Hejnowicz, A.

A COMPARATIVE STUDY OF THE ANATOMICAL CHARACTERS OF WOOD OF *PICEA ABIES* KARST. AND OF *LARIX POLONICA* RACIB.

(Badania porównawcze cech anatomicznych drewna *Picea abies* Karst. i *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, Budkevich 1956 and 1961, Greguss 1955, Diannelidis 1953, Phillips 1941, Jay 1947, Moskaleva 1962, Huber 1951, Vikhrov 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 on the basis of the microscopic characters of wood it was necessary to:

1. Analyze 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 performed 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 dimensions of early wood tracheids (x_2).
4. Number of tracheids on 1 sq mm 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 differentiating characters are: 1) radial dimension of an early wood tracheid (x_1), 2) ratio of both the cross-section dimensions of early wood tracheids (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 boundary between the two species it is not possible to use the values directly for discrimination between them. For this

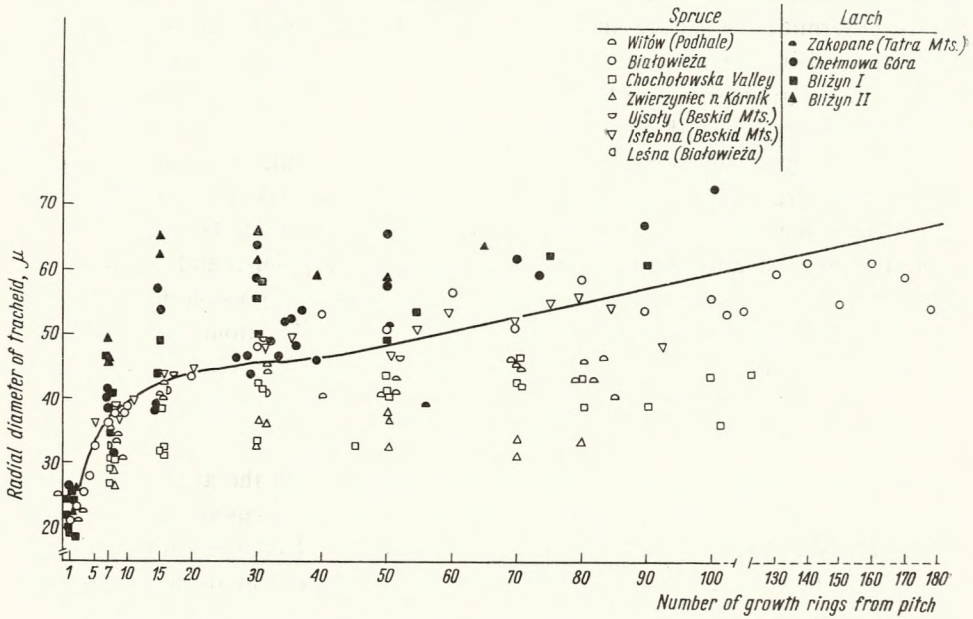

Fig. 1. Mean radial dimension of an early wood tracheid (x_1).

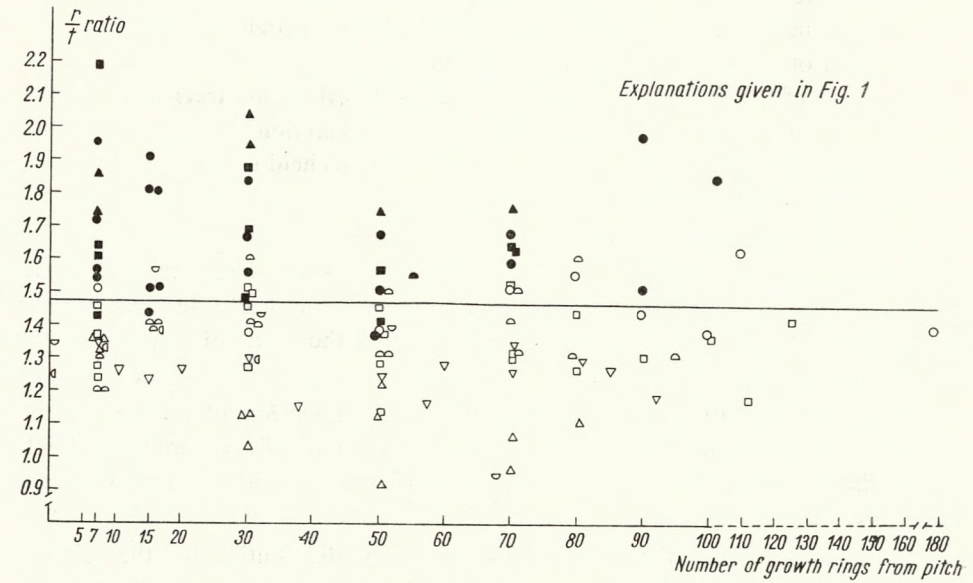

Fig. 2. Ratio of the two cross-section dimensions of an early wood tracheid (x_2).

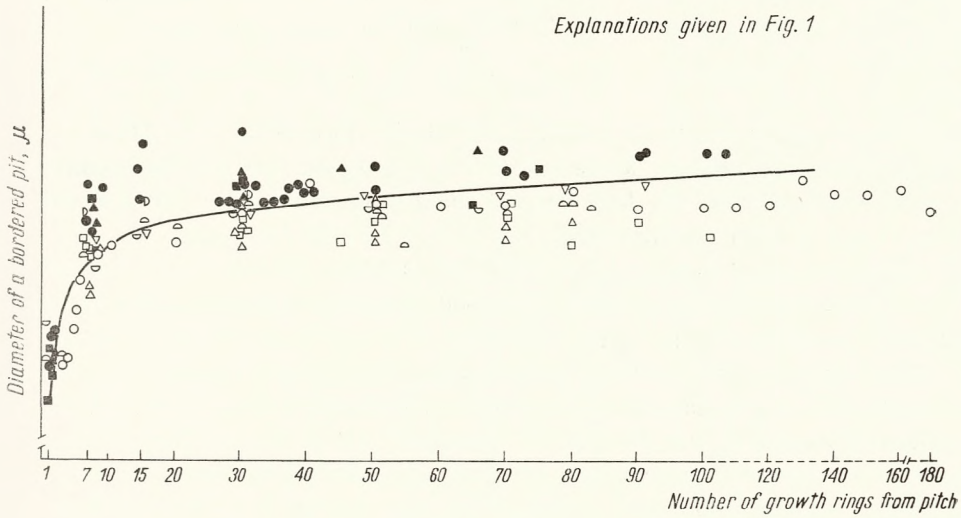

Fig. 3. Diameter of a bordered pit in an early wood tracheid (x_3).

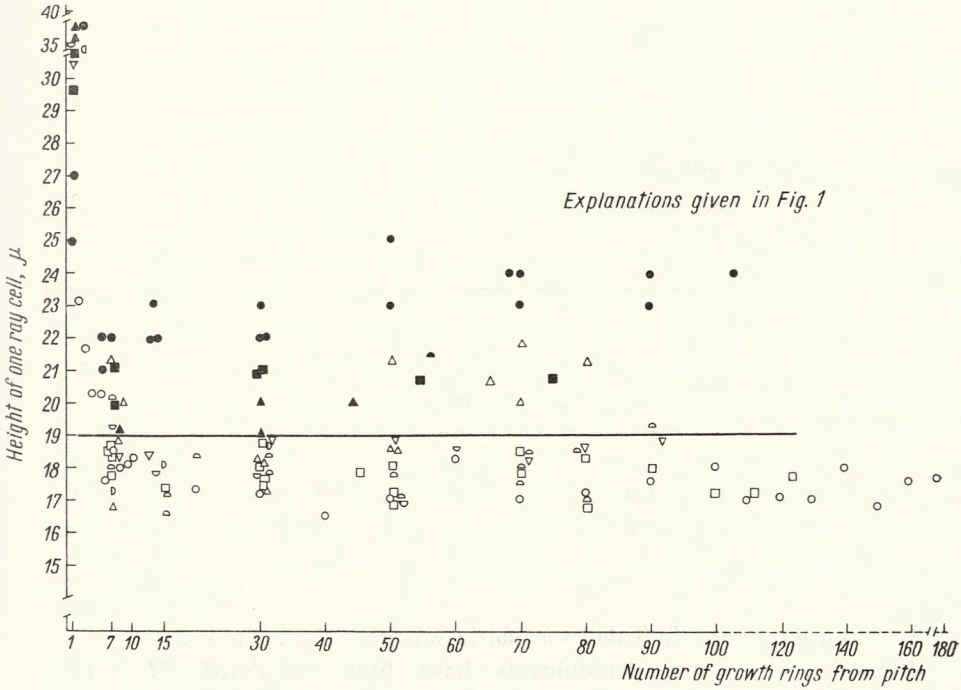

Fig. 4. Mean height of one ray cell (x_4).

reason it was considered necessary to 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:

$$Z = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_3 + c \quad (1)$$

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).

Table 1

Means, Variances and Covariances of Characters 1, 2, 3, 4, for Growth Rings Above the 15th

	Means			Variances			Covariances			
	larch	spruce	difference	larch	spruce	sum	characters	larch	spruce	sum
x_1	59.86	42.27	17.59	37.819	51.529	89.348	1/2	0.7491	0.9302	1.6793
x_2	1.69	1.13	0.56	0.028	0.026	0.054	1/3	4.5247	4.3326	8.8573
x_3	23.36	20.46	2.90	1.167	0.973	2.140	1/4	2.8521	−5.0205	−2.1684
x_4	21.63	18.03	3.60	2.088	1.445	3.533	2/3	0.0698	0.0672	0.1330
							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

3. From the figures in Table 1 a matrix was developed (Table 2).

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

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

constants of the discriminant function Z_1 have been calculated:

$a_1 = -0.057$, $a_2 = 13.331$, $a_3 = 0.153$, $a_4 = 0.929$, 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 (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 funtion (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 has been calculated for all rings from the 15th onward.

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 are 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.

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 onward z_2	from 15th ring onward 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 I	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
Tatra Mts.	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
Chochołowska Valley	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 (continued)

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 n. Kórnik	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	−4.3
	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 Mts.)	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

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 Professor A. Środoń, who got interested in the method, samples of fossil wood identified as *Picea* vel *Larix*. 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 Professor 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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SUMMARY

The paper is an attempt at summing up the results of several years' investigations on larch and spruce wood from the territory of Poland. The main purpose of this study was to establish microscopic traits according to which both these genera can be distinguished in cases when macroscopic characteristics fail (archeological material, fossil remains).

Twenty three anatomical traits of wood were studied. Statistically significant differences between larch and spruce wood were established only in the case of the following characters:

(1) thickness of early wood tracheids in radial measurement (x_1),

(2) surface area of cross section of tracheids,

(3) ratio of the two cross section dimensions of early wood tracheids, g/s, where g is the mean radial measurement, and s — the mean tangent measurement of one tracheid (x_2),

(4) number of tracheids on 1 sq mm surface area of cross section,

(5) diameter of a bordered pit in early wood tracheids (x_3),

(6) height of ray cells (x_4),

(7) width of ray cells.

The characters denoted x_1, x_2, x_3 and x_4 deserve particular attention since their range of variability for the larch and spruce hardly overlap within the investigated group of trees. They were, therefore, utilized for constructing a discrimination function ($Z = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + c$) in which the a_1 coefficients were calculated from the covariance matrix for four of the characters.

The values of the discrimination function obtained in this way (Table 1, column 7) were always positive for the larch and negative for the spruce.

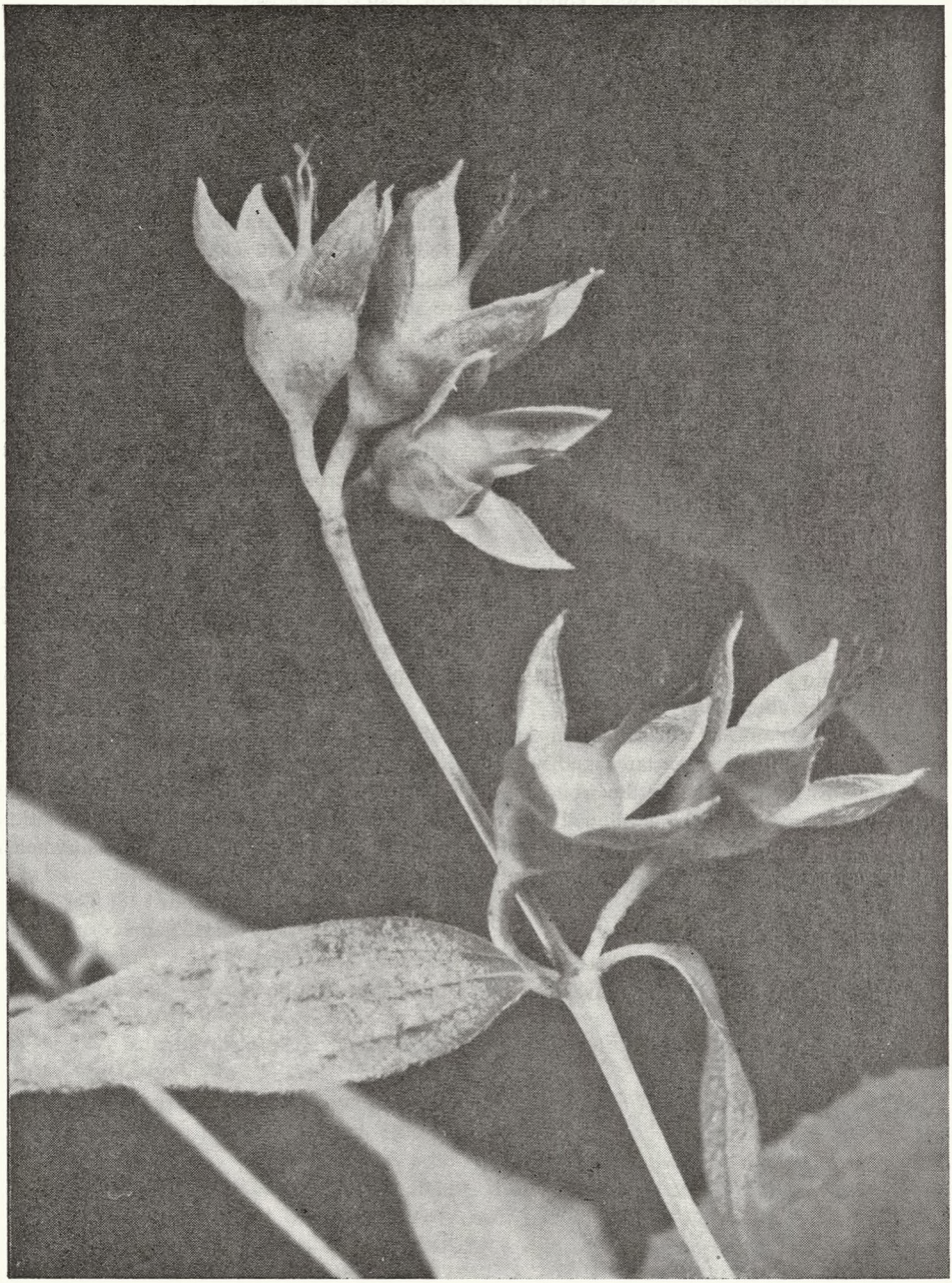
It seems, therefore, that the wood of the larch may be distinguished from that of the spruce by the method here developed by substituting in the formula for the discrimination function, Z, the mean values for the characters x_1, x_2, x_3 and x_4 obtained from measurements and the constant coefficients corresponding to these characters:

$$a_1 = -0.057,\ a_2 = 13.331,\ a_3 = 0.153,\ a_4 = 0.929$$

and the constant $c = -37.930$.

The final formula of the above discussed function is as follows:

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



Sweet mockorange (*Philadelphus*) fruits. Photo by K. Jakusz.