The occurrence of insect pests on pedunculate oak tested on the Chrostowa II experimental plot

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ABSTRACT: The present paper is about the provenance and family diversity of insect occurrence on the offspring of 58 pedunculate oak (*Quercus robur* L.) trees representing 5 populations from the Polish range of species. Researches were conducted on the Chrostowa II test plot, located in the Brzesko Forest District (southern Poland). Differences in symptoms of trees inhabitation by *Andricus kollari* (Hartig, 1843) ♀♀, *Andricus lignicolus* (Hartig, 1840) ♀♀, *Andricus foecundatrix* (Hartig, 1840) ♀♀, *Biorrhiza pallida* (Olivier, 1791) ♀♂, *Andricus inflator* (Hartig, 1840) ♀♂, *Andricus conglomeratus* (Giraud, 1859) ♀♀, *Andricus quercusradicis* (Fabricius, 1798) ♀♀, and *Lachnus roboris* (Linnaeus, 1758) were evaluated. Approximately 45% of oaks grown at the test site were damaged. The majority of trees were inhabited by *A. kollari* (35.7%) while the lowest number of trees was inhabited by *A. inflator, A. conglomeratus* and *A. quercusradicis* (0.1%). Analysis of variance showed that certain species prefer the offspring of certain provenances. Also a high diversity among families within provenances was found. The effect of the family and provenance was statistically significant on oaks with galls caused by *A. kollari, A. foecundatrix* and *B. pallida* share. High heritability values were obtained for *A. kollari* on the population and family level (0.86 and 0.70 respectively) and for the rest of the species only on the provenance level. The presence of *L. roboris* was greatly influenced rather by environmental than genetic factors, also being characterized by low heritability values.

Keywords: *Quercus robur*; insects; Carpathian natural-forest province; resistance; heritability; variability

An interesting aspect of the population and family selection of oaks is the evaluation of tree resistance against infestation by insects or fungi. Observed differences may be caused by greater susceptibility of provenances or individuals to biotic factors, which was proved by Byington's et al. (1994) research on the resistance of 9 oak families to defoliation caused by gypsy moth (*Lymantria dispar* L.) larvae. The majority of researches are focused on gall development and their influence on tree health, as well as on the role of cell chemistry in the extent of damage (Roche, Fritz 1997; Strauss, Agrawal 1999; Skrzypczyńska 2001; Rudgers, Whitney 2006; Stevens et al. 2008). Also in forestry, species inhabiting buds, leaf stems, flowers or seeds play an important role. The infestation of buds, especially of apical bud, leads to growth deceleration and crown deformations.

The aim of the present studies was to determine oak diversity on the basis of the analysis of pest inhabitation. Observations were conducted on the Chrostowa II experimental plot located in the Brzesko Forest District. The site is one of the four provenance-family plots, established in 1999 within the programme co-ordinates by the Forest Research Institute in Warsaw.

The paper presents results of the analysis of offspring of 58 maternal pedunculate oak trees (families) representing 5 Polish provenances.

MATERIAL AND METHODS

Planting material used to establish the Chrostowa II experimental plot was obtained from the Wielkie Buki forest nursery situated in the Bierzwnik Forest District (North-western Poland). Saplings represented 5 populations: Młynary-1, Młynary-2, Opole, Milicz and Krotoszyn (Table 1). In total, at the test site, 1,920 seedlings were outplanted

Table 1. The location of pedunculate oak provenances, the offspring of which are tested on the Chrostowa II experimental plot (Banach 2005)

Provenance name	Forest District	Region of State Forests	Forest range	Compartment	Geographical coordinates		Number of families
					latitude	longitude	
Młynary-1	Młynary	Olsztyn	Kisielewo	165b	54°01'	19°40'	28
Młynary-2			Słobity	173g	54°06'	19°43'	19
Opole	Opole	Katowice	Narok	1g	50°44'	17°47'	3
Milicz	Milicz	Wrocław	Kaszowo	54g,h; 55a,c	51°30'	17°20'	4
Krotoszyn	Krotoszyn	Poznań	Smoszew	24d,f,g,j,k; 25d,f; 39m; 40b,f,g; 41b,d	51°40'	17°30'	4
Total number of families							58

on hand-prepared 60 × 60 cm places. The spacing between individuals was 2.0 × 2.0 m. More details on the experiment, e.g. localization and maternal stand characteristics can be found in former works (Banach 2002, 2005, 2006, 2007).

The test site is situated in the area of the Carpathian foothills, Wiśnickie hills mesoregion (Kondracki 2002). An experimental plot was established in 8 replications (blocks) in sub-compartments 81d, g, h, i in the Chrostowa forest range of Brzesko Forest District (Fig. 1). The oaks were planted in the system of single-tree plot, and the neighbouring individuals were from different provenances and families. Distribution of families on the experimental plot was random (different in each of the blocks). Distribution of individual oaks is presented in Fig. 2. During the establishment of the experiment, each family was represented by an average of 32 oak seedlings.

The range of activities covered the evaluation of biotic damage caused to the tested trees. The presence of galls was determined on each tree. The noxious species were as follows: *Andricus kollari* (Hartig, 1843) ♀♀, *Andricus lignicolus* (Hartig, 1840) ♀♀, *Andricus foecundatrix* (Hartig, 1840) ♀♀, *Biorrhiza pallida* (Olivier, 1791) ♀♂, *Andricus inflator* (Hartig, 1840) ♀♂, *Andricus conglomeratus* (Giraud, 1859) ♀♀, *Andricus quercusradicis* (Fabricius, 1798) ♀♀, and *Lachnus roboris* (Linnaeus, 1758). The names of the species and the designation of generations were adopted from the Fauna Europea (2010) and Redfern et al. (2002).

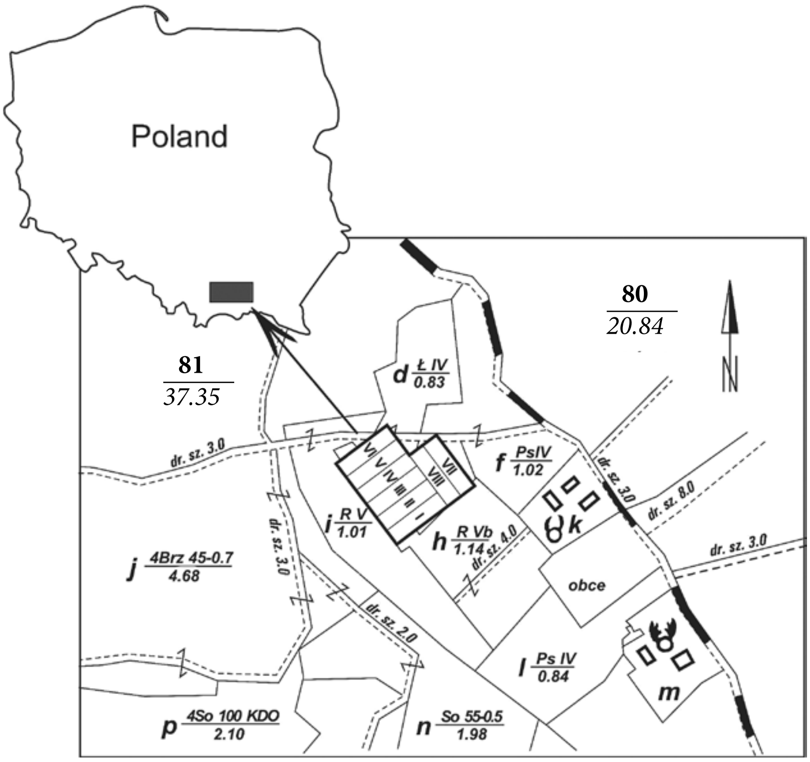

Fig. 1. Location of the Chrostowa II experimental plot (Brzesko Forest District, Chrostowa forest range, sub-compartment 81d, g, h, i); I–VIII – number of blocks (Banach 2005)

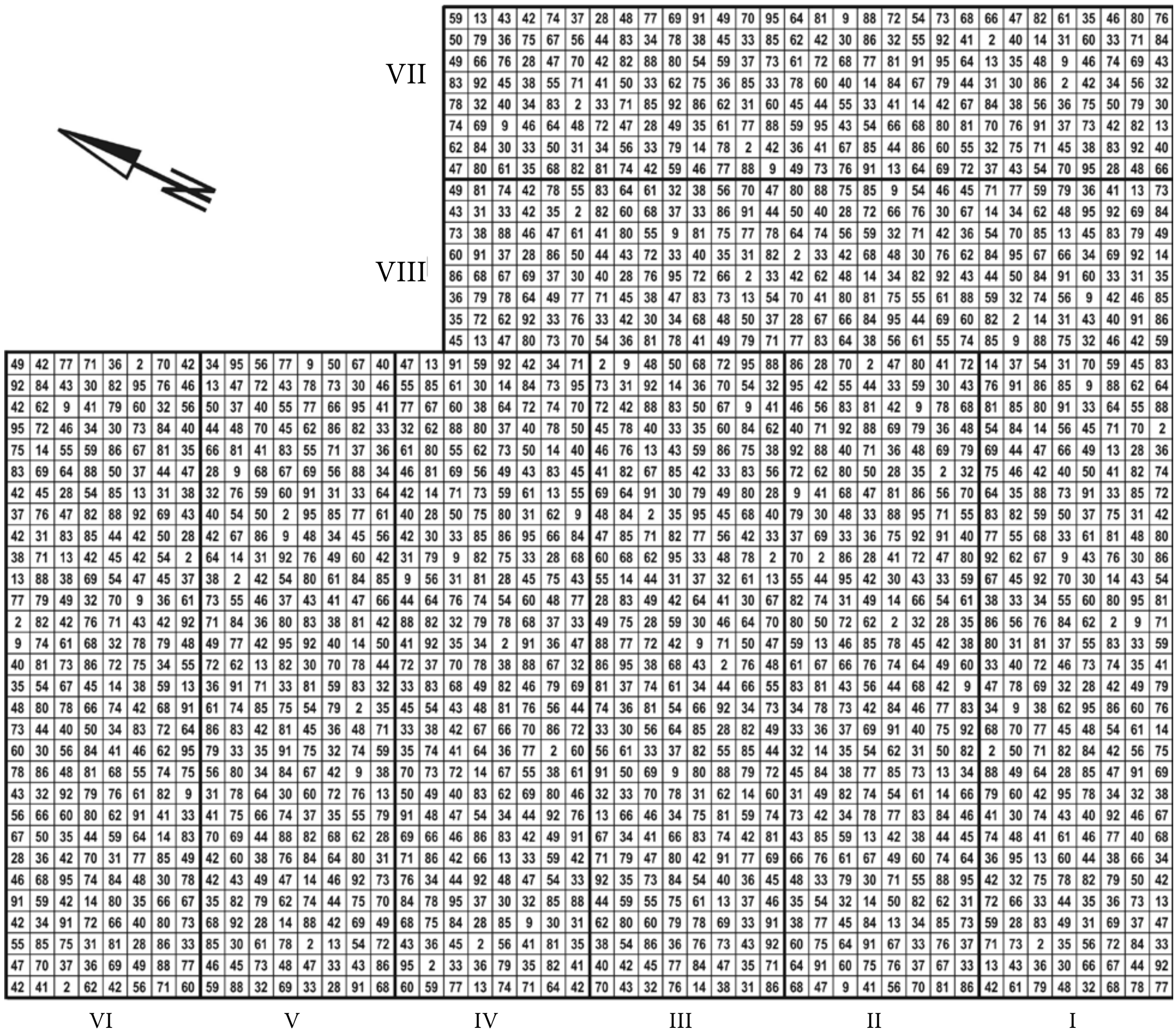

Fig. 2. Distribution of oak trees on the Chrostowa II experimental plot; 2–95 – numbers of families (the name of the provenance see Table 3), I–VIII – number of blocks

The inhabitation of buds by *A. kollari* leads to their deformation into a sphere-shaped smooth gall, *A. lignicolus* causes the formation of spherical, hard and rough outgrowths. *A. foecundatrix* changes buds into hop-cone shaped galls, while *B. pallida* produces yellowish, sometimes reddish, soft galls. The infestation by *A. inflator* leads to a change of twigs into bludgeon-like outgrowths. *A. conglomeratus* causes the formation of a spherical, brown, tough gall, the outer surface of which is wholly covered by small hollows. The occurrence of *A. quercusradicis* leads to the formation of tuber shaped, multi-chambered galls. The aphid *L. roboris* is found in colonies on oak's young stems and causes necrotic thickenings (Fig. 3) (Schnaider 1976).

Statistical significance of effects: genetic (provenance and families within provenances), environmental (block) and interaction (provenance × environment) was evaluated using MANOVA (multi-way analysis of variance).

The components of variance were evaluated considering data non-orthogonality (uneven number of families among populations, and trees on certain plots) and factor hierarchy. The MANOVA model considered all sources of variation: plots, provenances, families and individuals. The model was described by the following equation:

$$y_{jkmn} = \mu + B_j + P_k + PB_{kj} + F_{m(k)} + E_{n(jkm)}$$

where:

y_{jkmn} – phenotypic value of the n^{th} individual of the m^{th} family from the k^{th} provenance in the j^{th} block,
μ – overall mean,
B_j – effect of the j^{th} block,
P_k – effect of the k^{th} provenance,

PB_{kj} – effect of the interaction between the k^{th} provenance and the j^{th} block,
$F_{m(k)}$ – effect of the m^{th} family in the k^{th} provenance,
$E_{n(jkm)}$ – effect of the n^{th} tree within the m^{th} family of the k^{th} provenance in the j^{th} block (effect of errors),
j – number of blocks,
k – number of provenances,
m – mean number of families per provenance,
n – mean number of trees in family and provenance.

Hick's method (according to GIERTYCH 1991) was used for the calculation of expected mean squares for analysed factors (Table 2).

The heritability of infestation symptoms was calculated, both for families and provenances, using the following equations (GIERTYCH 1991):

$$h_p^2 = \frac{\sigma_p^2}{V_P} \qquad \text{provenance heritability,}$$

$$h_F^2 = \frac{\sigma_F^2}{V_F} \qquad \text{family heritability.}$$

The provenance variance (V_P) and family variance (V_F) were calculated using the following equations (BANACH 2005):

$$Vp = \frac{\sigma_E^2}{jmn} + \frac{\sigma_{PB}^2}{j} + \frac{\sigma_F^2}{m} + \sigma_P^2,\ V_F = \frac{\sigma_E^2}{jn} + \sigma_F^2$$

In the case of binary traits that are not characterized by a normal distribution, a probit transformation according to method published by ŻUK (1989) was conducted before the statistical analysis. An analysis of variance was carried out in STATISTICA (StatSoft 2008) using the General Linear Models (GLM) procedure.

The cause of a relatively small proportion of trees damaged by *A. inflator*, *A. conglomeratus*, and *A. quercus radicis* (0.1%); these three species were excluded from the analysis.

RESULTS

Damage occurrence

In the test area damage was observed on almost half (44.3%) of the analysed oaks. *A. kollari* was the most noxious agent (35.7% of infested trees), while *A. inflator*, *A. conglomeratus* and *A. quercusradicis* caused the least damage, with very scarce occurrence and almost no harm done (0.1%). Most frequently there was only one gall forming species on a single tree. An infestation by two or three species occurred only on 9% of trees (Fig. 4).

A. inflator damaged only trees representing the Młynary-1 provenance (0.1%). Opole, despite being the least represented provenance, was the only provenance damaged by *A. conglomeratus* (2.6%). *A. quercusradicis* sporadically occurred on the northern provenances Młynary-1 and Młynary-2 (0.1%).

Table 3 shows the percentage of damage in some provenances and families. Data are presented for 5 species with the occurrence exceeding 1%. *A. kollari* most frequently damaged Młynary-1 (46.1%) and seldom Krotoszyn (22.0%) and Milicz (16.3%). *A. lignicolus* caused the most severe damage to Milicz (1.8%) and Krotoszyn (1.6%). *L. roboris* was the most noxious factor for Młynary-1 (0.7%), whereas Opole and Milicz were not damaged by insects at all. *B. pallida* caused the greatest damage to Młynary-1 (3.5%) and the smallest damage to Krotoszyn (0.3%). In the case of *A. foecundatrix* the damage of analysed trees was severe. The most damaged population was Opole (11.1%) and the least damaged one was Milicz (0.9%). A high variability among families within the provenance diversity was observed. The highest variability was found in the Krotoszyn population for *A. kollari* species, from 0.0 (family 88) to 65.5% (family 91). Variability between families in the other populations was slightly lower.

Table 2. Expected mean squares for analysis of variance

Source of variance	Degree of freedom	Expected mean squares
Block	$j - 1$	$\sigma_E^2 + mn\sigma_{FB}^2 + kmn\sigma_B^2$
Provenance	$k - 1$	$\sigma_E^2 + jn\,\sigma_F^2 + mn\sigma_{PB}^2 + jmn\sigma_P^2$
Provenance × block interaction	$(j - 1)(k - 1)$	$\sigma_E^2 + mn\sigma_{PB}^2$
Family within provenances	$p(m - 1)$	$\sigma_E^2 + jn\sigma_F^2$
Error	$jkm(n - 1)$	σ_E^2
Total	$jkmn - 1$	

σ_p^2 – variance component of the provenance, σ_F^2 – variance component of the family within provenance, σ_{PB}^2 – variance component of the interaction provenance × block, σ_B^2 – variance component of the block, σ_E^2 – variance component of the error

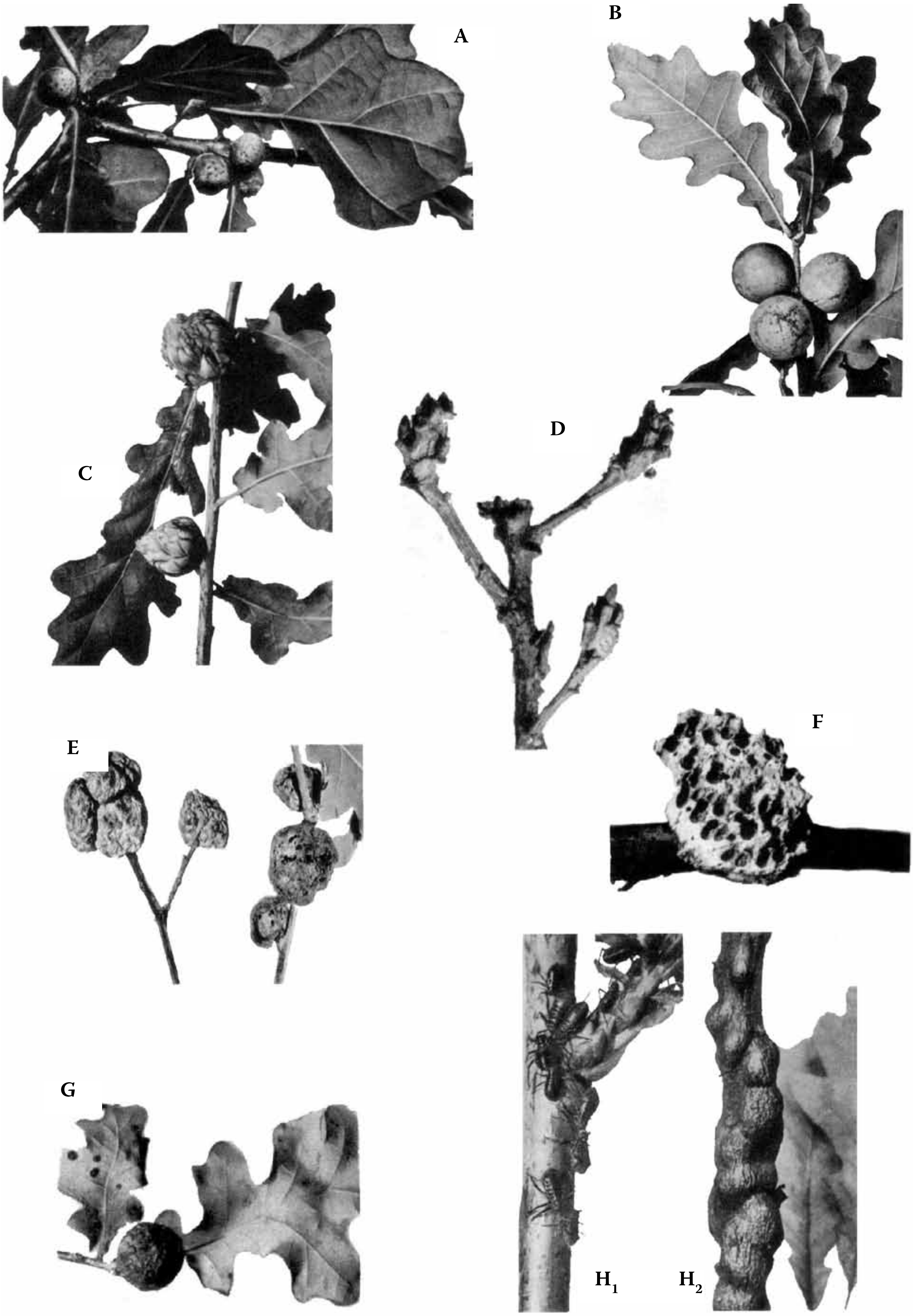

Fig. 3. Damage to twigs and buds caused by: A – *A. lignicolus,* B – *A. kollari,* C – *A. foecundatrix,* D – *A. inflator*, E – *B. pallida*, F – *A. quercusradicis*, G – *A. conglomeratus*, H_1, H_2 – *L. roboris* (damage according to Schnaider 1976)

Table 3. The percentage of trees for families and provenances that showed symptoms of pest infestation on the Chrostowa II experimental plot at the age of 11 years (in 2006)

Provenance	Family No.	Percent of damages caused by				
		Andricus kollari	*Andricus lignicolus*	*Andricus foecundatrix*	*Biorrhiza pallida*	*Lachnus roboris*
Młynary-1	31	48.4	3.2	3.2	12.9	0.0
	33	46.0	9.1	30.3	15.2	3.0
	34	51.6	5.9	5.9	0.0	0.0
	36	46.9	0.0	0.0	2.8	0.0
	37	51.7	8.1	16.2	2.7	0.0
	38	50.0	10.5	10.5	2.6	2.6
	39	48.4	10.3	7.7	0.0	0.0
	40	58.6	2.5	2.5	2.5	0.0
	41	54.8	9.8	12.2	9.8	0.0
	45	71.0	11.1	13.3	0.0	0.0
	60	36.7	3.3	1.7	5.0	0.0
	61	46.7	1.6	9.8	6.6	1.6
	62	40.0	6.5	6.5	1.6	1.6
	64	45.2	6.3	3.1	3.1	0.0
	66	67.7	7.6	3.0	4.5	0.0
	67	46.9	1.5	1.5	0.0	0.0
	68	43.8	5.9	1.5	5.9	1.5
	69	55.2	4.3	4.3	1.4	0.0
	70	39.3	2.9	4.3	0.0	1.4
	71	26.7	5.6	4.2	0.0	0.0
	72	53.3	4.2	2.8	2.8	2.8
	73	63.3	2.7	4.1	0.0	1.4
	74	40.6	1.4	2.7	9.5	0.0
	76	30.0	1.3	3.9	2.6	0.0
	77	21.4	2.6	2.6	0.0	0.0
	78	40.0	2.6	0.0	3.8	1.3
	79	17.2	1.3	5.1	1.3	0.0
	82	50.0	1.2	4.9	2.4	2.4
Total in provenance		**46.1**	**4.8**	**6.0**	**3.5**	**0.7**
Młynary-2	2	38.2	50.0	50.0	11.8	0.0
	28	61.3	10.7	17.9	0.0	0.0
	30	22.6	0.0	6.7	0.0	0.0
	32	21.4	0.0	3.1	0.0	0.0
	35	9.4	2.9	11.4	0.0	0.0
	42	33.3	7.1	4.8	0.0	0.0
	43	46.9	0.0	0.0	4.7	0.0
	46	25.0	0.0	0.0	0.0	2.2
	47	21.4	4.3	4.3	0.0	0.0
	48	12.5	0.0	2.1	0.0	2.1
	49	48.3	2.0	6.1	0.0	0.0
	50	31.3	0.0	8.0	2.0	0.0
	75	40.0	1.3	2.7	4.0	0.0
	80	6.3	0.0	2.5	0.0	0.0
	81	19.4	2.5	0.0	2.5	0.0
	83	20.0	1.2	1.2	2.4	0.0
	84	33.3	2.4	4.8	0.0	1.2
	85	32.3	2.4	0.0	2.4	0.0
	86	42.4	3.5	1.2	0.0	1.2
Total in provenance		**29.7**	**4.7**	**6.7**	**1.6**	**0.3**

Table 3 to be continued

Provenance	Family No.	Percent of damages caused by				
		Andricus kollari	*Andricus lignicolus*	*Andricus foecundatrix*	*Biorrhiza pallida*	*Lachnus roboris*
Opole	9	25.8	11.1	33.3	0.0	0.0
	13	45.2	23.1	0.0	0.0	0.0
	14	3.1	7.1	0.0	7.1	0.0
Total in provenance		**24.7**	**13.8**	**11.1**	**2.4**	**0.0**
Milicz	54	6.5	1.9	0.0	3.7	0.0
	55	33.3	3.6	1.8	0.0	0.0
	56	15.6	1.8	1.8	1.8	0.0
	59	9.7	0.0	0.0	0.0	0.0
Total in provenance		**16.3**	**1.8**	**0.9**	**1.4**	**0.0**
Krotoszyn	88	0.0	0.0	2.3	0.0	0.0
	91	65.5	6.6	5.5	0.0	2.2
	92	10.0	0.0	1.1	1.1	0.0
	95	12.5	0.0	0.0	0.0	0.0
Total in provenance		**22.0**	**1.6**	**2.2**	**0.3**	**0.5**

Table 4. Multi-way analysis of variance for insect pest occurrence on Pedunculate Oaks (age of 11 years) tested on the Chrostowa II experimental plot

Species	*F*-test value and significance level of factor			
	provenance	block	provenance × block interaction	family within provenances
Andricus kollari	8.041 (< **0.001**)	26.094 (0.064)	0.710 (0.867)	3.343 (< **0.001**)
Andricus lignicolus	3.063 (**0.036**)	0.560 (0.769)	1.069 (0.367)	1.207 (0.148)
Andricus foecundatrix	4.325 (**0.011**)	69.003 (0.924)	0.555 (0.972)	1.493 (**0.013**)
Biorrhiza pallida	3.287 (**0.024**)	15.317 (0.249)	0.615 (0.919)	1.982 (< **0.001**)
Lachnus roboris	1.642 (0.219)	3.130 (0.421)	0.664 (0.909)	1.071 (< 0.340)

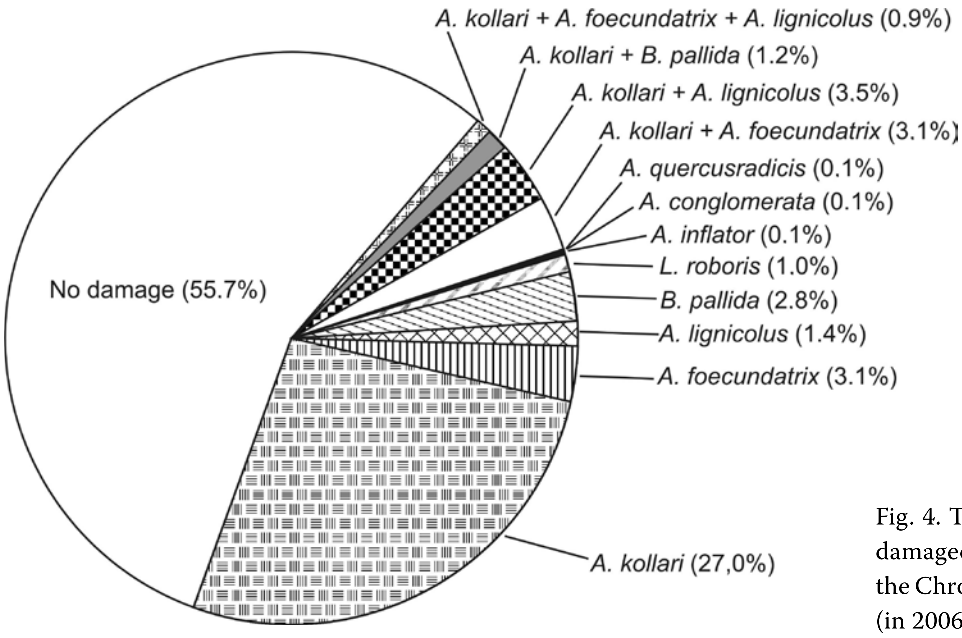

Fig. 4. The percentage of oak trees damaged by some insect species on the Chrostowa II experimental plot (in 2006)

Table 5. Family and provenance heritability of insect occurrence on 11-years-old oaks tested on the Chrostowa II experimental plot

Species	Heritability	
	provenance	family
Andricus kollari	0.86	0.70
Andricus lignicolus	0.67	0.17
Andricus foecundatrix	0.64	0.33
Biorrhiza pallida	0.61	0.50
Lachnus roboris	0.09	0.07

The analysis of variance showed the significance of ($P < 0.05$) population and family among population effect for oak infestation by *A. kollari*, *A. foecundatrix*, and *B. pallida*, and significant provenance effect for *A. lignicolus*. The influence of a genetic factor on the damage caused by *L. roboris* appeared to be insignificant. The block and provenance × block effects were not significant in any case (Table 4).

Heritability

The evaluation of heritability of pest occurrence (on the provenance and family level) on oaks is presented in Table 5.

Certain types of heritability for analysed traits had different trends. Provenance heritability varied from 0.09 to 0.86 while more variable family heritability ranged from 0.07 to 0.70. In both cases the highest values of heritability were observed for *A. kollari*, and the lowest for *L. roboris*.

DISCUSSION

The analysis of the occurrence of biotic damage to pedunculate oak showed its presence on 45% of individuals. A similar extent of damage was reported by Cha et al. (2010) during research on the offspring of 12 northern red oak (*Quercus rubra* L.) families. Collected data proved considerable diversity among provenances and families. The majority of oaks was infested by *A. kollari*, which damaged 35.9% of all trees grown on the Chrostowa II experimental plot. The provenance Młynary-1 and family 45 were damaged the most frequently by this species. The rest of the pests infested the test trees to a far lesser extent and did not cause so much damage.

Presented data are consistent on a large scale with results acquired during the author's former experiments conducted on the Chrostowa I and Chrostowa II tests plots (Banach 2005). *Biorrhiza pallida* became another species significantly differentiating oak families and provenances.

The analysis of oak resistance based on the diversity of damage symptoms showed a tendency that some insects prefer certain provenances. A statistically significant proportion of trees with galls produced by *A. kollari, A. foecundatrix* and *B. pallida* was obtained both on the family and provenance level. Such results would confirm evaluations made by Madziara-Borusiewicz (1982) on the presence of gall wasps (family: Cynipidae) in the stands of the Niepołomice Forest and the Lubin Forest District. The highest percentage of damage caused by *A. kollari* was observed in the northern populations from the Młynary Forest District. The smallest numbers of infested trees were observed in south-western populations (Krotoszyn, Milicz, and Opole). A similar geographical trend recorded by Banach (2005) for spring flushing would suggest the relationship between this trait and pest infestation (strong and significant correlation for families and provenances). Such a hypothesis is also supported by Crawley and Akhteruzzman's (1988) former research, which showed significant differences among trees varying in phenology and insects damaging them. The results obtained by Mopper and Simberloff (1995) also showed the statistically significantly lower occurrence of insect pests on individuals characterized by earlier flushing. However, Wesołowski and Rowiński (2008) came to other conclusions. During their analyses of two Pedunculate Oak phenological forms (*praecox* and *tardiflora*), they proved far lesser damage caused by *Operophtera brumata* to later flushing trees. Such a different result leads to conclusions that the extent of damage is greatly influenced by a convergence of the tree phenological phase and pest emergence. Other factors determining an increased resistance to insect attacks might be the concentration of minerals, secondary metabolites (tannins, phenols, terpenes) and insect hormones or kairomones synthesised by plants (Malinowski 2008). Although no such analysis was conducted in the present paper, the importance of the above-mentioned compounds was reported in Abrachamson's et al. (2003) paper on gall development on 6 North American oak species. Different concentrations of chemical compounds significantly differentiated the examined oak species, and were strongly correlated with the quantity of gall-forming insects.

The analysis of heritability (for provenances and families) showed a large influence of the genetic factor on the occurrence of insect inhabitation symptoms. Heritability for *A. kollari* had high values, both on the provenance and family level (0.86 and 0.70, respectively), while for the rest of the species only on the provenance level. The occurrence of *L. roboris* was conditioned rather by environmental than genetic factors, with a low value of heritability as well. The obtained heritability values (especially for populations) appeared to be very high, almost as high as those obtained for other quantitative and qualitative traits (e.g. height, DBH, straight stem) (Fober 1998; Jensen 2000; Baliuckas, Pliura 2003; Bogdan et al. 2004; Barzdajn 2008). Similar values of heritability were obtained for resistance of several families of *Salix sericea* to two insect species infestation (Fritz, Nobel 1989). The high value of heritability and significance of genotype effect give an opportunity to select provenances, families and individuals more resistant to insect pest infestation.

Based on the results obtained from the analysis of Pedunculate Oak (*Q. robur*) resistance during its juvenile growth on the Chrostowa II experimental plot, the following conclusions can be drawn:

(1) Tested offspring varied in the occurrence of infestation symptoms. Five (*A. kollari, A. lignicolus, A. foecundatrix, B. pallida,* and *L. roboris*) out of the eight species were present to a large extent (from 1.0% to 35.7%) while the quantity of the other three species (*A. inflator, A. quercusradicis,* and *A. conglomeratus*) was minimal and did not exceed 0.1%.

(2) A significant effect of the family and provenance was observed for damage caused by *A. kollari, A. foecundatrix,* and *B. pallida*. *Andricus kollari* was the species that infested trees the most frequently. Northern provenances (Młynary-1 and Młynary-2) appeared to be most susceptible to infestation, while oaks from the south-western part of the country (Opole, Milicz and Krotoszyn) were most resistant.

(3) For all analysed species, with the exception of *L. roboris*, high values of provenance heritability and only slightly lower values of family heritability were obtained. It gives an opportunity to select the offspring of populations or individuals that would be less susceptible to insect pest infestation in conditions of southern Poland.

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