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PhD thesis

The elements of environmentally friendly thrips control in forced pepper

by
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I. INTRODUCTION AND RESEARCH OBJECTIVES

In the last decade, the importance of investigating integrated pest management (IPM) technologies and introducing the new research results into horticulture has gradually increased. This is consistent with the increasing global demand for integrated plant production. Therefore, studying the changes in plant production technologies is inevitable so as to reveal those elements which may lead to new plant health problems and which should be environmentally friendly controlled.

The profitability of forced pepper production in Hungary is determined primarily by the effective control of the western flower thrips (*Frankliniella occidentalis* Pergande, 1895). The damage of this pest is confined to the young leaves initially, but later on the specimens climb and start feeding on the new growth, and finally they get into the buds. On the fruit, the thrips larvae hide under the calyxes where they contact the fruit, and the specimens cause a damage symptom well visible on the skin and called "flecking" by feeding. This damage might be so serious that the fruits completely become unmarketable. The pest can cause an especially significant yield loss in early vegetable growing. The main goal of domestic pepper forcing is to meet the Hungarian consumers' demands. The conical, white-fleshed pepper cultivars are the most favoured in the Hungarian market, however, according to former studies, these cultivated varieties may be the most severely damaged by the western flower thrips. Besides the direct damage caused by sucking, the western flower thrips can also spread viral diseases of which the tomato spotted wilt virus (TSWV) has become one of the most significant diseases of pepper.

The most popular forced pepper cultivars were developed by Hungarian breeders, who carry out a high quality work. The value of new hybrids could be increased considerably if they were resistant to the direct damage of the western flower thrips. To reach this aim, the investigation of presently grown pepper cultivars considering their susceptibility to the western flower thrips is required.

In Hungary, about 50 ha of forced pepper is under biological pest control, and the target pest is almost exclusively the western flower thrips. For the required enlargement of this surface, new

research results on the susceptibility of pepper cultivars to the western flower thrips are necessary. These could contribute to the implementation of the most effective biological control method of the pest in the case of forcing a given cultivar. Therefore, my main research objectives were to examine the susceptibility of commonly used pepper cultivars to the western flower thrips, to find the reasons of differences in susceptibility, and to study the possibilities of changings in growing conditions in order to increase the efficacy of pest control. Furthermore, I planned to get acquainted with the beneficial arthropods controlling the populations of *Frankliniella occidentalis* in pepper by surveying the arthropod assemblages and rearing the natural enemies.

II. MATERIALS AND METHODS

Conditions of the examinations

Samples were taken at Ráckeve and Soroksár between 2007 and 2009. At Ráckeve, the research was carried out in a high-roof, heated greenhouse of 3000 m², where conical and white-fleshed Hó F1 and green, tapered and hot Titán F1 and Keceli F1 cultivars were grown on rockwool medium in long culture. The plants were set in two rows, spaced apart to a density of 4 plants per square meter and were trained to two stems. Arthropod predators were released as a basic control method of pests in the greenhouse, but additional applications of insecticides were also needed in all the three years. The predatory mite, *Amblyseius cucumeris* and the flower bug, *Orius laevigatus* were released against thrips species. During the trials, the temperature and the relative humidity inside the greenhouse were measured by digital instruments placed among the plants.

At Soroksár, the experiments were carried out in two different greenhouses of the Research and Experimental Farm of the Corvinus University of Budapest. In 2007 and 2008, fifteen pepper cultivars were grown in an unheated ‘Soroksár-70’ type greenhouse, which was 7.5 m wide and 30 m long. The cultivars grown were the following: Apollo, Brillant, Cecil, Century, Cheops, Creta, Emese, Hajdú, Hó, HRF, Julianus, Kaméleon, Kincsem, Rimava, Táltos.

Pepper plants were set in two rows and pruned to a single stem, and 6 plants were set per square meter. The plants were in containers. Drip irrigation was used, and the nutrient solution was added once or twice a week. Insecticides against pest thrips were not applied at all during the trials. In 2008 and 2009, trials were also set in a FILCLAIR greenhouse of 1500 m² under conditions of 'emergency heating' (Δt = 5°C) at the Experimental Farm. Twelve plants per cultivar were planted out on rockwool slabs in two rows, trained to two stems, and 4 plants were set per square meter. Besides the cultivars which were set in the 'Soroksár-70' type greenhouse, Balaton was also evaluated in 2008, but in 2009, only Cecil, Century, Hajdú, Hó, HRF, Kaméleon and Táltos were evaluated at this place. Conventional chemical pest control was applied. Broad-spectrum insecticides were used against pest thrips once a week initially and three or four times a week later.

Comparison of the cultivars set in the 'Soroksár-70' type greenhouse regarding the quantity and quality of the yield

In 2007, fruits were picked 8 times between July 9 and October 19 and, in 2008, 7 times between June 30 and October 13. Yield quantity per cultivar was measured in each case. In 2008, the fruits of the different cultivars were grouped in four classes based on the size: extra, 1st class, 2nd class and substandard. 5-5 fruits from each class were chosen, and the length and width of them were measured, too.

Study on the arthropod assemblages present in the pepper flowers

The study on the arthropod assemblages was carried out by the same method in the cases of all the three greenhouses. Flowers were put into vials containing 70% ethyl alcohol in the way that no arthropods could escape during picking the flowers.

50 flowers of each cultivar were collected at Ráckeve in every second week during the three years. In 2008, the number of flowers was also recorded during the samplings. In order to observe thrips species and their predators established spontaneously, 40-40 flowers of each cultivar were collected in the 'Soroksár-70' type greenhouse at Soroksár two times in 2007, while in 2008, 40 flowers of each cultivar were collected during the first sampling and only 10 on the second

occasion. In the FILCLAIR greenhouse, 20 and 25 flowers were collected during the two samplings in 2008, while in 2009, 40 flowers were collected on one occasion.

In the laboratory, the collected mites and thrips were mounted on separate slides for each flower using a stereomicroscope. Predatory mites were identified based on the key of Karg (1993), and thrips species were identified using the keys of Moritz et al. (2001) and Jenser (1982). Thrips larvae were identified to the family level using the key of Dr. Sueo Nakahara (unpublished). Adults of collected bugs were determined by the identification book of Péricart (1972).

Evaluation of pepper cultivars regarding their resistance to thrips

a) Evaluation of pepper cultivars regarding the number of thrips found in the flowers

The study was carried out using the data of the flower collections. The species within the family Thripidae were not separated in this case. There were two methods: the number of adults and larvae counted together, and the number of adults counted separately. The data of the single evaluations which were carried out in the same year were analysed together.

b) Evaluation of pepper cultivars regarding the damage on fruits caused by thrips

The degree of damage caused by thrips in the 'Soroksár-70' type greenhouse was assessed two times in 2007 using 40 fruits of each cultivar. All the data were analysed together. In 2008, 40 fruits of each cultivar were evaluated in this greenhouse on only one occasion, but living pepper leaves were fixed to this fruits two weeks before the evaluation to provide refuge for thrips. The extent of the damaged area appearing under the leaf was expressed as a percentage of the whole covered surface. Using the same method (covering with leaf), evaluations were carried out in the FILCLAIR greenhouse on 1-1 occasion in 2008 and 2009.

c) Evaluation of pepper cultivars regarding the number of thrips larvae found on the fruits

The study was carried out in the FILCLAIR greenhouse in 2009. Living pepper leaves were fixed to 40 fruits per cultivar two weeks before the evaluation. For the evaluation in the laboratory, the fruits with the leaves were collected by cultivar in plastic bags. In the laboratory, the leaves were carefully detached from the fruits, and the thrips larvae under the leaves were counted with the help of a magnifier.

Statistical analysis

The distribution and variance of the data was tested before the statistical analysis by Kolmogorov-Smirnov and Levene tests, respectively. If the distribution was normal with uniform variance, ANOVA was used to compare means and pairwise comparisons of the means were calculated using Tukey's HSD test. If the distribution of the data was skewed, Kruskal-Wallis test was used to compare means and pairwise comparisons of the means were calculated using Mann-Whitney U test. Correlation analysis was carried out to verification of relation between certain variables. The means and their 95% confidence intervals were plotted on graphs, on which statistically significant differences between the treatments were coded by letters. The statistical analyses were carried out by using the SPSS and Past software packages.

III. RESULTS

Evaluation of the pepper cultivars grown under unheated conditions regarding the quantity and quality of the yield

The average yield was 9.19 kg/m² but only 6.5 kg/m² in 2007 and 2008, respectively. In 2007, Hó, Cheops and Julianus gave the best results, in 2008, however, Brillant, Cecil and Century came first. The yield during the first four pickings was the highest in the cases of Hó, Apollo and Creta in 2007, while in 2008, Brillant and Cecil gave the best results. The quantity of the best priced extra and 1st class yield

was highest in Hó, Creta, Cecil, Century and Brillant. The characteristic fruit size agreed with the standard in each cultivar. The quantity of the substandard yield was the highest in the cases of Julianus, Brillant and Hó, while the yield loss was the smallest in Century, Cheops, Kincsem and Creta.

Arthropod assemblages present in the pepper flowers

In the heated greenhouse at Ráckeve, where integrated pest management was applied, a total of 11323 predatory mites, 1105 thrips and 79 predatory bugs were collected between 2007 and 2009. All of the collected predatory mites were identified as *Amblyseius cucumeris* with the exception of one specimen, which was *Garmaniella bombophila* Westerboer, 1963. The latter species was recorded for the first time in Hungary. According to my results, the number of phytophagous thrips species was considerably higher in this greenhouse in 2007 compared to the following two years when specimens were present in the pepper flowers only in very low numbers. *Thrips tabaci* (Lindeman, 1889) and *Frankliniella intonsa* (Trybom, 1895) were the dominant pest thrips species in all the three years, while the most harmful pest of forced pepper, *Frankliniella occidentalis* could not be found here in either year. In spite of introduction attempts of *Orius laevigatus* (Fieber, 1860) to the greenhouse repeated three times in 2007, adults of the species could not be found in the pepper flowers. Even in the following two years, this species could be collected from the pepper flowers only in very low numbers. During the vegetation period, further predatory bugs established spontaneously in the forced pepper, and the dominant species was *Orius niger* (Wolff, 1811) among them.

In the greenhouse, where insecticides against pest thrips were not applied at all during the trials, adults of 8 thrips species were collected between 2007 and 2008. Specimens of *Frankliniella occidentalis*, *F. intonsa* and *Thrips tabaci* belonging to the family Thripidae were found in the highest numbers. Adults of the other three Thripidae species (*Thrips flavus* Schrank, 1776, *T. atratus* Haliday, 1836 and *T. physapus* Linnaeus, 1758) were found only occasionally in the pepper flowers. However, about half of the collected adults were identified as *Frankliniella occidentalis* in both years. Among the

spontaneously established predatory bugs *Orius niger* was the dominant species. Predatory mites belonging to the family Phytoseiidae were present in high numbers in the pepper flowers, and *Amblyseius andersoni* (Chant, 1957) was the dominant species. On average, more than 4 predatory mites per flower were found in September, 2008. Most of them were *A. andersoni*.

In the greenhouse under conditions of 'emergency heating', where conventional chemical pest control was applied, the population of the western flower thrips increased considerably in spite of the regular treatments with insecticides. Moreover, the beneficial arthropods were not present in the pepper flowers at all.

Population changes of beneficial arthropods introduced against thrips species in forced pepper

The mean numbers of *Amblyseius cucumeris* specimens per flower were very similar comparing the vegetation periods. The predatory mites were found in high numbers through 6–7 weeks after their introduction, but there was a drastic decrease later probably as a consequence of the unfavourable relative humidity conditions in the greenhouse. This coincides with the data found in different publications which show that the mean numbers of predatory mites in pepper flowers decrease when the period with relative humidity under 70% increases. On the other hand, it should be emphasized that the changes in the population density of *A. cucumeris* during the vegetation period depend not only on the varying relative humidity but also on other factors, e.g. the number of flowers on pepper plants.

The establishment of *Orius laevigatus* in the greenhouse was elongated. Throughout the growing season in 2007, native predatory bugs coming spontaneously from outside were only found in the pepper flowers, while in the following two years, the introduced *Orius laevigatus* became the dominant species. In 2008, the number of predatory bugs increased considerably between the end of July and the beginning of August, but in 2009, the population increase could not be observed. According to my results the temperature inside the greenhouse was favourable for the introduced predatory bug, *Orius laevigatus*, as averagely 21–24 days were enough for the species to reach the adult stage in a generation.

Resistance of the pepper cultivars to thrips

a) Evaluation of pepper cultivars regarding the number of thrips found in the flowers

Under unheated conditions in 2007, thrips were found in the highest numbers in the flowers of Hó and HRF, in the cases of which nearly 5 specimens per flower on average could be found. Compared to these, the mean number of thrips per flower was between two and three in the case of each cultivar with the exceptions of Emese, Julianus and Creta. Nevertheless, in the flowers of Kaméleon and Hajdú less than two specimens on average were found. In 2008, less than two specimens per flower on average could only be found. As the differences among the cultivars were uncertain in this case, these data were not taken into consideration when evaluating the resistance.

In the greenhouse under conditions of 'emergency heating', numbers of the western flower thrips were considerable, more than 11 specimens (adults and larvae together) per flower on average could be found in 2008. This year, 4 thrips per flower could be found in the flowers of Rimava and Táltos. Compared to these, the mean number of thrips per flower was over 8 in the case of each cultivar with the exceptions of Hajdú, Cecil and Brillant. The difference was significant according to statistical analysis. In 2009, thrips were found in the highest numbers in the flowers of Hó and HRF, in the cases of which nearly 8 specimens per flower on average could be found. Compared to these, the mean number of thrips per flower was below 4 in the cases of Táltos, Kaméleon and Hajdú.

b) Evaluation of pepper cultivars regarding the damage on fruits caused by thrips

In 2007, in the unheated greenhouse, where plants were pruned to a single stem and hence airy conditions were provided, thrips caused less damage to the pepper fruits. Nevertheless, there were considerable differences among the cultivars. The highest extent of damage on the fruits (about 0.5% per fruits) was measured in Hó and HRF. Compared to these, less damage was measured in the cases of Táltos, Rimava, Emese, Kaméleon, Apolló and Hajdú. In 2008, in spite of the very low thrips population density, significant differences

could be found among the cultivars due to the fixing of living pepper leaves to the fruits (providing refuge for thrips) four weeks before the evaluation. The extent of thrips damage under the leaves was 12% of the whole covered surface in Hó and Emese. Compared to these, less damage was measured in all the cultivars with the exceptions of HRF and Century. The least extent of damage on the fruits was measured in Julianus, Hajdú and Cecil, where the extent of "flecking" under the leaves was below 5%.

In the greenhouse under conditions of 'emergency heating', the fruits of HRF, Hó and Emese were the most sensitive to the damage caused by thrips. In their case, the extent of damage under the leaves was more than 15%. Compared to these, less damage was measured in all the cultivars with the exceptions of Cheops, Creta, Kincsem and Julianus. The extent of damage was 5.6% in the green-fleshed Balaton and, among the white-fleshed cultivars, 5.9% in Táltos. In 2009, the extent of damage under the leaves reached almost 30% of the whole covered surface in Hó, while it remained below 7% in Táltos, Kaméleon and Cecil.

c) Evaluation of pepper cultivars regarding the number of thrips larvae found on the fruits

More than three and two thrips larvae on average were found on the surface of the fruits covered by pepper leaves in Hó and HRF, respectively, while less than one larva on average was found in Táltos, Kaméleon, Century and Cecil. The difference was significant according to statistical analysis. According to correlation analysis there is a close relation between the number of thrips larvae under the leaves and the extent of damage appearing under the covered surface (Pearson's correlation coefficient: $r = 0.963$).

IV. NEW SCIENTIFIC RESULTS

1. It has been established that the relative dominance of thrips species occurring regularly in forced pepper (*Frankliniella occidentalis*, *Thrips tabaci*, *Frankliniella intonsa*) is determined primarily by the plant protection technology. In the case of conventional pest control when broad-spectrum insecticides are applied, the western flower thrips will become the dominant species.

2. 6 predatory mites species (*Garmaniella bombophila*, *Blattisocius tarsalis*, *Amblyseius andersoni*, *Neoseiulus agrestis*, *Anthoseius pirianykae*, *Amblyseius barkeri*) have been collected from forced pepper in Hungary for the first time.

3. It has been established that the populations of *Amblyseius andersoni* originating from the natural fauna and occurring in forced pepper could largely increase, and they could also control the populations of phytophagous thrips species if pesticides not harmful for predatory mites were applied.

4. It has been established that significantly more thrips were found in the flowers of Hó and HRF compared to Hajdú, Kaméleon, Rimava and Táltos.

5. It has been established that among the 16 examined cultivars the fruits of Hó, HRF and Emese were sensitive to the damage caused by thrips. Contrary to these cultivated varieties, the white-fleshed Apollo, Brillant, Rimava, Cecil and Táltos, the greenish-white-fleshed Kaméleon and Hajdú and the green-fleshed Balaton showed the highest resistance to the damage caused by the western flower thrips. Considering all the examined plant characteristics like yield quality and productivity, besides the resistance to thrips, Cecil could be recommended for forcing in less modern, unheated plastic tunnels.

V. DISCUSSION

Effect of the growing technology on the arthropod populations present in pepper flowers

Faunistic survey of arthropods living in pepper flowers was carried out in three greenhouses, where the applied growing technologies differed from each other basically. In the heated greenhouse at Ráckeve, where integrated pest management was applied, specimens of the western flower thrips were not found in any years, while in the greenhouse under conditions of 'emergency heating' at Soroksár, where conventional chemical pest control was applied, only this species was found. Significantly more *Frankliniella occidentalis* adults were collected from pepper flowers here than in the other greenhouse, where insecticides against pest thrips were not applied at all during the trials. The exact reason for this is not known, however, the intensive fertilizer application and the balanced climatic conditions due to the ventilation, vaporization and shading controlled by an automatic system, and the high-roof form of the greenhouse could play a significant role in it. The hiding thrips found favourable refuge in the dense stock of plants (8 plants/m²) with thick foliage and a lot of flower and fruit. Therefore, the efficacy of the insecticide applications might decrease. Higher infestation of the pest was observed in flower samples in this greenhouse, and damage on the fruits was also more frequent and severe. The beneficial arthropods controlling thrips were totally absent from the pepper flowers probably due to regular application of broad-spectrum insecticides, but in the greenhouse, where insecticides against pest thrips were not applied at all, spontaneous establishment and increase of populations of Phytoseiid predatory mites could be observed. In my opinion, the spontaneous appearance of predatory bugs and especially predatory mites originating from the local fauna could play a significant role in suppressing thrips, especially the western flower thrips, which cause damage to forced pepper, if available pesticides are used thoughtfully and appropriately.

Discussion of the results of the biological control of thrips based on the data of trials in the greenhouse under integrated pest management

Monitoring the population dynamics of the predatory mite *Amblyseius cucumeris* and the predatory bug *Orius laevigatus* I found that predatory mites provided good control of phytophagous thrips species only in the first half of the forcing period in all the three years, while numbers of the predatory bug increased only in the second half of the forcing period. Although the predatory bugs could not build up a large population in either year, the number of thrips remained below the economic damage threshold (1 thrips/flower) in 2008 and 2009, too. I think that the reasons for this were both the presence of predatory bugs and the application of insecticides. Insecticide treatments for the control of aphids and thrips must be taken into consideration in case of studying the population dynamics of the arthropods during the vegetation periods. The active substance acetamiprid sprayed out in the spring of 2007 significantly reduced the number of thrips specimens, but it did not harm the predatory mites. It can be supposed, however, that this treatment eradicated the earlier introduced predatory bugs. The following two chemical treatments were directed decidedly against the thrips species. As a result of the treatments with dichlorvos, predatory mites almost completely disappeared from the greenhouse. The *Orius* species collected during the vegetation period settled in the greenhouse from the natural fauna. In 2008 and 2009, pymetrozine against aphids and spinosad against thrips were applied, which active substances are harmless to *A. cucumeris*, but, according to many sources, are harmful to predatory bugs. In my opinion, the predatory bugs would have been able to build up a large population in the greenhouse in case of avoiding the use of chemical insecticides, and hence they would have been able to suppress the increase of thrips populations.

Discussion of the resistance of pepper to thrips based on the results of trials in the unheated greenhouse and in the greenhouse under conditions of 'emergency heating'

The assessment of pepper cultivars regarding their resistance to thrips was based on three criteria. On the one hand, I examined the number of thrips in flowers as well as on the surface of pepper fruits covered by leaves. On the other hand, I assessed the extent of damage on fruits. On the basis of the distribution of the collected Thysanoptera species, I concluded that the degree of resistance of pepper cultivars to thrips refers to that of to the western flower thrips. *Thrips tabaci* and *Frankliniella intonsa* were collected in large numbers in the unheated greenhouse only on one occasion, by the other evaluations *Frankliniella occidentalis* was the dominant species, while in the greenhouse under conditions of 'emergency heating' only specimens of the western flower thrips were collected.

Considering the thrips density in flowers I found the highest density of pest thrips on cultivar Hó and HRF, whereas Táltos and Rimava supported a much smaller thrips population. Considering the damage on pepper fruits the cultivars Hó, HRF and Emese were about equally susceptible to thrips, while the cultivars Apollo, Brilliant, Balaton, Hajdú, Kaméleon, Rimava, Táltos and Cecil were somewhat resistant to the damage caused by thrips.

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