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Thrips abundance on sweet corn in southeastern Poland and the impact of weather conditions on their population dynamics

Paweł K. BEREŚ[1], Halina KUCHARCZYK[2], Marek KUCHARCZYK[3]
[1]*Institute of Plant Protection – National Research Institute, Regional Experimental Station, Rzeszów, Poland*
[2]*Department of Zoology, Maria Curie-Skłodowska University, Lublin, Poland*
[3]*Department of Nature Conservation, Maria Curie-Skłodowska University, Lublin, Poland*

Abstract

In the study years, thrips (Thysanoptera) began infesting the sweet corn plants from the first (2008) or the second (2009-2010) decade of May. A single population peak was observed during pest development and it took place in the second decade of July. The pests ceased from the plants by the second (2008-2009) or third (2010) decade of September. Field and laboratory observation demonstrated that thrips fed on all the aboveground plant parts. Initially, the highest number of individuals was found on the bottom side of leaves, and later in sheaths, on fresh silk, under the cob husk, and on tassels. In total, during the study years, 16 species of thrips were found on sweet corn. *Anaphothrips obscurus* (Muller) was found on plants at the earliest time. *Frankliniella tenuicornis* (Uzel) was the dominant species, and its individuals accounted for 65.4 to 80.5% of the total number of thrips collected in consecutive years. The second most frequent species was *Haplothrips aculeatus* (F.), and its share in the collected samples was between 13.6 and 22.1%. *H. aculeatus* normally attained its population peak two weeks after the dominant species, i.e. *F. tenuicornis*. Weather conditions (precipitation and temperature) affected the speed of corn plant growth, date of plant infestation by thrips, and the duration of the population peak of thrips on the plants. However, weather conditions had no effect on the date of the thrips population peak occurrence, which was between 13 and 15 July in consecutive years.

Key words: *Frankliniella tenuicornis*, *Haplothrips aculeatus*, population dynamics, species composition, Thysanoptera, *Zea mays* var. *saccharata*.

Introduction

Sweet corn (*Zea mays* var. *saccharata* [Sturtev.] L.H. Bailey) is a commercially important crop in many countries. In the USA, this vegetable is grown on over 200,000 ha, and in China on about 100,000 ha. Other large producers of sweet corn are Brazil and Australia (about 40,000 ha), and Thailand (about 30,000 ha). In Europe, the leading producers of sweet corn are Hungary and France. In Poland, sweet corn is still grown on a small scale, but the growing consumer demand for sweet corn may lead to its increased production. The acreage of this vegetable is estimated at about 5,000 ha (FASonline, 2004; Nelson *et al*., 2011; Waligóra and Skrzypczak, 2012).

Similarly to fodder corn (*Zea mays* L.), sweet corn is infested by many harmful organisms, which can lead to losses in yield and quality in case of high pest population levels. Particularly dangerous are species damaging cobs, as it disqualifies them from direct consumption or for processing industry (Waligóra, 1992; O'Day *et al*., 1998; Carena and Glogoza, 2004).

So far, about 30 pest species, which may potentially damage plants, have been identified on fodder corn in Poland (Bereś and Pruszyński, 2008; Bereś, 2011). However, the species composition of pests infesting sweet corn has not been established. Currently, major pests of fodder corn and sweet corn in Poland include the European corn borer (*Ostrinia nubilalis* Hubner), and the frit fly (*Oscinella frit* L.), (Mazurek and Hurej, 1999; Mazurek *et al*., 2003; Waligóra *et al*., 2008, 2011). These species are also commercially important pests of sweet corn in other countries (Jepson and Mathias, 1960; Malvar *et al*., 2002; Bailey *et al*., 2005; Nelson *et al*., 2011).

Pests of sweet corn that may influence the size and, particularly, the quality of the yield also include aphids (Aphididae) and, increasingly frequently, thrips (Thysanoptera) (Stoetzel and Miller, 2001; Obrist *et al*., 2005; Khan *et al*., 2006; Kucharczyk *et al*., 2011; Nelson *et al*., 2011; Waligóra and Skrzypczak, 2012). Thrips, because of their minute size and cryptic behaviour, are a relatively poorly studied group of corn pests, although in Poland studies on their effect on corn plants were carried out in the 1950s and 1960s (Kania, 1962a; 1962b; Zawirska, 1969). Lisowicz (2001) reported an important role of thrips as fodder corn pests and the need for their control in the southeastern part of Poland. Thrips feeding on plants usually do not have a direct significant effect on corn yield, but their indirect harmfulness is considerably greater because the infested plants are more susceptible to pathogens infections, including fungal ones, like mycotoxin-producing *Fusarium* spp. (Parsons and Munkvold, 2010). Trzmiel and Lubik (2001) confirmed that the risk of viral diseases in fodder corn is increasing in Poland, and this may also concern sweet corn. Corn thrips (*Frankliniella williamsi* Hood) is the major vector of viral corn diseases, e.g. corn chlorotic mosaic virus (MCMV) in Hawaii and in Central America (Nelson *et al*., 2011), while western flower thrips (*Frankliniella occidentalis* Pergande), recorded as the major component of Thysanoptera fauna on corn in the Czech Republic (Habuštowá and Sehnal, 2007) are able to transmit many plant viruses, as was observed in greenhouse cultivations (Cloyd, 2009).

The growing interest of researchers in studies on the

thrips abundance on corn also results from the fact that the insects ingest the Cry protein from genetically modified plants and may transfer it to the higher trophic levels (Dutton *et al*., 2004; Eckert *et al*., 2006; Bereś *et al*., 2011). This information is vital, particularly because the acreage of GM corn is growing worldwide (James, 2011).

The objective of the study was to identify the species composition of thrips assemblages present on sweet corn, to indicate the plant parts mostly infested by the highest number of thrips at individual plant growth stages, and to identify the impact of weather conditions on the seasonal dynamics of Thysanoptera populations in the consecutive growing seasons.

Materials and methods

The studies were carried out between 2008-2010 in Terliczka (50°06'N, 22°05'E), near Rzeszów (southeastern Poland), in a 0.1-0.15 ha field of sweet corn cv. Candle. In all study years, two sides of the corn field were adjacent to a mown meadow, and the two other sides to winter wheat (2008), potato (2009), and spring wheat (2010). The sweet corn was sown in the third decade of April each year. Apart from herbicides, no other plant protection chemical was used on the study plots.

Thrips were collected throughout the entire corn vegetation period. For that purpose, from the end of April, when plants had developed 1-2 leaves (BBCH 11-12) (Adamczewski and Matysiak, 2011) to the beginning of October, when plants reached full maturity (BBCH 97), ten random plants were sampled diagonally once a week. The plants were cut down, packed into sealed plastic bags and transported to the laboratory, where they were inspected under a stereoscopic microscope. Observations for the presence of thrips were done on all the internal plant parts, as well as in sheaths, under cob husks, on silk, between kernels, and in tassels, including individual spikelets. The sites infested by the highest number of insects were recorded. All the collected thrips were counted and preserved in 75% ethyl alcohol. Adults of all species were identified using the keys of zur Strassen (2003) and Schliephake and Klimt (1979). Larvae were identified according to the key of Vierbergen *et al*. (2010) (tables 1, 2). Some of the specimens were mounted in Berlese fluid, or as permanent slides, prepared according to the recommendation of Mound and Kibby (1998).

Weather data concerning average daily air temperature and daily total precipitation for the study region were obtained from the Institute of Meteorology and Water Management – National Research Institute in Jasionka, near Rzeszów (50°06'N, 22°03'E) located about 2 km north of the experimental field. Changes in weather conditions are presented for the period from May to September, when the presence of thrips on corn plants was monitored (figure 1).

Correlations between the number of thrips and temperature and precipitation have been tested using a rank-based nonparametric test, Kendall's tau (Kendall, 1975). We analyzed both the entire period of observations for thrips on sweet corn, i.e. from the beginning of May until the end of August (table 3), and the period of infestation and increase in population, i.e. from the beginning of May until the second ten days of July (table 4). Statistical analysis was performed with the STATISTICA package for Windows, ver. 10.0 PL.

Table 1. Species composition of thrips infesting sweet corn in Terliczka in 2008-2010.

List of species	Number of specimens in years: 2008				2009				2010			
	Adults		Larvae	Pupae	Adults		Larvae	Pupae	Adults		Larvae	Pupae
	♀	♂			♀	♂			♀	♂		
Aeolothrips fasciatus (L. 1758)	0	0	0	0	0	0	0	0	1	0	0	0
Aeolothrips intermedius (Bagnall 1934)	1	0	2	0	0	0	1	0	6	3	16	0
Anaphothrips obscurus (Muller 1776)	40	1	4	0	84	0	1	0	102	0	9	0
Aptinothrips rufus (Haliday 1836)	12	0	8	0	3	0	1	0	5	0	1	0
Aptinothrips stylifer Trybom 1894	1	0	0	0	0	0	0	0	1	1	0	0
Bolacothrips jordani Uzel 1895	1	0	0	0	1	0	0	0	4	0	0	0
Chirothrips manicatus Haliday 1836	0	0	1	0	0	0	0	0	0	0	0	0
Frankliniella intonsa (Trybom 1895)	0	0	0	0	0	0	0	0	0	0	6	0
Frankliniella tenuicornis (Uzel 1895)	690	88	321	26	766	98	413	56	513	57	270	66
Limothrips denticornis Haliday 1836	1	0	0	0	0	0	0	0	2	0	0	0
Thrips atratus Haliday 1836	1	0	0	0	2	0	0	0	0	0	0	0
Thrips fuscipennis Haliday 1836	0	0	0	0	1	0	0	0	4	2	0	0
Thrips major Uzel 1895	1	1	0	0	1	0	0	0	1	3	0	0
Thrips nigropilosus Uzel 1895	0	0	0	0	0	0	0	0	0	0	1	0
Thrips tabaci Lindeman 1889	0	0	0	0	1	0	0	0	3	0	0	0
Haplothrips aculeatus (F. 1803)	74	30	92	16	61	56	92	17	151	73	63	20
Total number of thrips	1,412				1,655				1,384			

Table 2. Total number (N) and dominance of thrips species infesting sweet corn in Terliczka in 2008-2010.

List of species	2008		2009		2010	
	N	%	N	%	N	%
Aeolothrips fasciatus (L. 1758)	0	0.0	0	0.0	1	0.07
Aeolothrips intermedius (Bagnall 1934)	3	0.21	1	0.06	25	1.81
Anaphothrips obscurus (Muller 1776)	45	3.19	85	5.14	111	8.02
Aptinothrips rufus (Haliday 1836)	20	1.42	4	0.24	6	0.44
Aptinothrips stylifer Trybom 1894	1	0.07	0	0.0	2	0.14
Bolacothrips jordani Uzel 1895	1	0.07	1	0.06	4	0.29
Chirothrips manicatus Haliday 1836	1	0.07	0	0.0	0	0.0
Frankliniella intonsa (Trybom 1895)	0	0.0	0	0.0	6	0.43
Frankliniella tenuicornis (Uzel 1895)	1,125	79.67	1,333	80.54	906	65.46
Limothrips denticornis Haliday 1836	1	0.07	0	0.0	2	0.14
Thrips atratus Haliday 1836	1	0.07	2	0.12	0	0.0
Thrips fuscipennis Haliday 1836	0	0.0	1	0.06	6	0.44
Thrips major Uzel 1895	2	0.14	1	0.06	4	0.29
Thrips nigropilosus Uzel 1895	0	0.0	0	0.0	1	0.07
Thrips tabaci Lindeman 1889	0	0.0	1	0.06	3	0.22
Haplothrips aculeatus (F. 1803)	212	15.02	226	13.66	307	22.18

Results

Species composition of thrips

In the three study years 4,451 thrips were collected and identified to 16 species (table 1). Eleven species of thrips were found on sweet corn in 2008, 10 in 2009, and 14 in 2010 (table 2). *Frankliniella tenuicornis* (Uzel) was the dominant species in 2008-2010, and its individuals accounted for 79.67; 80.5 and 65.4% of the total thrips assemblages in the consecutive study years, respectively. The second most frequent species was *Haplothrips aculeatus* (F.), and the share of its individuals was between 13.6% (2009) and 22.1% (2010). The third most abundant species found during study period was *Anaphothrips obscurus* (Muller) infesting mainly juvenile plants. It accounted for 3.19%, 5.14% and 8.0% of the total number of the collected individuals (table 2).

Four other thrips species, apart from those listed above were recorded each year as: predatory *Aeolothrips intermedius* (Bagnall), *Aptinothrips rufus* (Haliday) and *Bolacothrips jordani* Uzel feeding also on grasses, and *Thrips major* Uzel, associated with dicotyledonous plants. *A. intermedius* in 2010 and *A. rufus* in 2008 had over 1.0% share in the total number of collected thrips, but in other years, only single individuals represented them. The presence of species other than *F. tenuicornis*, *H. aculeatus,* and *A. obscurus*, feeding and reproducing on corn plants, was accidental and resulted probably from the migration of the insects from the fields or the meadow adjacent to the corn field. Fifty per cent of the species found on corn, including the predominant ones, are eurytopic and graminicolous taxa. The dominant species were represented mainly by females (tables 1 and 2).

The impact of weather conditions on the population dynamics of thrips

Figure 2 presents the general population dynamics of total Thysanoptera individuals and adult forms and larvae of the two most numerous species: *F. tenuicornis* and *H. aculeatus*. Figure 1 presents changes in the most important weather parameters during the occurrence of Thysanoptera.

Temperatures were significantly related to the number of *F. tenuicornis* adults in 2008 and 2009 years and *H. aculeatus* adults in 2009. The positive impact of temperatures was found according to number of all thrips species collected on whole plants and particularly in sheats both throughout the whole study period and between May and July (tables 3 and 4).

The analysis of the number of thrips on sweet corn and rainfall did not show any statistically significant correlation in the entire study period (table 3), nor during the infestation of plants by thrips and increase in the pest population (table 4). However, the analysis of individual cases (figures 1 and 2) demonstrated that rain in late May and early June, combined with a decrease in temperature, limited the infestation of corn plants by thrips in all study years. That process was most evident in 2009 and 2010, and caused the subsequent colonization of maize plants by thrips (BBCH 14-15) compared to 2008 (BBCH 12-13).

In 2008 the first adult thrips occurred on corn at the earliest date in the analyzed three-year period, i.e. on 5 May, when plants had 2-3 leaves developed (BBCH 12-13). Females of *F. tenuicornis* occurred first. Due to prolonged rainfall that continued into the second decade of May the increase in the thrips population was very slow. A clear increase was observed from the end of May, and females *F. tenuicornis* predominated among the captured insects. The first larvae of this species occurred on 24 June, and their population peak was on 8 July (196 individuals/10 plants). The general peak of the thrips population (291 individuals/10 plants) was on 14 July, when corn was shedding pollen (BBCH 63-65). At that time females and males of *F. tenuicornis* (220 individuals) predominated among the captured insects, and the first individuals of *H. aculeatus* occurred. The highest number of individuals representing that species was

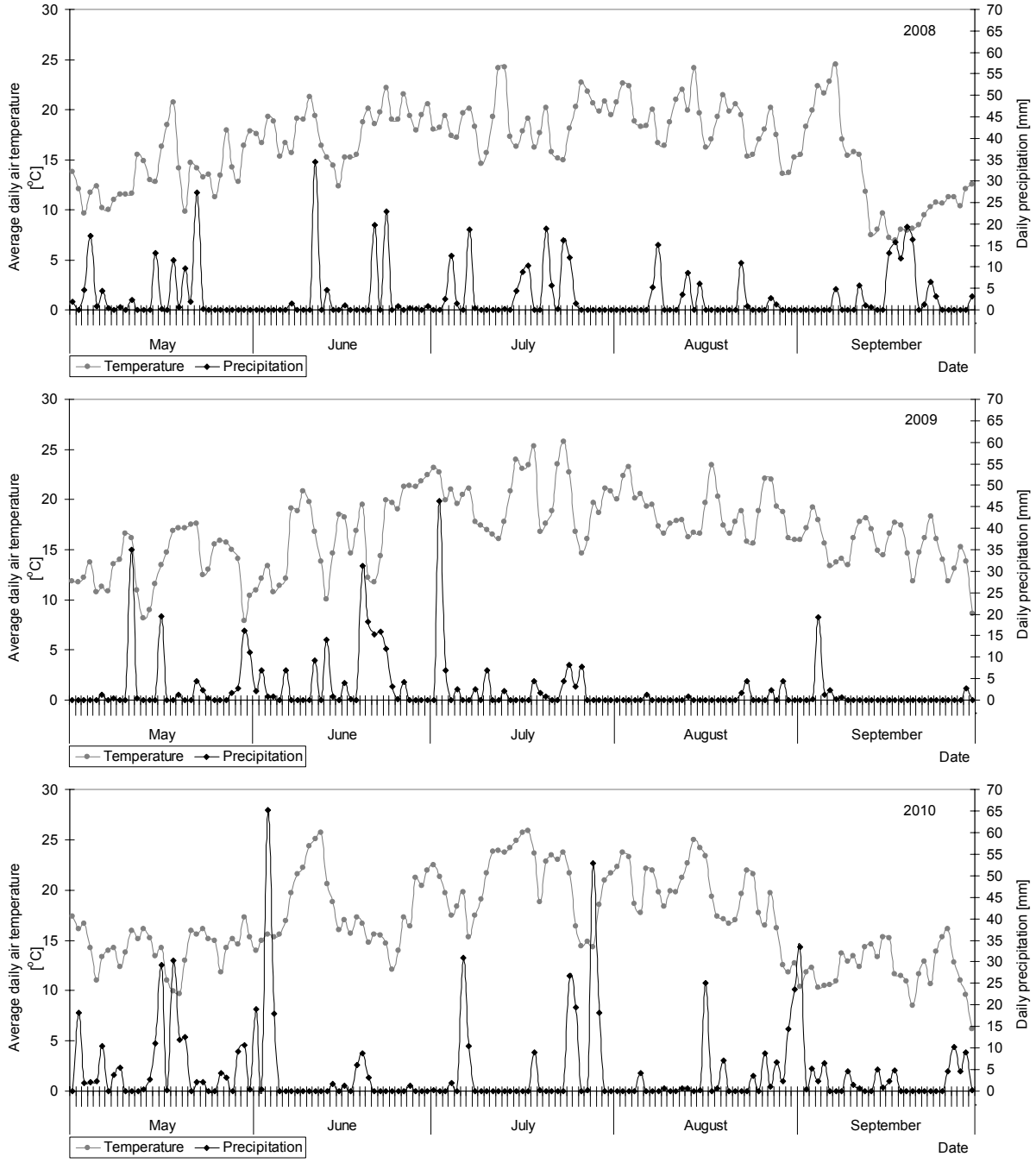

Figure 1. Changes in weather conditions in Terliczka in 2008, 2009 and 2010.

Table 3. Kendall's tau correlation coefficients between number of thrips and temperature and precipitation. Marked correlations are significant at $p < 0.05$. (Calculations in columns: corn leaves and corn sheaths for all collected thrips).

Year	Weather parameters	Number of thrips						
		Frankliniella tenuicornis		*Haplothrips aculeatus*		Corn leaves	Corn sheaths	Total
		Adults	Larvae	Adults	Larvae			
2008	Temperature*	**0.505**	−0.110	0.048	0.000	0.313	**0.351**	**0.463**
	Precipitation**	0.095	0.183	0.333	0.414	0.101	0.137	0.095
2009	Temperature*	**0.664**	0.283	**0.648**	0.690	**0.505**	**0.598**	**0.577**
	Precipitation**	−0.158	0.057	0.286	−0.414	0.047	−0.074	−0.138
2010	Temperature*	0.172	0.267	0.394	**0.619**	**0.356**	**0.510**	**0.472**
	Precipitation**	0.038	−0.038	0.079	−0.333	−0.047	−0.190	−0.165

* average temperature within 7 days before the date of thrips collection from plants.
** total precipitation within 7 days before the date of thrips collection from plants.

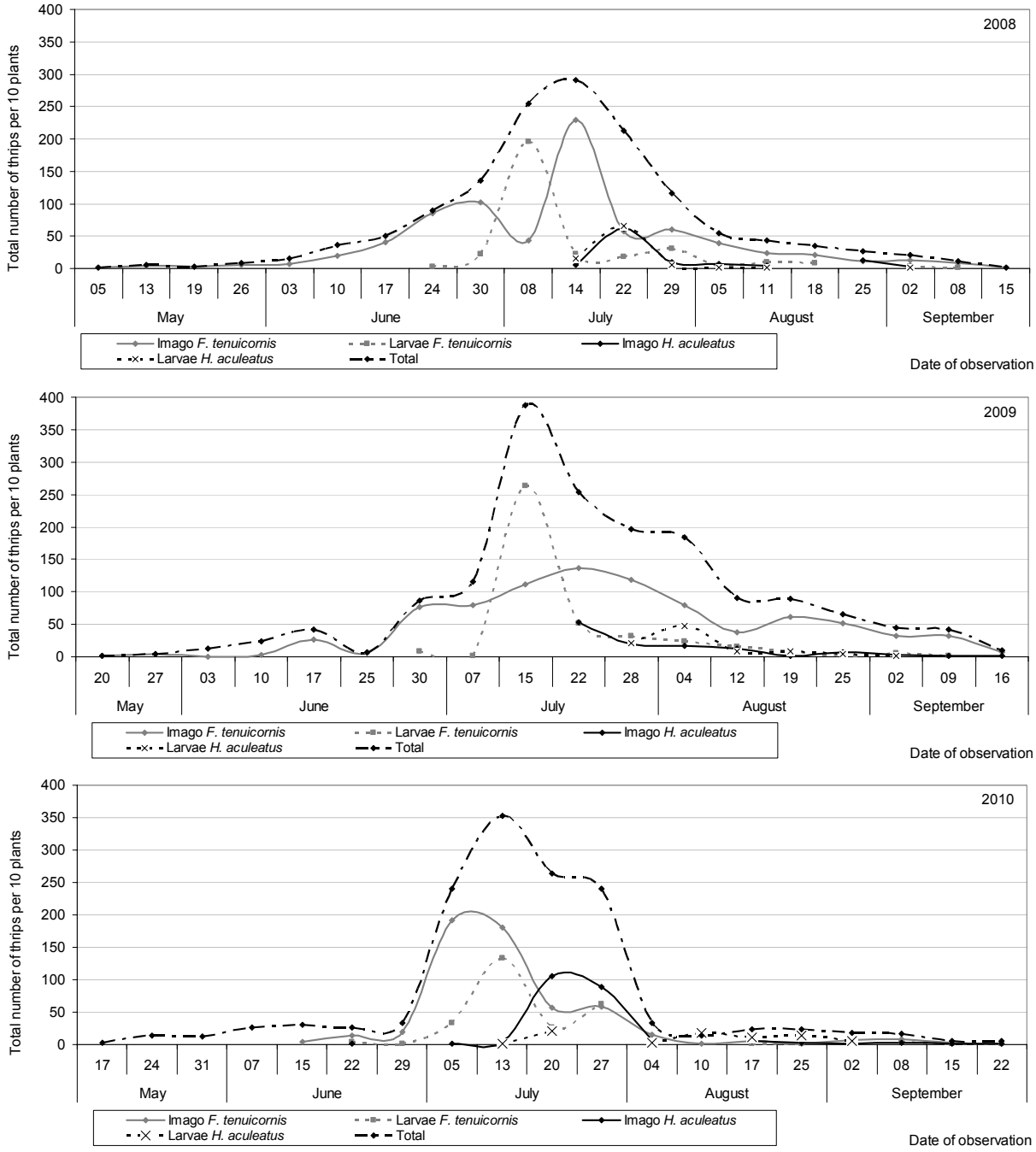

Figure 2. Population dynamics of thrips on sweet corn in Terliczka in 2008, 2009 and 2010.

recorded on 22 July - 126 individuals/10 plants. After that period the population of thrips on the plants declined dynamically, which may have been associated with a several-day long rainfall that continued until the third decade of July. A slight increase in the number of adults and larvae of *F. tenuicornis* occurred only on 29 July. The last larvae of both dominant species were recorded on 8 September, and adult forms of *F. tenuicornis* on 15 September, when the corn plants reached physiological maturity of kernels (BBCH 87). In total, 1,412 thrips were collected from the plants in 2008 (figure 2, tables 3 and 4).

In 2009 the first adult thrips occurred on corn at the latest date in the analyzed three-year period, i.e. on 20 May, when the plants had 5 leaves developed (BBCH 15). That may have been caused both by the short but intense rainfall that occurred on 11 and 16 May, and significant changes in temperature observed in that month, with a periodic drop below 10 °C. Similarly to the previous year, the first individuals of *F. tenuicornis* that occurred were adults.

The impact of temperature on the population of dominant thrips species was significant for adults only and for all specimens collected in sheaths both in whole study period and between May and July. In the latter period there was not correlation between temperature and number of specimens collected on leaves (tables 3 and 4). Individuals of *A. obscurus* predominated among

Table 4. Kendall's tau correlation coefficients between number of thrips and temperature and precipitation during the period of the beginning of May to the second decade of July. Marked correlations are significant at $p < 0.05$. (Calculations in columns: corn leaves and corn sheaths for all collected thrips).

Year	Weather parameters	Number of thrips				
		Frankliniella tenuicornis		Corn leaves	Corn sheaths	Total
		Adults	Larvae			
2008	Temperature*	**0.727**	0.000	0.267	**0.550**	**0.636**
	Precipitation**	0.061	−0,200	−0,038	0.147	0.091
2009	Temperature*	**0.644**	−0.333	0.405	**0.500**	**0.467**
	Precipitation**	−0.244	−0.333	−0.135	−0.167	−0.156
2010	Temperature*	0.172	0.267	**0.356**	**0.510**	**0.472**
	Precipitation**	0.038	−0.038	−0.047	−0.190	−0.165

* average temperature within 7 days before the date of thrips collection from plants.
** total precipitation within 7 days before the date of thrips collection from plants.

the captured insects until mid-June. From the end of June, a gradual increase in the population of thrips was observed, with predominance of *F. tenuicornis*. The first larvae of this species were collected on 30 June. Improvement in weather conditions after 2 July (higher temperatures) had a decisive effect on the rapid increase in the thrips population on the plants. Within one week the population of the insects increased from 115 individuals/10 plants (7 July) to 387 individuals/10 plants (15 July), when corn plants intensely shed pollen (BBCH 67). Larvae of *F. tenuicornis* accounted for about 68% of total thrips individuals collected that day. A lower number of thrips was collected in the third decade of July, and adult forms predominated among them. The first adult forms of *H. aculeatus* occurred on 22 July, and larvae on 28 July. One week later, the number of larvae of *H. aculeatus* was higher than that of *F. tenuicornis*. The last representatives of Thysanoptera were found on sweet corn on 16 September, when the plants reached physiological maturity of kernels (BBCH 87). The last observed forms were adults of both dominant species. In total, 1,655 thrips were collected in 2009 (figure 2, tables 3 and 4).

In 2010 the first thrips infested the corn field on 17 May, when the plants had 4-5 leaves developed (BBCH 14-15). *A. obscurus* occurred first. In May, due to relatively low temperatures (about 15 °C) that continued for a few days and low rainfall in the last days of the month, the insects did not find favourable conditions for development (figure 1). The weather in June did not facilitate an increase in the thrips population either. After a rainstorm on 3 June, when 65.2 mm of rain fell in one day, some insects were most probably washed down from the plants or drowned in water trapped in sheaths. Individuals of *A. obscurus* dominated among the collected insects until mid-June, while the first adult forms of *F. tenuicornis* were found on 15 June, and their larvae on 22 June. The first adult forms of *H. aculeatus* occurred on 22 June, and their larvae on 13 July (figure 2).

An intense increase in the population of Thysanoptera on sweet corn occurred late, in the first decade of July. The insects reached the population peak on 13 July, when corn began shedding pollen (BBCH 63). At that time, 353 individuals were collected from 10 plants, and the number of *F. tenuicornis* individuals at the pre-adult stage (133 larvae and 27 pupae) was almost the same as the number of adults (181). After about two weeks following their population peak (in the third decade of July) another increase in the number of *F. tenuicornis* larvae on the plants was observed. At that time, the number of captured individuals of *H. aculeatus* was also higher. Larvae of this species predominated among the collected insects in the last ten days of August. This was the only case where a significant positive correlation was found between temperature and the number of captured larvae (table 3). The last thrips were found on sweet corn on 22 September, when corn plants began drying out (BBCH 89). In total, 1 384 thrips were collected from the investigated plants in 2010 (figure 2, table 3).

Parts of plants infested by thrips

Individual parts of plants infested by the highest number of thrips, along the changing developmental stages of sweet corn, were recorded during the entire period of the insect occurrence. Thrips infested almost all the aboveground plant parts, including leaves, sheaths, cob buds, cobs and tassels.

At the initial stage of corn vegetation, when plants had developed 2-3 leaves (BBCH 12-13), the highest number of adult thrips were found on leaves, feeding particularly on the underside. When the plants developed from 4 to 9 leaves (BBCH 14-19), an increasing number of insects was found in sheaths and between undeveloped leaves. On these parts of plants, the females were both feeding and depositing eggs. At the stage of stem elongation and development of the first few internodes in corn plants (BBCH 30-34), the highest number of thrips was found in sheaths and on the underside of the leaves of lower levels. Observation of the leaves strongly infested by these insects revealed clear damage - silver-grey discolouration and black specks of faeces (thrips leaf damage). In study years thrips found on leaves and in sheaths accounted for 28.70% to 38.95% of all individuals recorded on corn plants (table 5). At the stage of tassel development and flowering (BBCH 51-67) the highest number of Thysanoptera were recorded in sheaths, on tassels, including individual spikelets, on fresh silk, and under cob husks. Adults that are more mobile fed mainly on flowers, while larvae fed on leaves and cob husks. The highest number of thrips

Table 5. Parts and development stages of sweet corn plant infested by thrips in 2008-2010.

Part of the plant	Number of thrips on plants in individual corn developmental stages					Total number of thrips	Percentage share
	05-26 May 2008 (BBCH 12-15)	03-30 June 2008 (BBCH 15-34)	08-29 July 2008 (BBCH 51-71)	05-25 August 2008 (BBCH 71-83)	02-15 September 2008 (BBCH 83-87)		
Leaves	13	193	313	26	5	550	38.95
Sheaths	5	135	348	35	11	534	37.82
Tassels	0	0	102	18	1	121	8.57
Silks	0	0	55	23	2	80	5.67
Cob husks	0	0	51	33	6	90	6.37
Kernels	0	0	4	24	9	37	2.62
Total	18	328	873	159	34	1412	
	20-27 May 2009 (BBCH 15-16)	03-30 June 2009 (BBCH 16-34)	07-28 July 2009 (BBCH 51-71)	04-25 August 2009 (BBCH 73-83)	02-16 September 2009 (BBCH 85-87)		
Leaves	3	87	278	85	22	475	28.70
Sheaths	3	83	290	151	37	564	34.08
Tassels	0	0	123	29	3	155	9.37
Silks	0	0	141	29	8	178	10.76
Cob husks	0	0	109	81	16	206	12.45
Kernels	0	0	12	54	11	77	4.65
Total	6	170	953	429	97	1655	
	17-31 May 2010 (BBCH 14-17)	07-29 June 2010 (BBCH 17-34)	05-27 July 2010 (BBCH 51-71)	04-25 August 2010 (BBCH 71-85)	02-22 September 2010 (BBCH 85-89)		
Leaves	16	70	393	17	11	507	36.63
Sheaths	14	47	373	43	21	498	35.98
Tassels	0	0	126	2	1	129	9.32
Silks	0	0	96	3	1	100	7.23
Cob husks	0	0	77	19	8	104	7.51
Kernels	0	0	32	11	3	46	3.32
Total	30	117	1097	95	45	1384	

on tassels was found in July, and their population found on these plant parts accounted for 8.57% to 9.37 % of all individuals recorded in the analyzed three-year period. When kernels were at the milk stage and dough stage (BBCH 71-85) the highest number of insects was found under the cob husks, between soft kernels, particularly if they were not covered with the husk, and in sheaths, where both larvae and the new generation of adult females fed by sucking tissue liquid from the most tender plant parts. Pests feeding on cobs (on silk, under cob husks and on kernels) during study years accounted for 2.62% to 12.45% of all representatives of Thysanoptera found on plants (table 5). At the stage of physiological kernel maturity (BBCH 87), the place most infested by thrips could not be conclusively identified because the population of insects declined significantly, and they were found on the entire plant, particularly in the places where the tissues were still green.

Adults were the most mobile developmental stage of thrips, and they actively migrated along the entire plant seeking food. Larvae were slightly less mobile, and they usually fed hiding in sheaths, under cob husks, inside silks, and in tassels. Exceptionally, high number of them was found on the underside of leaves of lower levels when corn was at the stage of stem elongation and developing the first few internodes. Prepupal and pupal forms were usually found hidden in sheaths and under the cob husks. The low number of prepupal and pupal forms found on plants indicates that the majority of thrips underwent this developmental stage in soil beneath the host plants.

Discussion

Studies on the population dynamics of thrips on sweet corn have not been carried out in Poland so far. Some observations of this order were carried out on fodder corn by Lisowicz (1996) in Krzeczowice, near Przeworsk (southeastern Poland) in 1982-1993, and by Kucharczyk *et al*. (2011) in 2006-2007 at the same location. Lisowicz (1996) found the first thrips individuals on corn plants in the third decade of May or in early June, while Kucharczyk *et al*. (2011) found them in the second decade of May and in the second decade of June. In our study thrips occurred on sweet corn at an earlier date, i.e. in the first (2008) or in the second decade of May (2009-2010). Based on many years of observation Lisowicz (1996) identified a single population peak in the development of these insects, which is consistent with studies by Kucharczyk *et al*. (2011). The quoted author found that the population peak of thrips on fodder corn usually occurs at the end of July or in the first half of August. The maximum number of insects was recorded on 15 July only in 1993. Kucharczyk *et al*. (2011) observed the population peak of Thysanoptera on the plants in the

third decade of July (2007), and in early August (2006). In 2008-2010, regardless of weather conditions, the peak of thrips population on sweet corn occurred between 13 and 15 July, when plants were shedding pollen. The difference between the dates of population peaks of thrips on fodder corn and sweet corn was probably associated with the type of corn grown, including the earliness of the variety. Both previous and present studies demonstrated that regardless of the corn type, thrips usually end feeding in the second, or in the third decade of September, when the plants began drying out (Lisowicz, 1996; Kucharczyk *et al*., 2011).

Studies analyzing the effect of Bt corn on non-target organisms (NTO) carried out in the Czech Republic demonstrated that *F. occidentalis* was the dominant species found on corn in this country (Habuštowá and Sehnal, 2007). The first individuals of this species were found by the quoted authors on plants developing the fourth leaf. The population peak was recorded at the end of June and in early July, during corn flowering. The last individuals of this species were found at the end of August.

Weather conditions in individual study years could have had an effect on the dynamics of thrips development. The life cycle of thrips is primarily affected by temperature: higher temperatures shorten the life cycle, while periodic reduction in temperature can inhibit the development of pre-adult stages, and extend the cycle. On the other hand, increased and continued temperatures over 30 °C may cause significant mortality in larvae and pupae (Lewis, 1973; Reitz, 2009; Varikou *et al*., 2009).

Our study demonstrated that thrips infested almost all the aboveground plant parts, which is consistent with observations by Kania (1962a; 1962b) and, in part, by Lisowicz (1996). Adults were the most mobile developmental stages of Thysanoptera. The highest number of larvae was found near the hatching place on the tenderest plant parts shaded from direct sunlight. It was observed that along with the changing developmental stages of sweet corn the number of thrips on individual plant parts also changed. Signs of the feeding of numerous thrips on leaves (discolouration) observed in our study were also found by Kania (1962a; 1962b).

Obrist *et al*. (2005; 2006), in their study carried out in Spain, found *F. tenuicornis* mainly on leaves and stems, while flowers were infested by *F. occidentalis*. A greater number of adult *F. occidentalis* individuals in flowers in the upper part of the plant canopy than in other parts of plants were also observed in other cultivations, including tomatoes. In contrast, the highest number of larvae of this species infested lower parts of plants, while *Frankliniella tritici* (Fitch) preferred tomato leaves as a feeding site (Cho *et al.*, 2000; Reitz, 2002).

The available literature provides relatively scarce information on the species composition of thrips found on corn. This problem, with a focus on sweet corn, has not been studied in Poland so far. However, as early as in the 1950s Kania (1962a; 1962b) identified two species on fodder corn: *Stenothrips graminum* (Uzel) and *H. aculeatus*. Studies by Kot and Bilewicz-Pawińska (1989) carried out in the 1970s and 1980s confirmed that *H. aculeatus* was the dominant species on corn. Zawirska (1969) carried out the first detailed analysis of Thysanoptera species on fodder corn in Poland. She found a high number of *F. tenuicornis, H. aculeatus,* and predatory *A. intermedius*. Studies by Zawirska were continued by Kucharczyk *et al*. (2011), who found 21 thrips species on fodder corn. The quoted authors found 12 Thysanoptera species in 2006, and 20 species in 2007. *F. tenuicornis* and *H. aculeatus* were the dominant species in both years, which is consistent with our observations for sweet corn. There were another eight species listed by Kucharczyk *et al*. (2011) and found on fodder corn: *A. intermedius*, *A. obscurus*, *Chirothrips hamatus* Trybom, *Frankliniella intonsa* (Trybom), *Limothrips denticornis* Haliday, *T. major*, *Thrips fuscipennis* Haliday and *Thrips atratus* Haliday. Majority of thrips species found both on fodder corn and sweet corn are cereal and grass pests (Kobro *et al*., 2000; Zawirska and Wałkowski, 2000; Kąkol and Kucharczyk, 2004; Reisig *et al*., 2010; 2011). The higher number of *F. tenuicornis* and *A. obscurus* found on sweet corn migrated to the experimental field from the adjacent mown meadows, where the insects were most probably wintering. The fact that *H. aculeatus* occurred on corn as late as in the second half of the experimental cycle indicates that this species prefers the nearby growing wheat as the major host plant, and after harvest (in the second half of July) begins feeding and depositing eggs on corn.

Conclusion

In the study years, thrips began infesting the corn plants from the first or the second decade of May. In the second decade of July a single population peak was observed. The pests ceased from infesting plants in the second or third decade of September.

Thrips fed on all the aboveground plant parts.

During the study years, 16 species of thrips were found on sweet corn. *F. tenuicornis* and *H. aculeatus* were the dominant species.

Regardless of weather conditions, the peak of thrips population on sweet corn occurred between 13 and 15 July, when plants were shedding pollen.

The study demonstrated a positive correlation between temperature and the number of adult *F. tenuicornis* and *H. aculeatus* individuals in the entire study period, but also from the moment of plant infestation until the population peak of pests on sweet corn.

Contrary to expectations, changes in precipitation during study periods did not have a significant impact on the number of thrips found on sweet maize. However, the analysis of individual cases indicated that precipitation may influence the number of thrips at the stage of plant infestation and population increase.

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Authors' addresses: Paweł K. BEREŚ (corresponding author: pawel.beres@iorpib.poznan.pl), Institute of Plant Protection, National Research Institute, Regional Experimental Station in Rzeszów, Langiewicza 28, 35-101 Rzeszów, Poland; Halina KUCHARCZYK (halina.kucharczyk@poczta.umcs.lublin.pl), Department of Zoology, Maria Curie-Skłodowska University, Akademicka 19, 20-033 Lublin, Poland; Marek KUCHARCZYK (marek.kucharczyk@poczta.umcs.lublin.pl), Department of Nature Conservation, Maria Curie-Skłodowska University, Akademicka 19, 20-033 Lublin, Poland.

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