute angles while in samples away from the pith the rays are almost parallel. Thus when it is known that the wood sample comes from the region away from the pith constants for the Z_1 function should be used, since this been calculated for all rings from the 15th onwards.

A discrimination analysis has also been made separately for each of the studied growth rings. As was expected in all the cases the discrimination was complete between the two species the values of the function for larch being always positive and values for spruce always negative.

The practical application of this method is very simple. It is necessary to make a certain number (30—50) of measurements of the four selected characters (x_i). The numbers is dependent on the scatter around the mean $\bar{x}_i$, using greater numbers for more variable samples. The wood sample should come from at least the 15th ring away from the pith. The mean values for the four characters should be entered into the function:

$$Z_1 = -0.057x_1 + 13.331x_2 + 0.153x_3 + 0.929x_4 - 37.930$$

If the value of the function proves to be positive it is reasonable to consider the wood sample as coming from larch and when Z_1 is negative the wood sample is most likely spruce.

It is still not certain whether this method could be used for the discrimination between other species of larch and spruce, and whether it is also applicable to wood samples coming from the root or from branches.

Some light on the problem can be thrown from the investigation I have made applying the function to the microscopic photographs of wood from various species of larch and spruce reproduced in Greguss'es (1955) key. On some of the photographs it was possible to measure without any difficulty the selected characters and to calculate the Z_1 value of the funcion for them. Without exception for all the photographs of larch the values obtained were positive and for spruce negative.

What practical value will the method have for archeologists and paleobotanists only further studies will tell.

After having written this paper I have obtained from Prof. A. Środoń, who got interested in the method, samples fossil wood identified as *Picea* vel *Lorix*. Two of these samples were preserved in good condition and it was possible to prepare from them microtome preparations and to measure the selected characters. According to the method described above one of the samples was wood of larch and one was wood of spruce. After having sent the results to Prof. A. Środoń he has informed me that my diagnosis was correct since the samples in question were accompanied by macroscopic remains of the two genera.

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ALINA HEJNOWICZ

Badania porównawcze cech anatomicznych drewna Picea abies Karst. i Larix polonica Racib.

Streszczenie

Praca jest próbą podsumowania kilkuletnich badań nad drewnem modrzewia i świerka z terenu Polski. Głównym jej założeniem było znalezienie takich cech mikroskopowych, na podstawie których można by odróżnić oba te rodzaje i to w tych przypadkach, w których określenie na podstawie cech makroskopowych jest niemożliwe (materiał archeologiczny, szczątki kopalne).

Przebadano 23 cechy anatomiczne drewna. Statystycznie istotne różnice pomiędzy modrzewiem i świerkiem stwierdzono tylko w przypadku następujących cech:

1) promienisty wymiar (grubość) cewki drewna wczesnego (cecha x_1),

2) powierzchnia poprzecznego przekroju (pole) cewki,

3) stosunek obu poprzecznych wymiarów cewki drewna wczesnego g/s gdzie g jest średnim wymiarem promienistym, a s średnim wymiarem stycznym jednej cewki (cecha x_2),

4) liczba cewek na powierzchni poprzecznego przekroju równej 1 mm^2,

5) średnica jamki lejkowatej w cewce drewna wczesnego (cecha x_3),

6) wysokość jednej komórki promienia drzewnego (cecha x_4),

7) szerokość jednej komórki promienia drzewnego.

Cechy oznaczone symbolami x_1, x_2, x_3, x_4 zasługują na specjalną uwagę; ich zakresy zmienności dla modrzewia i świerka w obrębie zbadanej grupy drzew tylko nieznacznie na siebie zachodzą. Wykorzystano je więc do zbudowania funkcji dyskryminacyjnej ($Z=a_1x_1+a_2x_2+a_3x_3+a_4x_4+c$), której współczynniki a_i zostały obliczone z macierzy kowariancji dla czterech wyróżnionych cech.

Otrzymane na tej drodze wartości funkcji dyskryminacyjnej (kolumna 7 tabeli 1) dla modrzewia przyjmowały zawsze wartości dodatnie, a dla świerka ujemne.

Wydaje się zatem, że można odróżnić drewno modrzewia od drewna świerka metodą opracowaną w tej pracy, podstawiając do wzoru na funkcję dyskryminacyjną Z średnie wartości cech x_1, x_2, x_3 i x_4 uzyskane z pomiarów oraz odpowiadające tym cechom stałe współczynniki:

$$a_1=-0{,}057, \quad a_2=13{,}331, \quad a_3=0{,}153, \quad a_4=0{,}929 \text{ i stałą } c=-37{,}930.$$

Ostateczny wzór omawianej funkcji wygląda więc następująco:

$$Z=-0{,}057x_1+12{,}331x_2+0{,}153x_3+0{,}929x_4-37{,}930.$$

АЛИНА ХЕЙНОВИЧ

Сравнительные исследования анатомических признаков древесины Picea abies Karst. и Larix polonica Racib.

Резюме

В настоящей работе сделана попытка подвести итоги работ по изучению древесины ели и лиственницы на территории Польши, которые проводились в течении нескольких лет. Главной их целью было выявление таких микроско-

пических признаков, основываясь на которых можно было различать оба рода в тех случаях, когда исключалось определение по макроскопическим признакам (археологические материалы, ископаемые остатки).

Статистически достоверные различия между елью и лиственницей установлены для следующих признаков древесины.

1) радиальный диаметр трахеид ранней древесины (x_1),

2) поле трахеиды (площадь ее поперечного разреза),

3) отношение радиального диаметра трахеид ранней древесины к тангентальному диаметру (x_2),

4) число трахеид на 1 мм² поперечного разреза,

5) диаметр окаймленной поры в трахеидах ранней древесины (x_3),

6) вышина одной клетки древесного луча (x_4),

7) диаметр одной клетки древесного луча.

Признаки x_1, x_2, x_3, x_4, заслуживают особого внимания, их амплитуды изменчивости у ели и лиственницы (у исследованных групп деревьев) лишь незначительно заходят друг на друга. Это обстоятельство использовано для построения т.н. дискриминационной функции ($Z=a_1x_1+a_2x_2+a_3x_3+a_4x_4+c$), коэффициенты которой (a_1, a_2, a_3, a_4) были вычислены на основе данных по измерению четырех выделенных признаков.

Полученные этим путем значения дискриминационной функции для лиственницы всегда имели положительный знак, а для ели — отрицательный.

Поэтому представляется возможным различать древесины лиственницы и ели методом, разработанным в данной статье. В приведенной формуле следует проставить средние значение x_1, x_2, x_3, и x_4 полученные в результате измерений и отвечающие им постоянные: $a_1=-0{,}057$; $a_2=13{,}331$; $a_3=0{,}153$; $a_4=0{,}929$, а также постоянную величину $c=-37{,}93$.

Fot. K. Jakusz

Owoce jaśminowca (*Philadelphus*)