Thrips (Thysanoptera) associated with onion (*Allium cepa* L.) and Welsh onion (*Allium fistulosum* L.)

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ABSTRACT

We determined the abundance, species composition, sex ratio and seasonal dynamics of thrips on one cultivar of Welsh onion (*Allium fistulosum*) and eight cultivars of onion (*Allium cepa*) in South Poland within three vegetation seasons (2014–2016). Nine species of Thysanoptera were identified on *A. cepa* and *A. fistulosum*. Irrespective of the onion cultivar, *Thrips tabaci* was the dominant species (64.4% of all collected thrips specimens), while *Frankliniella intonsa* also occurred in high numbers (28.3%). Conversely, Welsh onion was most often inhabited by *F. intonsa* (62.7%), although *T. tabaci* was also numerous (28.3%). The predatory *Aeolothrips intermedius* accounted for 4.5% on *A. cepa* and 2.9% on *A. fistulosum*. In the most numerous species, *T. tabaci*, *F. intonsa* and *A. intermedius* populations were formed mainly by females. The cultivar most colonised by thrips was Kroll of *A. fistulosum*. The tested cultivars of *A. cepa* demonstrated varying degrees of attractiveness to thrips in the subsequent years. The relationship between populations of *T. tabaci*, *F. intonsa* and *A. intermedius* changed in the subsequent months of the growing season. In June, mainly *T. tabaci* and *F. intonsa* occurred on onion plants, while from July, the percentage shares of *F. intonsa* and the predatory *A. intermedius* in the thrips population on many onion cultivars increased. The level of attractiveness of *A. cepa* related to onion thrips, which is reported as a main pest of onion, varies depending on the year and cultivar.

Keywords: *Aeolothrips intermedius*, arrhenotokous, cultivar, *Frankliniella intonsa*, thelytokous, *Thrips tabaci*

INTRODUCTION

Onions have been consumed for thousands of years in various forms in most cultures of the world. They are most commonly used as an aromatic spice and food supplement, but they are also a valuable source of vitamins, minerals, health-promoting substances and essential oils (Dossa et al., 2018). Nowadays, numerous cultivars of onion (*Allium cepa* L.) are cultivated, from the most popular yellow to red and white onions, as well as the more exquisite Welsh onion (*Allium fistulosum* L.). Welsh onion is grown mainly for its chives, although the small bulbs are also edible. The largest producers of *A. cepa* are China, the United States and India, while the production of *A. fistulosum* is centred in Japan, Korea,

China and Taiwan (Ford-Lloyd and Armstrong, 1993). Among the European Union countries, the leaders in the production and export of onion are Spain, the Netherlands and Poland, while Germany and the Ukraine also have a high onion production (Zaremba, 2015). In Poland, the production of onion amounted to 630,000 and 650,000 tonnes in 2014 and 2016, respectively, while in 2015, due to drought, it fell to 585,000 tonnes. In 2017, the onion production amounted to 667,000 tonnes and was higher compared to next year, when it decreased by 15.6% to 563,000 tonnes in 2018 (Statistics Poland, 2020). In addition to abiotic factors (water deficiency and temperature), which have a significant impact on onion

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yield, important biotic factors limiting its production include pests and pathogens (Kalbarczyk et al., 2011).

Among the onion pests, one of the most harmful ones is the *Thrips tabaci*. Larvae and adults of onion thrips live in the leaf sheath and stalk, sucking up the contents of plant cells and causing direct damage, which manifests in the silverying of the leaves and, consequently, inhibited plant growth and reduced bulb weight. In addition, it has indirect effects by promoting the development of fungal and bacterial pathogens as well as the transmission of Iris yellow spot virus (IYSV) (Lewis, 1973). Furthermore, the rapid mass appearance and the high density of thrips on onion crops, particularly during the hot and dry growing seasons, are associated with serious yield loss (Diaz-Montano et al., 2011; Gill et al., 2015). Fournier et al. (1995) demonstrated that in the absence of any control measures, onion thrips infestations of yellow onions resulted in yield losses of 34.5% and 43%. Similarly, Pandey et al. (2011) reported that onion thrips damaged 90% of the onion crop in India and >50% in the United States (Boateng, 2012). It is also one of the major limiting factors affecting yields of leek (Kucharczyk and Legutowska, 2002), cabbage (Fail and Pézses, 2004; Trdan et al., 2008a), tomato, pepper, cucumber (Riefler and Koschier, 2009; Ssemwogerere et al., 2013) and peas (Pobożniak et al., 2020). The high potential for a rapid population increase of *T. tabaci* on onion crops is because of a result of their complex lifestyle with a high reproductive rate, a short generation time, a high survival of non-feeding instars (prepupa and pupa), the ability to reproduce without mating (parthenogenesis) and their ability to develop resistance to insecticides (Morse and Hoddle, 2006; Diaz-Montano et al., 2011). Onion thrips do not comprise a homogeneous species and are composed of two distinct reproductive modes: thelytokous and arrhenotokous populations (Nault et al., 2006). The number of generations per year depends on the climatic conditions. In cold areas, from two to three generations may be produced, while in warmer regions, their number can increase up to eight (Gill et al., 2015).

Besides the above-mentioned harmful species *T. tabaci*, other phytophagous thrips taxa arising from neighbouring crops and wild plants can colonise onion plants. Most of them are not known to cause crop damage (Pobożniak et al., 2007), but their presence on onion plants and sticky traps, which are a useful tool for monitoring onion thrips infestation, can be misleading for farmers. Many authors also observed the presence of *Aeolothrips intermedius* on onion crops (Pobożniak et al., 2007; Mautino et al., 2014; Pobożniak et al., 2016), and this predatory taxa reduces the densities of other thrips populations and is a predator of 44 species of the Thysanoptera order (Riudavetes, 1995), potentially controlling onion thrips (Trdan et al., 2005). Accurate identification of thrips pests is fundamental to their effective control. Knowledge of this insect pest biology and seasonal dynamics would allow establishing control strategies in a future Integrated Pest Management (IPM) programme.

In this context, this study aimed to determine thrips abundance, species composition and seasonal fluctuation on eight cultivars of *A. cepa* and one cultivar of *A. fistulosum*. We also assessed the entity of the autochthonous predator *A. intermedius*, which is a potential biological control agent of *T. tabaci*.

MATERIALS AND METHODS

Field and laboratory research on the determination of composition, abundance and significance of particular thrips species was conducted in the Department of Botany, Physiology and Plant Protection of the University of Agriculture in Krakow, Poland.

Plant material

All onion cultivars of *A. cepa* used in the experiment were obtained from three Polish seed breeding companies: PlantiCo Zielonki in Stare Babice (cv. Alibaba with white bulb, cv. Bila, Kristine, Niagra F₁ with yellow bulb and cv. Wenta with red bulb), Polan in Krakow (cv. Karmen with red and cv. Polanowska with yellow bulb) and Spójnia in Nochowó (cv. Tęcza with yellow bulb). The cultivar Kroll, the only cultivar of the Welsh onion *A. fistulosum* (with white bulb), was obtained from PlantiCo Zielonki in Stare Babice.

Study area

In the years 2014–2016, field experiments were conducted at the Experimental Station of the University of Agriculture in Krakow, located in Mydlniki (near Krakow, southern Poland, 50°04'N, 19°51'E, 207 m above sea level) on a typical brown soil with pH 6.5 and an organic carbon content of 18 g · kg⁻¹. The experiment was established using the method of random blocks in four replications. The size of the experimental plots was 12 m² (3 × 4 m²), with a distance of 1 m between the plots. Seeds were sown (25 kg · ha⁻¹) in rows, 0.3 apart, on 6th April 2014, 10th April 2015 and 6th April 2016. The experimental plots were fertilised according to the Integrated Production recommendations for onions in the field. The plots were kept free of weeds throughout the season. No chemical treatments were carried out on the plots during the experiment, and weeding was performed manually. The crops that surrounded the experimental plot were as follows: potatoes, herbs, red beets, white cabbage, zucchini and pumpkin; additionally, sunflowers and ornamental plants, such as marigold and dahlia, grew in the near surroundings. At a distance of about 0.5 km from the experimental site, cereals and rape were grown.

Entomological analyses

In the three successive years (2014–2016), the period of entomological analyses lasted from the second decade of June to the end of August. In 2014, analyses were performed at intervals of 14 days, while in 2015 and 2016, analyses were performed weekly, between 10:00 am and 3:00 pm on sunny days. Sampling

thrips consisted of two methods: thrips collected with sweeping net and the method composed of plant bagging in plastic bags and then analysis in the laboratory. Thrips landing and spreading on plants were gathered in the net, while the second method allowed collecting of specimens hidden under folded leaves and near the base of the bulb. Thrips were collected from onion leaves using a standard entomological sweeping net (35 cm in diameter). Within each testing plot, 25 sweeps were made, and the sweeping nets and samples were placed individually into plastic bags. In parallel to the sweeping net analysis, 10 randomly selected plants from each plot (40 plants for cultivar) were collected and placed in plastic bags, followed by appropriate labelling. The collected material was transported to the laboratory, where insects were hand-separated using a soft brush and thrips were placed in vials containing 75% ethyl alcohol. Because the species complex of thrips and percentage share from net and direct counting from harvested plants were the same or similar (Tables S1 and S2 in Supplementary Materials), specimens collected by both methods from the same plots and date are shown combined in Tables 1–4 and Figures 1–3.

Identification of thrips species

Microscopic slides were prepared under laboratory conditions according to the technique described by Zawirska (1994). The specimens (adults and immature) were identified to species rank with the use of a microscope, following the keys of Zawirska (1994), Zur Strassen (2003) (adults) and Kucharczyk (2010) (larvae).

Sex ratio

The sex ratio (the percentage of females in a population) was calculated using the standard sex ratio formula as presented below (Vasiliu-Oromulu, 2002):

$$Sr = f : (m + f) \times 100,$$

where Sr is the sex ratio, f is the number of females (imago) and m is the number of males (imago).

Statistical analysis

Statistical analyses were performed using the Statistica 13 software (Dell Inc. 2016). In the case of lack of normality, the data were normalised with $\log(x + 1)$ transformation. Tables and figures contain untransformed data. One-way analysis of variance (ANOVA; the factor was onion cultivar) was performed for the data, i.e. mean number of thrips. Differentiation of the mean values was determined based on Tukey's HSD (honestly significant difference) test ($p < 0.05$).

RESULTS

Abundance and composition of species

In 2014, during the field study, 3,791 thrips belonging to six species were identified in the collected material from the different onion cultivars (Table 1). A significantly

higher number of thrips was recorded on Welsh onion cv. Kroll (932 individuals) ($F = 3.531$, $p < 0.006$) compared with five other cultivars of onion: Wenta, Alibaba, Karmen, Bila and Niagara F_1 , with 349 to 310 specimens on cv. Wenta and Niagara F_1 , respectively (Table 1).

The most abundant species on Welsh onion (cv. Kroll) was *Frankliniella intonsa* (flower thrips) (86.48%); in turn, *T. tabaci* predominated on onion cultivars. In cultivars of *A. cepa*, thrips accounted for 78.75% (cv. Karmen) to 45.60% (cv. Kristine) of the total number of collected thrips specimens. Of the tested onion cultivars, those most inhabited by onion thrips were cv. Tęcza and Polanowska, while the least colonised cultivar was Kristine. The number of *T. tabaci* infested Welsh onion (cv. Kroll) plants was low and almost 1.8 times smaller than the least populated onion cultivar. The third species in terms of the number of individual thrips collected was the predatory *A. intermedius*. Its share in the collected material ranged from 1.22% on cv. Tęcza to 7.74% on cv. Niagara F_1 ; the other three species *Thrips flavus*, *Haplothrips aculeatus* and *Haplothrips leucantemi* accounted for only 2.48% of the total number of thrips (Table 1).

In 2015, 19,450 individuals, belonging to nine species, were identified (Table 2). The highest number of thrips was found on Welsh onion cv. Kroll (4,536 specimens) in comparison to each onion cultivar ($F = 9.995$, $p < 0.000$). With regard to *A. cepa*, significant differences in the number of collected thrips were found only between cv. Karmen (2,439 individuals) and cv. Polanowska (1,475 individuals) (Table 2). In all the collected material from both *Allium* species, from three (cv. Tęcza) to eight (cv. Bila and Niagara F_1) species of thrips were identified. The most numerous species on all onion cultivars was onion thrips, with a total number of individuals of 10,257 (68.89%), while this taxa was second in terms of the number of individuals collected from Welsh onion (39.26%). The share of *T. tabaci* in the collected material from tested *A. cepa* cultivars was from 64.97% (cv. Tęcza) to 73.77% (cv. Wenta). In 2015, the cultivar most inhabited by onion thrips was the Welsh onion cv. Kroll, followed by the cultivars Karmen and Tęcza, both from *A. cepa*. Similar to the previous year, flower thrips constituted the most abundant taxa registered on cv. Kroll (2,687 specimens), accounting for 59.24% of the collected material from *A. fistulosum*. From all tested cultivars of *A. cepa*, 4,260 specimens of *F. intonsa* were collected, comprising 28.62% of all thrips. The highest percentage share of this species was detected on cv. Tęcza (33.31%) and the smallest was on cv. Wenta (24.27%). Of the species *A. intermedius*, we collected 368 individuals, accounting for 0.88% (cv. Kroll) to 2.88% (cv. Kristine) of the total species. Only 0.49% of the total number of thrips constituted the other six species. In addition to species that had been identified in the previous year, we also registered *Thrips fuscipennis*, *Chirothrips hamatus* and *Haplothrips niger* (Table 2).

Table 1. Species composition of thrips (imago and larvae) collected from *Allium cepa* and *Allium fistulosum* by sweeping net and directly from plants in 2014

Cultivars	*Alibaba	*Bila	*Karmen	*Kristine	**Kroll	*Niagara F ₁	*Polanowska	*Tęcza	*Wenta	*Total
<i>Thrips tabaci</i> Lindeman, 1889	N (%)	221 65.38	179 56.65	252 78.75	176 45.60	99 10.62	190 61.29	261 60.70	178 51.00	1,829 48.25
<i>Frankliniella intonsa</i> Trybom, 1895	N (%)	93 27.51	101 31.96	51 15.94	187 48.45	806 86.48	84 27.10	148 34.42	141 40.40	1,740 45.90
<i>Aeolothrips intermedius</i> Bagnall, 1934	N (%)	14 4.14	14 4.43	9 2.81	13 3.37	20 2.15	24 7.74	11 2.56	18 5.16	128 3.38
<i>Thrips flavus</i> Schrank, 1776	N (%)	6 1.78	13 4.11	1 0.31	6 1.55	5 0.54	6 1.94	7 1.63	3 0.86	50 1.32
<i>Haplothrips leucantemi</i> Schrank, 1781	N (%)	3 0.89	6 1.90	6 1.88	4 1.04	1 0.11	4 1.29	1 0.23	5 1.43	30 0.79
<i>Haplothrips aculeatus</i> Fabricius, 1803	N (%)	1 0.30	3 0.95	1 0.31	– 0.00	1 0.11	2 0.65	2 0.47	4 1.15	14 0.37
Total	N	338	316	320	386	932	310	430	349	3,791
Mean (± SE)		84.5 b ± 11.2	79.0 b ± 13.8	80.0 b ± 22.2	96.5 ab ± 8.9	233. a ± 47.4	77.5 b ± 15.1	107.0 ab ± 20.8	87.2 b ± 17.3	
F										3.531
p										0.006

*Cultivars of *A. cepa*.**Cultivar of *A. fistulosum*.Means marked with different letters are significantly different from each other (multiple Tukey's test $p < 0.05$).

Table 2. Species composition of thrips (imago and larvae) collected from *Allium cepa* and *Allium fistulosum* by sweeping net and directly from plants in 2015.

Onion cultivars	*Alibaba	*Bila	*Karmen	*Kristine	**Kroll	*Niagara F ₁	*Polanowska	*Tęcza	*Wenta	Total
<i>Thrips tabaci</i> Lindeman, 1889	N 1,312 (%) 68.58	1,241 69.68	1,672 68.55	1,157 66.53	1,781 39.26	1,403 68.31	1,024 69.42	1,059 64.97	1,389 73.77	12,038 61.89
<i>Frankliniella intonsa</i> Trybom, 1895	N 557 (%) 29.12	474 26.61	705 28.91	523 30.07	2687 59.24	584 28.43	417 28.27	543 33.31	457 24.27	6,947 35.72
<i>Aeolothrips intermedius</i> Bagnall, 1934	N 38 (%) 1.99	36 2.02	55 2.26	50 2.88	40 0.88	58 2.82	29 1.97	28 1.72	34 1.81	368 1.89
<i>Haplothrips niger</i> Osborn, 1883	N 3 (%) 0.16	6 0.34	0 —	3 0.17	12 0.26	3 0.15	3 0.20	0 —	0 —	30 0.15
<i>Chirothrips hamatus</i> Trybom, 1895	N 2 (%) 0.10	4 0.22	2 0.08	3 0.17	10 0.22	2 0.10	1 0.07	0 —	2 0.11	26 0.13
<i>Thrips fuscipennis</i> Haliday, 1836	N 0 (%) —	6 0.34	5 0.21	2 0.12	3 0.07	2 0.10	0 —	0 —	0 —	18 0.09
<i>Thrips flavus</i> Schrank, 1776	N 0 (%) —	13 0.73	0 —	0 —	0 —	1 0.05	0 —	0 —	0 —	14 0.07
<i>Haplothrips aculeatus</i> Fabricius, 1803	N 1 (%) 0.05	1 0.06	0 —	0 —	3 0.07	1 0.05	1 0.07	0 —	1 0.05	8 0.04
<i>Haplothrips leucantemi</i> Schrank, 1781	N 0 (%) —	0 —	0 —	1 0.06	0 —	0 —	0 —	0 —	0 —	1 0.01
Total	N 1,913	1,781	2,439	1,739	4,536	2,054	1,475	1,630	1,883	19,450
Mean (± SE)	478.2 bc ± 52.8	445.2 bc ± 64.8	609.7 b ± 45.7	434.7 bc ± 41.4	1134.0 a ± 150.4	513.5 bc ± 44.9	368.7 c ± 23.7	407.5 bc ± 32.1	470.7 b ± 51.3	
F										9,995
p										0,000

*Explanations: see Table 1.

Table 3. Species composition of thrips (imago and larvae) collected from *Allium cepa* and *Allium fistulosum* by sweeping net and directly from plants in 2016.

Onion cultivars	*Alibaba	*Bila	*Karmen	*Kristine	**Kroll	*Niagara F ₁	*Polanowska	*Tęcza	*Wenta	Total
<i>Thrips tabaci</i> Lindeman, 1889	N 723 (%)	494 64.74	578 64.22	639 63.77	1,084 44.10	579 64.12	848 69.28	232 80.28	616 58.17	5,793 58.96
<i>Frankliniella intonsa</i> Trybom, 1895	N 320 (%)	177 23.20	207 23.00	240 23.95	1043 42.43	214 23.70	247 20.18	29 10.03	298 28.14	2,775 28.24
<i>Aeolothrips intermedius</i> Bagnall, 1934	N 137 (%)	68 8.91	86 9.56	101 10.08	137 5.57	88 9.75	84 6.86	28 9.69	94 8.88	823 8.38
<i>Haplothrips aculeatus</i> Fabricius, 1803	N 9 (%)	4 0.52	12 1.33	8 0.80	77 3.13	6 0.66	12 0.98	0 —	13 1.23	141 1.44
<i>Thrips fuscipennis</i> Haliday, 1836	N 10 (%)	4 0.52	11 1.22	8 0.80	74 3.01	6 0.66	9 0.74	0 —	12 1.13	134 1.36
<i>Chirothrips hamatus</i> Trybom, 1895	N 22 (%)	9 1.18	4 0.44	1 0.10	23 0.94	7 0.78	20 1.63	0 —	12 1.13	98 1.00
<i>Chirothrips manicatus</i> Haliday, 1836	N 4 (%)	6 0.79	1 0.11	4 0.40	14 0.57	3 0.33	1 0.08	0 —	10 0.94	43 0.44
<i>Haplothrips leucantemi</i> Schränk, 1781	N 2 (%)	0 —	1 0.11	1 0.10	5 0.20	0 —	3 0.25	0 —	4 0.38	16 0.16
<i>Thrips flavus</i> Schränk, 1776	N 0 (%)	1 0.13	0 —	0 —	1 0.04	0 —	0 —	0 —	0 —	2 0.02
Total	N 1,227	763	900	1,002	2,458	903	1,224	289	1,059	9,825
Mean (± SE)	306.7 b ± 21.2	160.7 b ± 15.3	225.0 b ± 29.4	250.5 b ± 42.1	614.5 a ± 55.6	225.7 b ± 28.0	306.0 b ± 20.7	72.2 c ± 15.2	264.7 b ± 29.0	
F										21.671
p										0.000

*Explanations: see Table 1.

Table 4. Sex ratio index of the most numerous species of thrips (imago) collected from *Allium cepa* and *Allium fistulosum* by sweeping net and directly from plants in 2015 and 2016.

Onion cultivars	<i>Thrips tabaci</i>			<i>Aeolothrips intermedius</i>			<i>Frankliniella intonsa</i>		
	Male	Female	Sex ratio	Male	Female	Sex ratio	Male	Female	Sex ratio
2015									
Alibaba	1	1,311	99.9	1	37	97.4	15	542	97.3
Bila	14	1,227	98.9	0	36	100.0	11	463	97.7
Karmen	20	1,652	98.8	4	51	92.7	15	690	97.9
Kristine	2	1,155	99.8	0	50	100.0	12	511	97.7
Kroll**	12	1,769	99.3	5	35	87.5	81	2606	97.0
Niagara F ₁	15	1,388	98.9	0	58	100.0	21	563	96.4
Polanowska	0	1,024	100.0	2	27	93.1	14	403	96.6
Tęcza	0	1,059	100.0	0	28	100.0	0	543	100.0
Wenta	0	1,389	100.0	3	31	91.2	5	452	98.9
2016									
Alibaba	0	723	100.0	33	104	75.9	3	317	99.1
Bila	0	494	100.0	18	50	73.5	2	175	98.9
Karmen	1	577	99.8	18	68	79.1	1	206	99.5
Kristine	1	638	99.8	22	79	78.2	2	238	99.2
Kroll**	0	1,084	100.0	21	116	84.7	21	1,022	98.0
Niagara F ₁	1	578	99.8	25	63	71.6	0	214	100.0
Polanowska	2	846	99.8	18	66	78.6	1	246	99.6
Tęcza	0	232	100.0	0	28	100.0	0	29	100.0
Wenta	0	616	100.0	23	71	75.5	7	291	97.7

**Cultivar of *A. fistulosum*, other cultivars are the *A. cepa*.

Figure 1. Share of the three most abundant species on *Allium cepa* and *Allium fistulosum* in 2014 (cv. Kroll – *A. fistulosum*, others cvs – *A. cepa*).

Figure 2. Share of the three most abundant species on *Allium cepa* and *Allium fistulosum* in 2015 (cv. Kroll – *A. fistulosum*, others cvs – *A. cepa*).

Figure 3. Share of the three most abundant species on *Allium cepa* and *Allium fistulosum* in 2016 (cv. Kroll – *A. fistulosum*, others cvs – *A. cepa*).

In 2016, a total of 9,825 individuals of thrips, belonging to nine species, inhabited Welsh onion and onion plants. The highest number of thrips was found on the Welsh onion cv. Kroll (2,458 specimens) ($F = 21.671$, $p < 0.000$; Table 3), while the lowest number of thrips was observed on the onion cv. Tęcza (289 individuals). Among the cultivars of *A. cepa*, thrips were most abundant on the cultivars Alibaba (1,227 specimens) and Polanowska (1,224 thrips) (Table 3). Irrespective of the number of thrips individuals collected from cultivars of *A. cepa*, the number of detected thrips species ranged from seven to eight, except for cv. Tęcza, where only three species were noted. The insects collected from cv. Kroll represented nine thrips species. The most abundant species on all tested onion cultivars and Welsh onion was onion thrips, with a total number of 5,793 individuals (58.96%). Its share on *A. cepa* cultivars ranged from 58.17% on cv. Wenta to 80.28% on cv. Tęcza, while on cv. Kroll, it reached 44.10%. Of the onion cultivars, the most inhabited one was cv. Polanowska, while the least was cv. Tęcza. The second most abundant species was *F. intonsa* with 2,775 specimens, accounting for 28.24%. Its percentage share was the highest on cv. Kroll (42.43%), while on the other cultivars, it did not exceed 28.14% (cv. Wenta). The third highest percentage share in terms of the number of individual thrips collected in 2016 was found for *A. intermedius* with 823 individuals, accounting for 8.38% (from 5.57% on cv. Kroll to 11.17% on cv. Alibaba). Similar to the previous years, the other six species only accounted for 4.42% of the total species (Table 3).

The comparisons of thrips complex and percentage share of species caught by both sampling methods are presented in Tables 1 and 2. Within 3 years (2014–2016), much more specimens were collected directly from sweeping (18,228 specimens from onion and 6,814 from Welsh onion) than during a direct counting of specimens from harvested plants (respectively, 6,898 and 1,126 specimens from onion and Welsh onion). The complex of dominant species gathered with net and directly from onion and Welsh onion plants was the same and there were little differences between both the methods in the case of accessory species in 2015 and 2016. In 2014, the share of *T. tabaci* caught with sweeping was greater than that collected by direct counting thrips from onion and Welsh onion plants, while in the next 2 years the opposite ratio was noticed in the total collection of sampled thrips from onion and in 2015 from Welsh onion. The share of *F. intonsa* and *A. intermedius* was higher in material collected by direct counting thrips from onion in 2014, while in the next 2 years it was higher in the material gathered in net. In material collected from Welsh onion, the share of *F. intonsa* in net was higher within 2014 and 2015, while the ratio of *A. intermedius* was higher in net only in 2015. In turn in 2016, the share of three dominated species was nearly the same in material gathered by both methods from Welsh onion.

Sex ratio index of the most abundant three species

The population of *T. tabaci* was mainly represented by females. In 2015, 64 males were collected from five cultivars of onion (cv. Alibaba, Bila, Karmen, Kristine and Niagara F₁) and from Welsh onion (cv. Kroll). The numbers ranged from 1 specimen on cv. Alibaba to 20 thrips on cv. Karmen. The calculated sex ratio collected from these cultivars ranged from 98.8% (cv. Karmen) to 99.9% (cv. Alibaba). In 2016, only single males were found on cv. Karmen, Kristine, Niagara F₁ and Polanowska, and the sex ratio was 99.8% in all cultivars (Table 4).

In the population of *F. intonsa*, males occurred in greater numbers. In both years of research, males were registered on all tested cultivars except only on cv. Niagara F₁ in 2016 and Tęcza in both years. Larger numbers of *F. intonsa* males (174 specimens) were caught in 2015, when the overall abundance of thrips was high. In 2016, we registered only 37 males of flower thrips. In both years, most males were caught from *A. fistulosum* (cv. Kroll), which was the cultivar most infested by this species. Its sex ratio on this cultivar was 97% in 2015 and 98% in 2016. On cultivars of *A. cepa*, the sex ratio of *F. intonsa* was similar on all cultivars and ranged from 96.4% to 98.9% in 2015 and from 97.7% to 99.6% in 2016 (Table 4).

In contrast to *T. tabaci* and *F. intonsa*, males of predatory *A. intermedius* were less numerous in 2015, and only single individuals (from two to four) were collected from four cultivars of *A. cepa* (Alibaba, Karmen, Polanowska and Wenta) and five males from cv. Kroll (*A. fistulosum*). Its mean sex ratio on *A. cepa* was 93.6%, while on *A. fistulosum*, it was 87.5% (Table 4). In 2016, from all cultivars infested by *A. intermedius*, 178 males were collected; the mean sex ratio was 76.05% on cultivars of *A. cepa* and 84.7% on cv. Kroll of *A. fistulosum* (Table 4).

Seasonal fluctuation of the most abundant three species

The seasonal fluctuations of *T. tabaci*, *F. intonsa* and *A. intermedius* throughout the three growing seasons (2014–2016) are shown in Figures 1–3.

As shown in Figure 1, in June, among the most numerous species *T. tabaci* and *F. intonsa*, the percentage share of onion thrips on cultivars of *A. cepa* ranged from 45.5% (cv. Alibaba) to 100% (cv. Tęcza). In turn, cv. Kroll (*A. fistulosum*) was at that time only colonised by *T. tabaci*. In the first half of July, *T. tabaci* was the dominant species on all tested cultivars of *A. cepa*, while on *A. fistulosum*, the dominant species was *F. intonsa*, accounting for 69.4%. From mid-July to the end of August, *T. tabaci* accounted for 25.0–87.5% on the onion cultivars, while its share on Welsh onion was low and did not exceed 11.5%. The predatory *A. intermedius* was recorded from the beginning of

June, and its percentage share on all tested cultivars ranged from 1.7% to 15.8%. Only in the second half of August, its share on cv. Niagara F₁ was much higher and amounted to 50.0%.

In June 2015, most of the tested onion cultivars were colonised only by *T. tabaci*, with the exception of cv. Polanowska, Tęcza and Kroll, on which this species accounted for 71.4%, 50.0% and 80.0%, respectively (Figure 2). In July (especially in the second half), the share of *F. intonsa* increased on *A. cepa* from 18.4% (cv. Kristine) to 44.0% (cv. Polanowska) and to 63.5% on *A. fistulosum*. In August, in all cultivars of *A. cepa*, the ratio of the number of both species was reversed, and *T. tabaci* was again the most abundant taxon. On *A. fistulosum*, the share of onion thrips was 36.2% and 59.4%, respectively, in the first and second half of August. Similar to the previous year, *A. intermedius* was caught from the beginning of July to the end of August, mostly from all tested cultivars, and in July, its share in the collected material did not exceed 4.2%, while in August it reached 7.0% (Figure 2).

In June 2016, *T. tabaci* occurred in greater percentages on all tested cultivars (from 61.3% on cv. Alibaba to 94.1% on cv. Tęcza) (Figure 3). This species was also most abundant in July and constituted >50%, except on the cv. Kroll. In August, its percentage share of *A. cepa* ranged from 37.0% (cv. Bila) to 75.0% (cv. Tęcza). The share of *F. intonsa* was the highest on *A. fistulosum*, and in the second half of July, it was as high as 65.9%. From mid-July, an increase in the *A. intermedius* percentage was noticed, with the highest level on the cv. Tęcza in the first half of August (43.8%) (Figure 3).

DISCUSSION

The obtained results indicate that *A. fistulosum* and *A. cepa* plants are colonised by six to nine thrips species throughout the growing season, primarily by the suborder Terebrantia and the family Thripidae. Two herbivorous (*T. tabaci* and *F. intonsa*) and one predatory (*A. intermedius*) species together accounted for over 97% of the material collected from onion and Welsh onion plants throughout 3 years. *T. tabaci* was the most abundant species on all tested cultivars of onion, the second most numerous was *F. intonsa*, while the opposite ratio was noticed on Welsh onion. The participation of thrips species differed by years and both species of *Allium*. The mean share of *T. tabaci* in the total collection of sampled thrips from *A. cepa* ranged from 60.5% to 68.8%, while for *F. intonsa* it was lower and accounted from 23.5% to 32.7%. In turn, in material collected from *A. fistulosum*, the share of onion thrips ranged from 10.6% to 44.1%, while for flower thrips it accounted from 42.4% to 86.4%. Also, Pobożniak et al. (2016) found that the population of *T. tabaci* in onion crops may vary depending on the year, and the share of this species on onions crops can range from 34% to 68%, while for *F. intonsa*, it can range from 29.8% to 58.0%. Onion thrips predominated, accounting for 82.6% to 84.9%

of the thrips on onion in Colorado (USA) (Mahaffey and Cranshaw, 2010). In Texas (USA), according to Bender and Morrison (1989) and Doederlein and Sites (1993), the species composition of thrips on onion is dominated by the western flower thrips (*Frankliniella occidentalis* Pergande) and by onion thrips. Sparks et al. (2011) reported that key arthropod pests on onions in Georgia (USA) are tobacco thrips (*Frankliniella fusca* Hinds), western flower thrips and onion thrips, which represented 49.9% of all detected thrips. The species *T. tabaci* is a major pest and predominant on onion fields in Europe (Hudák and Péntzes, 2004; Diaz-Montano et al., 2011; Gill et al., 2015; Pobożniak et al., 2016), the United States (Macintyre-Allen et al., 2005; Smith et al., 2016), Asia (Pandey et al., 2011; Reitz et al., 2011; Li et al., 2014), Australia (Herron et al., 2008), New Zealand (Martin et al., 2006) and Africa (Maniania et al., 2003). In addition to onion, onion thrips may attack garlic and leek (Afifi and Haydar, 1990; Theunissen and Schelling, 1998; Duchovskienė, 2006; Akhtari et al., 2014) and other vegetables, such as cauliflower, cabbage, pea, cucumber and carrot (Farrugia, 1997; Pourian et al., 2009; Li et al., 2014; Pobożniak et al., 2020; Silva et al., 2020). Notably, the extent and frequency by which onion thrips damage crops vary across plant species, but onion is its preferred host and the most damaged crop. Also, *F. intonsa* has been determined in Poland on the onion by Pobożniak et al. (2016) and on leek by Legutowska and Theunissen (2003). This species is mainly associated with flowering plants and is the dominant species in legume field crops such as peas, beans, soybeans, lentils and lupine in Poland (Pobożniak, 2011; Hurej et al., 2014; 2015). There is no information in the literature on the possibility of *F. intonsa* feeding on onion plants. The author's own observations, however, suggest that this species is not likely to feed on onion, and the presence of *F. intonsa* specimens on onion at least partially may be due to the presence of many flowering plants in the vicinity of the experimental plots. However, Hazir et al. (2011) discussed the possibility of this species feeding on organs other than the flowers. The authors report that *F. intonsa* feeding on ovary tissue caused brown blemishes and scars on nectarine fruit, and feeding on mature fruit caused whitish skin patches called silvering. Also, Murai (1988) noted that swollen white spots were produced as a result of this species feeding on tomato fruits. Moreover, Molnár et al. (2008) observed that in addition to *T. tabaci* and *F. occidentalis* also *F. intonsa* feeds on pepper and can also spread the tomato spotted wilt virus (TSWV) with the same efficacy as the other two species. The very high abundance of *F. intonsa* on onion and the observations of the cited authors indicate a potential possibility of this species feeding also on onions, but this issue requires further clarification.

The predatory *A. intermedius* was a less abundant species and accounting for about 4.5% of all species on *A. cepa* and 2.9% on *A. fistulosum*. Similarly, Pobożniak et al. (2016) found about 5% of *A. intermedius* on *Allium* sp. The appearance of this predatory thrips species

was noticed on *A. fistulosum* in Ljubljana (Trdan et al., 2005). In turn, Ábrahám (2012) observed about 9% of this taxon on alfalfa, and Pobożniak et al. (2020) registered about 8.6% on peas, with the first maximum appearance during the flowering and the second during forming pods phases, when the number of potential victim, onion thrips, was the highest. The occurrence of *A. intermedius* in the flowers of many plants may be due to the fact that pollen can be used as an alternative source of food by this species (Trdan et al., 2005; Conti, 2009). In Europe, *A. intermedius* has usually been mentioned as a predator of onion thrips (Franco et al., 1999). In our experiment, the percentage share of predatory thrips increased on the onion plants from mid-July. In our opinion, *A. intermedius* certainly limited the number of onion thrips on onion plants. However, despite its presence, the numbers of herbivorous onion thrips were so high that they caused damage to the onion leaves. Also, Pobożniak et al. (2020) and Ábrahám (2008) noted that the number of *A. intermedius* was insufficient to reduce the population of phytophagous thrips in pea and soybean. Other species associated with flowers (*Thrips flavus*, *Thrips fuscipennis*, *Haplothrips leucantemi* and *Haplothrips niger*) and mainly with grasses (*Chirothrips hamatus*, *Chirothrips manicatus* and *Haplothrips aculeatus*) were observed on *A. cepa* and *A. fistulosum* in small numbers. They have also been found in small amounts on onion by Pobożniak et al. (2007), on leek by Legutowska and Theunissen (2003) and on cabbage by Fail and Péntzes (2004) and their presence was accidental and resulted from the neighbourhood of flowering plants and cereals.

The species *T. tabaci* can reproduce asexually (parthenogenesis) and sexually. The most common reproductive mode is thelytoky, a parthenogenesis in which females are produced from unfertilised eggs. Onion thrips also reproduce via arrhenotoky, a parthenogenesis in which males are produced from unfertilised eggs and females from fertilised eggs. Onion thrips that reproduce via thelytoky differ genetically and ecologically from those that reproduce via arrhenotoky (Toda and Murai, 2007). According to Kobayashi et al. (2013), in some instances, arrhenotokous and thelytokous onion thrips populations can coexist in the same field, but it is difficult to distinguish between thelytokous and arrhenotokous female adults morphologically (Jenser and Szénási, 2004). On onion, arrhenotokous *T. tabaci* performed better than thelytokous form and produced more progenies, while on cabbage, the opposite occurred (Li et al., 2014). In our experiment, both females and males of *T. tabaci* were found on *A. cepa* and *A. fistulosum*, and the average sex ratio on all tested onion cultivars was about 99.5% and 99.9% in 2015 and 2016, respectively, and 99.3% and 100% on Welsh onion in subsequent years. Different sex ratios on onions crops, garlic and leeks have also been confirmed by Torres-Vila et al. (1994) in Spain. Both females and males of *T. tabaci* were found also by Bosco and Tavella (2010) on leek under field conditions in northwest Italy. In the Netherlands, the male/female ratio of onion

thrips on leek was 1:26 (Vierbergen and Ester, 2000). In turn, in Ontario (USA), Macintyre-Allen et al. (2005) did not notice the presence of *T. tabaci* males on onion crops. According to Jenser and Szénási (2004), the rare occurrence or absence of male *T. tabaci* is associated with the geographical area from which the host plants originate, including onions and leeks. Their area of origin is Central Asia and the eastern Mediterranean region; *T. tabaci* has been introduced in moderate climate zones, which is likely to explain the absence of males (Jenser and Szénási 2004).

In the case of *F. intonsa*, the average sex ratio on onion cultivars and Welsh onion was nearly the same and accounted for 97.8% and 97.0% on *A. cepa* and 97.0% and 98.0% on *A. fistulosum* in 2015 and 2016, respectively (Table 4). In a population of *F. intonsa* in flowers of food legume plants, participation of males was even higher, with a sex ratio of over 79% Pobożniak (2011). Hurej et al. (2015), in their analysis of thrips settlement on both forms of *Andean lupine*, pointed out that in the case of flower thrips, the morphological form of the plant did not affect the occurrence of male thrips, and the calculated sex ratio was 86.2%.

Mautino et al. (2014) noted that the adult population of *A. intermedius* consists of both female and male zoophages. In our experiment, the sex ratio of this species on *A. cepa* and *A. fistulosum* was about 96.8% and 79.0% on onion and about 87.5% and 84.7% on Welsh onion in 2015 and 2016, respectively (Table 4). Hurej et al. (2017) reported that the sex ratio of *A. intermedius* on linseed ranged from 61.5% to 77.1%, but never exceeded 80%. In turn, on peas, beans, lentil, French beans or soya beans, the percentage of males in the population of *A. intermedius* was lower, and the sex ratio ranged from 82.4% to 89.6% (Pobożniak, 2011).

The relationship between populations of the most numerous species *T. tabaci*, *F. intonsa* and *A. intermedius* changed in the subsequent months of the growing season. In June 2014 and 2015, only *T. tabaci* and *F. intonsa* occurred on onion plants, while in 2016, also a small number of the predatory *A. intermedius* was observed. From July, the percentage shares of *F. intonsa* and predatory *A. intermedius* in the thrips populations on many onion cultivars increased, most likely because of the presence of many flowering plants near the experimental plots and the growing population of *T. tabaci* on onion plants, potential *A. intermedius* prey. Pobożniak et al. (2007; 2016) reported that the peak flight activity of thrips on onion crops in South Poland took place from the beginning of July to the beginning of August and was slightly earlier than that reported for Germany (Richter et al., 1999). In turn, in North Italy, the peak population of onion thrips was reached in September (Bosco and Tavella, 2010), while in South Texas (USA), it peaked in April (Liu, 2004).

Differences in the infestation levels of thrips between the all tested onion cultivars were observed in successive years. In all 3 years of the study, the cultivar most populated by thrips specimens was cv. Kroll (*A. fistulosum*), on which the number of *F. intonsa* was

8 and 1.5 times as high compared to *T. tabaci* in 2014 and 2015, respectively, while the numbers of both species in 2016 were similar. The number of thrips caught from the *A. cepa* cultivars was about from 2 to 3 times lower compared to the thrips population on Welsh onion (cv. Kroll). However, the number of *T. tabaci* on cultivars of *A. cepa* was always higher than that of *F. intonsa*. In the case of some cultivars, the number of *T. tabaci* was even about 3, 5 or 8 times as high compared to *F. intonsa* or was almost the same. In turn, Pobożniak et al. (2016) found that in some years, onion thrips inhabited Welsh onion more frequently compared to onion cultivars. The tested onion cultivars demonstrated varying degrees of attractiveness to thrips species and underwent changes in the subsequent years. The level of attractiveness of onion cultivars related to *T. tabaci*, which is reported as a main pest of onion, varied depending on the year and cultivar. The differences in thrips infestation of the studied cultivars are caused by a number of factors, and clarifying them requires further research. Presumably, factors affecting the colonisation of cultivars by *T. tabaci* were their biochemical and morphological features, influencing the vision, taste and smell senses of thrips, and could be responsible for antixenosis and antibiosis (Smith, 2005; Trdan et al., 2008b; Diaz-Montano et al., 2012; Silva et al., 2014).

CONCLUSIONS

1. In the 3 years of the study, nine species of Thysanoptera were identified on *A. cepa* and *A. fistulosum*. Irrespective of the cultivar of *A. cepa*, *T. tabaci* was the most dominant species, but *F. intonsa* also occurred in high numbers. Conversely, *A. fistulosum* was most often inhabited by *F. intonsa*, although *T. tabaci* was also highly abundant. The predatory *A. intermedius* was among the most numerous species.
2. Of the most numerous species, *T. tabaci* and *F. intonsa*, in each cultivar of *A. cepa* and *A. fistulosum*, populations were formed mainly by females. In the population of *A. intermedius*, males occurred in greater numbers than in the two previously mentioned species.
3. The relationship between populations of the most numerous species *T. tabaci*, *F. intonsa* and *A. intermedius* changed in the subsequent months of the growing season. In June, mainly *T. tabaci* and *F. intonsa* occurred on onion plants, while from July, the percentage shares of *F. intonsa* and the predatory *A. intermedius* in the thrips population on many onion cultivars increased. Throughout the experimental period, the onion cultivar most colonised by thrips was cv. Kroll of *A. fistulosum* in comparison to all tested cultivars of *A. cepa*. The tested cultivars of *A. cepa* demonstrated varying degrees of attractiveness to thrips in the subsequent years.
4. The level of attractiveness of *A. cepa* related to onion thrips, which is reported as a main pest of onion, varies depending on the year and cultivar. The cultivars with higher colonisation rates were Polanowska and Karmen, while the less populated ones were cvs. Tęcza, Bila and Kristine.

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AUTHOR CONTRIBUTIONS

M.O. and M.P. contributed equally to the experimental design, analytical measurements and manuscript writing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPLEMENTARY MATERIALS

Table S1. Total number and percentage share of thrips species (Thysanoptera) (imago and larvae) collected from *Allium cepa* (mean % for eight tested cultivars) and *Allium fistulosum* (one cultivar) directly from plants in 2014–2016.

Species/year	<i>A. cepa</i>						<i>A. fistulosum</i>		
	2014		2015		2016		2014	2015	2016
	Min–max*	Mean	Min–max	Mean	Min–max	Mean	Mean		
<i>Thrips tabaci</i> Lindeman, 1889	38.24–61.19	51.23	71.96–81.50	78.35	71.53–81.30	76.45	20.11	49.92	40.20
<i>Frankliniella intonsa</i> Trybom, 1895	16.54–41.26	32.17	16.38–25.18	19.84	3.5–20.05	19.36	72.06	49.20	44.64
<i>Aeolothrips intermedius</i> Bagnall, 1934	1.42–19.17	9.69	0.46–2.31	1.49	1.75–3.50	3.73	5.46	0.48	6.14
<i>Chirothrips hamatus</i> Trybom, 1895	–	–	0.00–0.28	0.10	0.00–0.57	0.10	–	0.20	1.11
<i>Chirothrips manicatus</i> Haliday, 1836	–	–	–	–	0.00–0.41	0.07	–	–	0.69
<i>Haplothrips aculeatus</i> Fabricius, 1803	0.00–2.13	1.51	0.00–0.17	0.05	0.00–0.99	0.23	–	–	3.55
<i>Haplothrips leucantemi</i> Schrank, 1781	0.00–3.57	1.41	–	0.03	–	–	0.52	–	0.22
<i>Haplothrips niger</i> Osborn, 1883	–	–	0.00–0.15	–	–	–	–	0.20	–
<i>Thrips flavus</i> Schrank, 1776	0.00–9.75	3.99	–	–	–	–	1.85	–	0.06
<i>Thrips fuscipennis</i> Haliday, 1836	–	–	0.00–0.46	0.14	0.00–0.31	0.06	–	–	3.39
Total number	–	629	–	3999	–	2270	153	659	314

*Min–mean percentage of thrips on onion cultivar with the lowest percentage share; max–mean percentage of thrips on onion cultivar with the highest percentage share.

Table S2. Total number and percentage share of thrips species (Thysanoptera) (imago and larvae) collected from *Allium cepa* (mean% for eight tested cultivars) and *Allium fistulosum* (one cultivar) using sweeping net in 2014–2016.

Species/Year	<i>A. cepa</i>						<i>A. fistulosum</i>		
	2014		2015		2016		2014	2015	2016
	Min–max*	Mean	Min–max	Mean	Min–max	Mean	Mean		
<i>Thrips tabaci</i> Lindeman, 1889	46.63–78.91	63.60	60.58–70.40	65.08	47.54–74.36	60.68	10.69	37.90	40.19
<i>Frankliniella intonsa</i> Trybom, 1895	14.31–49.64	31.58	27.08–37.92	32.04	7.70–17.09	22.09	87.49	60.82	44.63
<i>Aeolothrips intermedius</i> Bagnall, 1934	14.31–49.64	2.44	27.08–37.92	2.36	7.86–17.09	12.85	1.38	1.02	6.69
<i>Chirothrips hamatus</i> Trybom, 1895	–	–	0.10–0.31	0.11	0.00–2.39	1.36	–	0.01	1.01
<i>Chirothrips manicatus</i> Haliday, 1836	–	–	–	–	0.00–1.89	0.64	–	–	0.69
<i>Haplothrips aculeatus</i> Fabricius, 1803	0.00–1.78	0.22	0.00–0.25	0.03	0.00–1.71	1.08	0.13	0.08	3.55
<i>Haplothrips leucantemi</i> Schrank, 1781	0.00–2.40	1.19	–	–	0.00–0.42	0.20	–	–	0.24
<i>Haplothrips niger</i> Osborn, 1883	–	–	0.47–1.02	0.72	–	–	–	0.1	–
<i>Thrips flavus</i> Schrank, 1776	0.31–2.12	0.97	0.00–0.76	0.10	0.00–0.21	0.03	0.31	–	0.06
<i>Thrips fuscipennis</i> Haliday, 1836	–	–	0.00–0.28	0.07	0.00–1.61	1.07	–	0.07	2.23
Total number	–	2230	–	10901	–	5097	779	3891	2144

*Min–mean percentage of thrips on onion cultivar with the lowest percentage share; max–mean percentage of thrips on onion cultivar with the highest percentage share.