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Seed damage to different cultivars of pea by the pea moth (*Cydia nigricana*) and the pea weevil (*Bruchus pisorum*) in Radzików, Central Poland

Lech Boros, Anna Wawer

Plant Breeding and Acclimatization Institute (IHAR) – National Research Institute
Department of Seed Science and Technology, Laboratory of Cereal and Pulses Seed Health and Identity
Radzików, 05-870 Błonie, POLAND

Abstaract. Two separate field trials per year, one with 22 white-flowering field pea cultivars and second with 8 cultivars of fodder pea, were conducted in several consecutive years (2013, 2014, 2016–2019) to determine the degree of damage to seeds caused by the pea moth (*Cydia nigricana*) and pea weevil (*Bruchus pisorum*) and to study important agronomic traits of pea cultivars. Damage to pea seeds by the pea moth and pea weevil was common in Radzików, central region of Poland. The pea cultivars tested differed in their susceptibility to these two pests, as reflected by the value of percentage seed damage. The percentage of seed damage caused by pea weevil in this study was tenfold higher than that by pea moth. Highly significant effect of years of cultivation on all examined traits was found. Seeds damage by both insects was most strongly affected by the precipitation and to lesser extent by mean daily temperature during pea growing seasons. For the set of white-flowering cultivars, the correlation between the amount of damaged seed and the amount of precipitation was r = -0.47 and r = -0.76 for pea moth and pea weevil respectively, while in fodder pea cultivars only for seeds damaged by pea weevil a significant correlation (r = -0.84) was found. The second abiotic factor, mean daily temperature had a positive effect on the amount of damaged seeds, particularly caused by pea weevil in feed pea (r = 0.84). The cluster analysis identified cultivars with the lowest percentage of damaged seeds and high yield performance.

Key words: field pea, seed damage, pests, cultivar performance.

INTRODUCTION

The cultivation of field pea has a long tradition in Poland. As a valuable protein plant, it is characterized by a diversity of cultivars and their suitability for different cultivation modes and uses (edible, feed, green pea, dry seeds or green forage). In 2019 in Poland, according to the latest FAO report, the area under peas grown for seed was 17.4 thousand ha, and for canned peas 9.0 thousand ha (FAOSTAT, 2021). There are currently 31 dry pea varieties in the National Register of Varieties, among them nine fodder pea varieties. Only two varieties of fodder peas are of normal leaf type, remaining are semi-leafless forms.

The pea seed yields vary from region to region and from year to year due to sensitivity to unfavorable weather conditions and inappropriate crop management practices. Additionally, the occurrence of various pests has impact on the quantity and quality of the harvest obtained. The insects which frequently damage pea crop worldwide are pea leaf weevil (*Sitona lineatus* L.), pea aphids (*Acyrthosiphon pisum* (Harris)), pea weevil (beetle) (*Bruchus pisorum* L.) and pea moth (*Cydia nigricana* F., previously *Laspeyresia nigricana* Steph.) (Clement et al., 2009; Teshome et al., 2014; Reddy et al., 2018; Huusela-Veitsola, Jauhiainen, 2006; Thöming, 2011). The last two species caused seed damage and are the most serious pests for pea in Poland (Matlosz, Kaniuczak, 2001; Kaniuczak, 2005; Kaniuczak, 2009; Kaniuczak, 2010; Szafranek, Rybczyński, 2014).

The adult pea moths emerge from cocoons in the soil from early June and after feeding on the plant flowers, the females lay their eggs on the pea plant. After 7–10 days the caterpillars emerge and burrow into the pods to feed on the developing peas. Mature caterpillars overwinter in the soil in a cocoon. Pea moth damage has greater impact on the quality of seeds rather than yield. An 0.5% infested pea seeds are the commercial threshold parameter of organic green pea production in Germany (Thöming et al., 2011).

The adults of pea weevil overwinter in pea seed if the seeds are kept in a cool, dry place, either in storage or in the field (Reddy et al., 2018). They appear at flowering time and feed on pollen, petals. Eggs are laid on the developing pods. The larvae burrow through the pods into the seeds, where they remain for four to five weeks. Adults develop in the seed until late summer, when most weevil development

Corresponding author:
Lech Boros
e-mail: l.boros@ihar.edu.pl
phone: +48 22 7334591

is complete. Although the adults emerge from pupas at the end of summer, substantial part of them have no tendency to leave the seeds and stay inside them through the winter. Only some part of the newly emerged adults leave the seeds before winter to hibernate outside under the climate conditions typical for central Europe. The larvae reduce the yield and quality of the pea crop by eating much of the infested seeds (Nikolova, 2016a; Baker, 2016; Kaplin et al., 2019). They do not reproduce on dry seed (Clement et al., 2009; Reddy at al., 2018). Both pests produce only one generation a year. Pea moth and pea weevil damage affecting the quality of the crop more than the quantity, especially when peas are being grown for human consumption or for seed. The effect of *B. pisorum* on losses in germination of *P. sativum* seed varies depending on cultivar (Nikolova, 2016a; Kaplin et al., 2019). Several studies have focused on searching for resistance to pea weevil among cultivated pea and among wild relatives of the crop (Clement et al., 2002; Clement et al., 2009; Byrne et al., 2008; Aryamanesh et al., 2012; Teshome et al., 2015; Aznar-Fernandes et al., 2018). However, commercial cultivars that combine good agronomic traits and useful resistance have still not been identified.

Periodic application of contact-pesticides to pea fields or fumigation of the harvested seed are the most common strategies for chemical control of *C. nigricana* and *B. pisorum* (Aryamanesh et al., 2012; Szafranek, Rybczyński, 2014; Baker, 2016; Nikolova, 2015; Wielkopolan et al., 2018).

The aim of the work was comparative evaluation of important agronomic traits including yield level and seed damage caused by pea moth and pea weevil to field pea varieties from the National Register (NL) and some from the Common Catalogue (CCA).

MATERIALS AND METHODS

Each year, two field experiments were carried out in the Plant Breeding and Acclimatization Institute – National Research Institute at Radzików, one with 22 white-flowering field pea cultivars (14 from National List: Ezop, Tarchalska, Wenus, Santana, Boruta, Lasso, Medal, Cysterski, Batuta, Mentor, Mecenas, Akord, Arwena, Audit and 8 from CCA: Casablanca, Alvesta, Madonna, Starter, Gregor, Navarro, Salamanca, La Manche), and the other one with 8 fodder pea cultivars form NL (Hubal, Milwa, Model, Muza, Pomorska, Roch, Sokolik, Turnia). Field pea cultivars were tested in 2016-2019 and fodder pea cultivars in 2013, 2014, 2016 and 2019. The basic elements of the integrated crop management were considered. Winter rape was the forecrop in each year. The soil type was sandy-clay loam, pH = 6.5. Mineral fertilization was applied at a dose of 30 N, 60 P_2O_5 and 90 K_2O kg ha^{-1} . The herbicide Stomp Aqua (pendimethalin) at the dose 2.5 l ha^{-1} was used for weed control at BBCH 00-01 stage. During the pea growing, pea leaf weevil (*Sitona lineatus)* and pea aphids (*Acyrthosiphon pisum* Harris) were controlled by a single spray of Fastac100 EC (alpha-cypermethrin) at a dose of 0.1 l ha^{-1} up to BBCH 39 stage. At later development stages, pea plants were kept free of insecticides to allow natural infestation by pea moth and pea weevil. Trials with field pea and with fodder pea cultivars were conducted in close proximity to each other.

The experiments were set up as a complete randomized block design in two replicates. Pea seeds were grown on 6 row plots with sowing densities 100 plants per m^2. Pest free manually inspected seeds were used for sowing. The sowing dates were 18 April 2013, 4 April 2014, 31 March 2016, 27 March 2017, 9 April 2018 and 29 March 2019. Phenotypic parameters, such as days to maturity according to BBCH scale, plant height (distance from soil to top of plants), lodging (with scale 9 – all plants erect to 1 – totally lodged) at full ripening for each plot were recorded. Prior to plots harvest with plot combine, 100 random pods per plot were collected from both replications for further evaluation. Harvested pods were stored at room temperature for approximately 3 months to allow pea weevil reach the adult stage. The number of damaged seeds by pea moth and pea weevil were recorded and expressed in % of seeds number from 100 pods per replication (200 pods per cultivar). Seed yield of pea cultivars is given in dt ha^{-1} from 10 m^2 plots at 15% moisture content.

The data on weather parameters temperature and rainfall was collected from meteorological station at Radzików. The brief summary of both 10-day sums of rainfall and mean 10-days air temperatures for each growing season is presented on Figure 1. The 2013 and 2014 growing seasons were characterized by similar average temperatures (15.5 °C and 15.9 °C) and sum of rainfall (respectively 289 mm and 277 mm). The 2017 growing season had the highest rainfall (312 mm) and lowest average temperature (14.8 °C). The 2018 growing season was the warmest with an average temperature of 17.9 °C and 204 mm of rainfall, while the 2019 season was the driest with 161 mm of rainfall and an average temperature of 16.7 °C, along with 17 days with a maximum temperature above 30 °C compared to 10 days in 2018.

The data were subjected to analysis of variance (ANOVA). followed by post hoc Tukey HSD test ($p = 0.05$) and Ward's clustering method with squared Euclidean distance using Statgraphics 5.1 Software. Data on pea moth and pea weevil incidence and on total damage to seeds expressed as percent values were subjected to Bliss transformation prior to variance analysis. Pearson's correlation was calculated to study possible relationship between seed damage by insects and mean daily temperature as well as sum of rainfall for growing seasons.

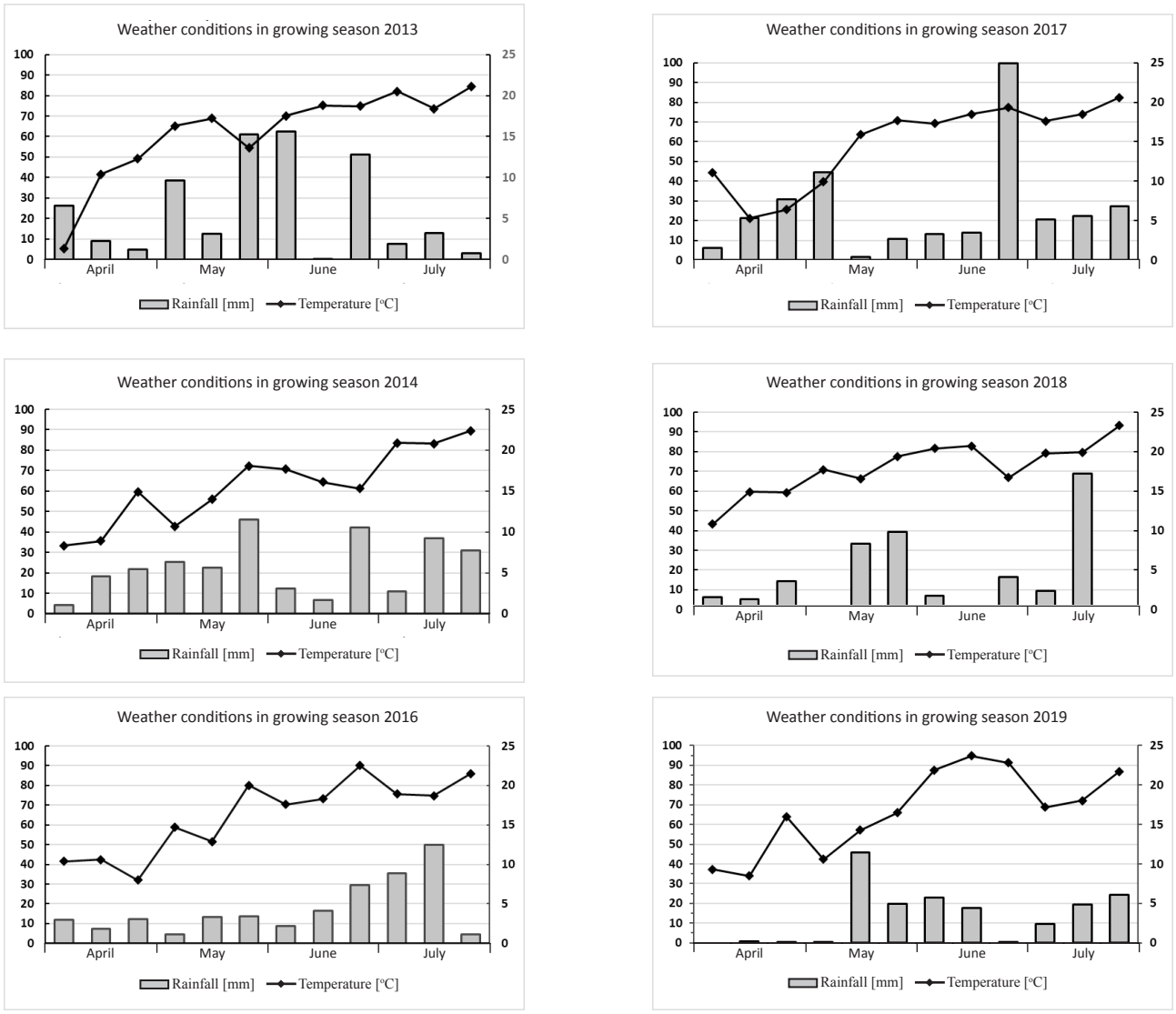


Figure 1. Average 10-days air temperature and 10-days sum of rainfall for pea growing seasons at Radzików.

RESULTS AND DISCUSSION

The period of study covered growing seasons that differed in meteorological conditions. This difference had a great impact on the performance of pea cultivars and on the level of seeds damaged by pea weevil and pea moth. Analysis of variance showed significant trait differences, except for protein content and the number of seeds damaged by pea weevil and pea moth as well as for total percentage of damaged seeds among fodder pea cultivars (Table 1).

Pea moth damaged the seeds of all tested cultivars and the average percentage of damage was 0.9% and 1.2% for white flowering and fodder pea cultivars, respectively, with high coefficients of variation among tested pea cultivars. The results showed a low percentage of seed damage compared to pod damage in previous studies. According to Kaniuczak (2005) the average pod damage by pea moth in Podkarpacie region was 15.3% in years 2001–2003 and 26.3% in period 2005-2007 and was much higher than 6.3% reported in an earlier study by Walczak (2001). Similarly, high level of pod damage ranging from 13.3% to 36% depending on location in the central region of Poland was observed by Szafranek and Rybczyński (2014). In contrast, damage of pea seeds in Poland according to other authors cited by Kamańczuk (2005, 2010) was lower, ranging from 0.2% to 20%, but with high variation between cultivars and was more comparable to a range of 3.8% to 26.3% found in Finland (Huusela-Veistola, Jauhiainen, 2006).

Twelve white flowering cultivars and three of the fodder cultivars showed lower level of seed damage compared to the respective averages. The highest level of seed damage was found for La Manche (2.07%) and Boruta (1.54%)

Table 1. Descriptive statistics of pea cultivars used in the study (average over cultivars and years).

Characters	Units	Mean value	Range		CV [%]	F-statistics for differences between cultivars
			Min	Max		
22 white-flowering field pea cultivars						
Vegetation period	days	102	100.4	105.5	1.24	12.42**
Plant height	cm	70.9	63.6	83.4	7.33	7.52**
Lodging	9-1°	8.2	7.5	8.6	3.28	-
Seed yield	dt ha^{-1}	38.6	31.4	47.2	8.98	4.05**
1000 seed weight	g	215	190	238	6.27	32.69**
Protein content	%	21.2	19.8	22.7	3.43	12.44**
Seeds per pod		4.2	3.5	4.7	7.8	12.45**
Pea moth damaged seeds	%	0.9	0.3	2.1	49.9	1.99* a)
Pea weevil damaged seeds	%	9.7	6.3	12.8	17.6	1.68* a)
Total damaged seeds	%	10.6	6.7	13.9	17.6	1.76* a)
8 fodder cultivars						
Vegetation period	days	102	99	104	1.88	11.49**
Plant height	cm	76.1	62.9	98.9	17.4	13.90**
Lodging	9-1°	6.7	3.7	8.6	22.2	-
Seed yield	dt ha^{-1}	33.6	29.6	39.8	11.6	6.03**
1000 seed weight	g	193	156	208	10.24	14.80**
Protein content	%	22.0	21.5	22.7	2.6	1.47 ns
Seeds per pod		4.1	3.8	4.4	5.5	2.53*
Pea moth damaged seeds	%	1.2	0.8	1.6	24.4	2.16 ns a)
Pea weevil damaged seeds	%	8.0	6.8	10.2	13.6	1.56 ns a)
Total damaged seeds	%	9.2	7.6	11.8	13.51	2.08 ns a)

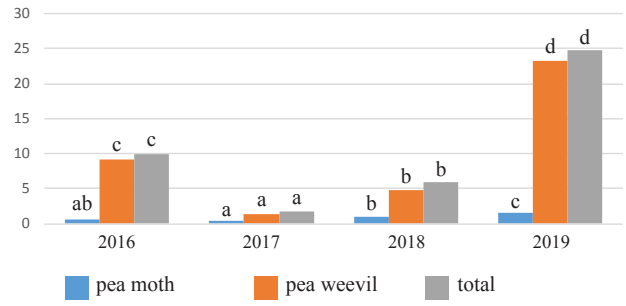
a) data prior to variance analysis were subjected to Bliss transformation
* $\alpha = 0.05$; ** $\alpha = 0.01$; ns – not significant
CV – coefficient of variation

cultivars, while the lowest level for Mecenas (0.31%) and Alvesta (0.31%). In fodder pea cultivars, the lowest seed damage was found in Milwa (0.80%) and Turnia (0.81%) and the highest in Roch (1.57%) and Hubal (1.51%).

Contrary to the levels of damage induced by *C. nigricana*, the percentage of seed damage caused by pea weevil in this study was tenfold higher. Pea weevil damaged the seeds of all tested cultivars with an average percentage of damage of 9.69% and 8.1% for white flowering and fodder pea cultivar, respectively, with much lower coefficients of variation among cultivars compared to that of pea moth. Eleven white-flowering and 3 feed pea cultivars showed less seed damage compared to the respective averages. The highest level of seed damage was found for Santana (12.83%) followed by Gregor (12.19%), Navarro (11.86%), Ezop (11.72%) and Cysterski (11.38%). Four of them, except Ezop, started to flower 2 days earlier comparing to mean value of all cultivars. The least seed damage was found in Madonna (6.43%), Tarchalska (7.35%), Alvesta (7.84%), Arwena (7.85%), Mentor (7.97%), Batuta (8.09%) and Mecenas (8.23%) which started to flower slightly later that the first group. The average percentage of seed damage of fodder cultivars was slightly lower, with the highest found in Muza (10.2%) and the lowest in Turnia (6.73%), Hubal (6.77%) and Milwa (7.76%).

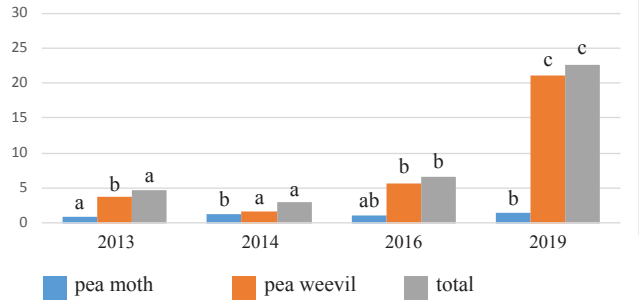
A highly significant effect of years of cultivation on all traits examined was shown. The lowest seed damage by pea moth of field pea cultivars (white-flowering) was observed in 2017 growing season (0.31%) and the highest in 2019 (1.56%). A similar relationship with growing seasons was found for seed damage by pea weevil, however, the damage scale was many times higher ranging from 1.43% to 23.25% in 2017 and 2019, respectively (Figure 2). With feed pea cultivars, pea moth caused the least seed damage in 2013 growing season and the most in 2019 season, while the percentage of seed damage caused by pea weevil was the lowest in 2014, significantly lower than in the 2013, 2016 and 2019 growing seasons (Figure 3).

Differences between years for seed damage by insects were reported by several authors (Szafranek, Rybczyński, 2014; Kaniuczak, 2005, 2010; Nikolova, 2016b; Kaplin et al., 2019). According to Huusela-Veistola and Jauhiainen (2006) the difference between years for the percentage of seed damage by pea moth ranged from 6.8% to 19.5%. Furthermore, the percentage of damaged seeds was higher in organic than in conventional cultivation (Huusela-Veistola, Jauhiainen, 2006; Thöming *et al.* 2011). Huusela-Veistola and Jauhiainen (2006) consider weather conditions (mostly temperature) and the local area under pea cultivation in the previous year as directly influencing the abundance of



Letters indicate Tukey's homogenous groups for comparison between years

Figure 2. Differences in the mean level of seeds damaged by pea moth and pea weevil in the group of field pea cultivars recorded for individual years of testing (2016–2019).



Letters indicate Tukey's homogenous groups for comparison between years

Figure 3. Differences in the mean level of seeds damaged by pea moth and pea weevil in the group of fodder pea cultivars recorded for individual years of testing (2013, 2014, 2016, 2019).

Table 2. Pearson's correlation coefficients of % seed damage to pea cultivars and daily mean temperature and sum of rainfall for growing seasons (IV–VII).

Parameters	Field pea (n = 88)		Fodder pea (n = 32)	
	% pea moth	% pea weevil	% pea moth	% pea weevil
Mean daily temperature	0.35	0.26	0.25	0.84
Σ rainfall	-0.47	-0.76	-0.28	-0.84

Table 3. Mean values of nine traits for groups revealed by cluster analysis among 22 field pea cultivars and 8 fodder pea cultivars.

Parameters	Clusters					
	Field pea				Fodder pea	
	A	B	C	D	A	B
Vegetation [days]	102	101	101	104	101	105
Lodging [9–1°]	7.8	8.3	8.4	8.2	7.5	5.9
Plant height [cm]	71	68	67	77	71	82
1000 seed weight [g]	211	209	230	213	195	171
Seed yield [dt ha^{-1}]	34.88	38.07	38.12	42.53	36.55	30.69
Protein content [%]	21.16	20.82	21.94	20.92	21.76	22.30
No. of seeds per pod	3.95	4.35	3.89	4.38	4.10	4.18
Pea moth damaged seeds [%]	1.54	0.61	1.08	0.71	1.11	1.24
Pea weevil damaged seeds [%]	10.05	9.95	11.23	7.85	7.32	8.72
No. of cultivars in clusters	5	6	5	6	4	4

pests and the main reason for the fluctuation in pea moth damage.

The results of correlation analysis (Pearson) show positive correlation between the levels of seed damage (by pea weevil and by pea moth) and the mean daily temperature. Contrary to that the seed damage was correlated negatively with the total sum of rainfall (Table 2). For white-flowering pea cultivars, the correlation between seed damage and precipitation was r = -0.47 and r = -0.76 for pea moth and pea weevil, respectively, while in fodder pea cultivars a significant correlation with rainfall (r = -0.84) was found only for seed damage by pea weevil. The second abiotic factor, mean daily temperature, had a positive effect on the amount of damage to seeds caused by pea weevil, particularly in fodder pea (r = 0.84). Similar relationships between the amount of seed damage by pest and precipitation and temperature were reported by Kaplin *et al.* (2019) and Aznar-Fernández and Rubiales (2019). This may be due to the fact that rainfall may disturb oviposition of pea weevil and reduce egg viability as suggested by Kaniuczak (2004) in a study with field bean.

Cluster analysis using mean values of seven pea agronomic traits and seed damage by both insects grouped white-flowered cultivars into four groups and feed culti-

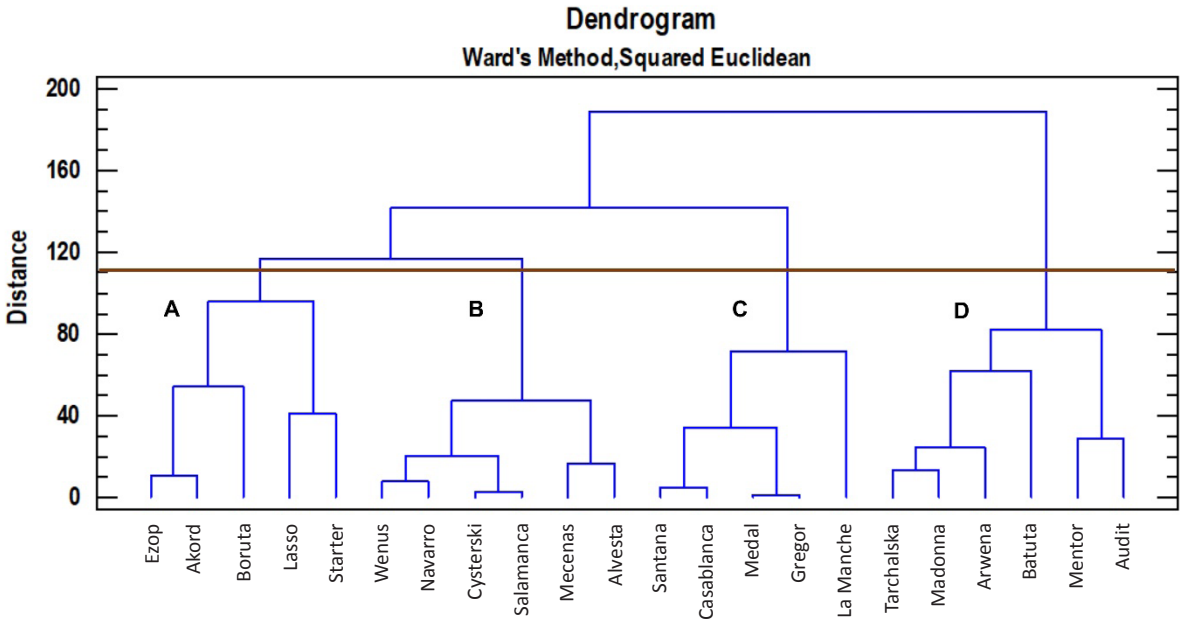


Figure 4. Dendrogram from cluster analysis using nine traits on 22 field pea cultivars.

vars into two groups with (Table 3. It was also found that cluster D consisting of 6 cultivars (Arwena, Audit, Madonna, Mentor, Batuta and Tarchalska) was characterized by the highest seed yield, number of seeds per pod and low seed damage by the pea moth and the lowest seed damage by pea weevil. The affiliation of the tested cultivars to particular groups is illustrated by a dendrogram (Figure 4). Among fodder pea cultivars, Hubal, Model, Milwa and Turnia from group A that showed the highest seed yield were more resistant to lodging and had lower percentage of seeds damaged by pea moth and pea weevil.

CONCLUSIONS

1. Damage to pea seeds by pea moth and pea weevil was common in the Radzików region. All tested pea cultivars were found to be susceptible to pea moth and pea weevil, as reflected percentage values of of damage to seeds. However, a few cultivars demonstrated lower level of seed damage by these pests.
2. An association was shown between the degree of seed damage by pests in individual years and the weather conditions during the growing season, mainly the amount of rainfall.
3. Cultivars with the lowest percentage of damaged seeds and high yield performance were indicated. The use of pea cultivars less preferred by pests with high yielding provides, beside other things, an environmentally safer strategy to reduce seed damage.
4. Global climate warming and mild winters is bound to aggravate the severity of pests in the cultivation of peas, especially that of pea weevil,

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Author	ORCID
Lech Boros	0000-0002-1691-2499
Anna Wawer	-

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