The Thesis of the PhD dissertation

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Analysis of the effect of different agrotechnological elements on arthropods occurring in field chili pepper

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1. Background of the work and its aims

These days, globalization gives the opportunity to spread international cuisine all over the world. The spicy taste is not far from Hungarian culinary customs, and it is due to this that the demand for chili peppers has increased significantly in our country as well. The target audience that enjoys chili peppers and products made from them should be served, which opens up market opportunities for producers and processors. So far, little is known about the lesser-known varieties of *Capsicum chinense*, especially about the appropriate agrotechnology, such as varietal character, irrigation, plant spacing, and their plant protection aspects. In the course of my work, I investigated this issue with regard to the pest and predatory arthropods that occur on plants and flowers.

The objectives:

1. Assessment of the arthropod assemblage of chili pepper on different cultivars with different spacing and irrigation frequency
2. Determining the abundance and seasonal dynamics of pests and natural enemies on the tested varieties and settings
3. Determining the damage of pests and yield on the studied species and settings
4. Examination of the correlation between the number of pests and natural enemies

2. Materials and methods

2.1. Setting of the experiment

The site of the study was the Plant Breeding Training and Demonstration Farm of MATE. The sowing of the pepper seeds and the raising of the seedlings were carried out with the help of the workers of the MATE Plant Growing Training and Demonstration Farm. In 2019, on March 12, and in 2021, on April 7, we sowed the seeds in Profi 2 peat planting medium in 8x13 propagation trays, which were previously treated with Polyversum containing the mycoparasitic fungus *Pythium oligandrum* at a dose of 2 kg/t. After sowing, the trays were placed in a germination chamber at a temperature of 24.2 °C. The peat was watered daily (1 l water/1 tray) in order to promote successful germination. After the seeds had germinated, we placed the trays in a foil tent. Before planting, the area was plowed to a depth of 30 cm and then cultivated. The week before planting, we spread Túkanyó poultry manure on the area.

In 2019, from the end of May to the end of June, in 2021, from the end of June to the end of July, we carried out mechanical weed control several times a week. After that, the rows closed and there was no need for regular weed control.

The planting took place on May 24, 2019 and June 25, 2021. In 2021, due to the poor germination rate of the plants and the unfavorable weather in May (constant cloud cover and rain), the size of the plots and thus the size of the entire experimental area was smaller compared to the experiment set up in 2019. With the exception of seed spraying, no chemical plant protection was applied during the entire period of the study.

In 2019, the size of the area was 28.8 m x 14.4 m, i.e. 414.72 m2. The size of a plot was 3.6 m x 3.6 m, so it had an area of 12.96 m2.

In 2021, the area was 9 m x 13.8 m, i.e. 124.2 m2. The size of a plot was 1.8 m x 1.2 m, so it was 2.16 m2.

We created 32 plots, where we used different combinations of varieties (Trinidad Scorpion Butch T and Yellow Scotch Bonnet), plant spacing and irrigation amount, in 4 replications. Irrigation was done by dripping system. In vegetable production, drip irrigation is the form of irrigation that allows for optimal application of water and nutrients, directly reducing water loss (Kirnak and Naim Demirtas 2006). According to O'Keefe and Palada (2002), the optimal row spacing for chili pepper is 61 cm, so we planted the plants at a row spacing of 60 cm.

The plots were marked with different codes. We distinguished between F1 and F2 varieties, T1 and T2 plant spacing, and Ö1 and Ö2 irrigation amounts. Based on these data, the parcels received their identifiers (e.g.: F1T2Ö1, F2T1Ö2). Due to the different plant height and habit of the Trinidad Scorpion Butch T and Yellow Scotch Bonnet varieties, we decided to have different plant spacing settings for the varieties.

2.2. Individual plant testing

Before starting the individual plant examination, ten seedlings were randomly marked with the marking label in the plots, so the same 320 plants were examined during the entire vegetation.

The individual plant testing was carried out at the following times:

2019:
10.07., 17.07., 24.07., 07.08., 21.08., 28.08., 04.09.
2021:
30.07., 04.08., 11.08., 18.08., 25.08., 13.09., 24.09.

During the recording, we inspected the entire surface of the marked plants. The leaves, shoots, stems, flowers, and fruits were carefully examined, and the different developmental stages of the phytophagous and predatory arthropods present there were recorded.

2.3. Flower testing

The flower testing was carried out at the following times:

2019:
24.07., 30.07., 07.08., 21.08., 28.08.
2021:
26.08., 13.09., 24.09., 30.09., 11.10.

To examine the pest and predatory arthropods in flowers, a total of 50 flowers were randomly collected per plot, from 10 plants (5 flowers/plant). If the number of plants per plot allowed, we did not sample the same plants as during the individual plant examination. The flowers were placed in vials with 60% propanol, coded with the plots and the date. We collected a total of 8,000 flowers during each growing season, which were examined using a stereo microscope in the laboratory of the Department of Integrated Plant Protection.

During the study, we recorded the number of larvae and adults of phytophagous thrips (Thripidae), predatory thrips (Aeolothripidae) and minute pirate bugs (Anthocoridae).

2.4. Fruit testing

In the 2019 and 2021 vegetation seasons, we collected fruit on the last sampling day (09/04/2019; 09/24/2021) for the purpose of fruit testing. The fruits were collected from the marked plants, on which individual plant tests were also carried out. The fruits from the ten plants of the given plot were collected in a bag and labeled with the code of the plot identification, then the fruits in the bags were weighed. Then we counted the fruits and determined how many of them were healthy and how many were damaged by *H. armigera*, Pentatomidae and thrips. Of course, there were fruits that had several types of damage. In this case, we recorded all damages per fruit.

2.5. Statistical analysis

The data was recorded in the Microsoft Excel program. The Excel workbooks were imported into the R Commander program. I performed the statistical analyzes and scatter plots (Scatter Plot) in R and R Commander interface (Fox 2017, R Core Team 2021). I fitted a linear model to the examined organizations. The explanatory variables were the individual settings: the varieties (F1, F2), the difference in irrigation (Ö1, Ö2) and the plant spacing setting (T1, T2), as well as the pairwise and triple interaction of these factors. Then I performed model selection based on the p values of the individual explanatory variables, so the explanatory variables with p values below 0.05 remained. In the model fitting, I performed diagram-based model diagnostics. I examined the normality of the residuals and the homoscedasticity. Based on this, I fitted a Generalized Linear Model (GLM, Poisson distribution) to the organizations that were not suitable due to the low number of individuals. For trophic tests between organisms, I calculated Pearson's correlation coefficient between the investigated groups, and then performed a hypothesis test to see if this correlation coefficient is significantly different from zero, i.e. from the case when the number of individuals in the two groups changes independently. I presented the results for which the Pearson's correlation coefficient was higher than 0.4 or lower than -0.4, and where the correlation relationship was significant ($p<0.05$). After examining the correlations, I plotted the correlations between the groups.

3. Results and discussion

During the individual plant testing in 2019, we found only 12.8% of the arthropods that occurred in 2021 on the plants. With regard to the flower examination, the data of the two years are similar, but in 2021 we found slightly more individuals. Comparing the data of the two recording methods, the number of arthropods was 80.66% more in 2021 than in 2019. Taking into account the numbers of phytophagous organisms, we found 90.1% more individuals on plants in 2021 than in 2019. Regarding the organisms leading a predatory lifestyle, the difference between the two years was smaller compared to 2021, in 2019 the predator 1/3 of arthropods were found. Examining the number of larvae and adults of phytophagous thrips, we can conclude that in 2021, more than twice as many occurred. At the same time, in the case of predatory arthropods, we found 35.2% fewer individuals in the flowers in the second study year than in 2019.

3.1. The results of individual plant testing from 2019

We found significantly more aphids in the less frequently irrigated area (Ö2) on the Yellow Scotch Bonnet (F2) variety (F:Ö $p<0.001$; Ö $p<0.001$). More frequently irrigated areas (Ö1) were chosen by significantly more ladybird females as egg-laying sites (Ö $p<0.001$). In the case of the interaction of the three factors, in the more frequently irrigated areas (Ö1), we found significantly more individuals on the Red Scorpion Butch T variety (F1) planted with a larger plant distance (T1) and on the Yellow Scotch Bonnet variety (F2) with a smaller plant distance (T2) (F: Ö:T $p=0.0281$). In the case of Asian marbled beetle adults, we found significantly more individuals in the less frequently watered plots (Ö2) (Ö $p=0.0446$).

3.2. The results of flower testing from 2019

In the case of phytophagous thrips adults, we found significantly more individuals in the less irrigated (Ö2) plots (Ö $p=0.0083$). The number of phytophagous thrips larvae was not significantly affected by the factors. A significant difference can also be detected based on the variety and the interaction of the three factors based on the number of *Orius* adults. The most individuals were found on the Yellow Scotch Bonnet variety (F2) planted with a increased plant distance (T1) and watered more often (Ö1) (F $p<0.001$; F:Ö:T $p=0.0241$). Significantly more *Orius* larvae occurred on plants of the F2 variety (F $p=0.0181$). Furthermore, significantly more larvae were found in the Yellow Scotch Bonnet variety (F2) in the less frequently watered plots (Ö2) (F:Ö $p=0.031$). Based on the total number of phytophagous thrips larvae and adults, the abundance of thrips was significantly higher in less watered plots (Ö2) (Ö $p=0.0092$). In the case of the number of Anthocoridae larvae and adults, significantly more individuals occurred in the less irrigated plots (Ö2) on the Yellow Scotch Bonnet variety (F2) (F:Ö $p=0.0381$). The number of predatory thrips adults was significantly higher in less watered plots (Ö2) (Ö $p<0.001$). Regarding the *Aeolothrips* larvae, there was a statistically detectable difference in the interaction of the three settings. We found more individuals on the Yellow Scotch Bonnet variety (F2Ö2T1), which was irrigated less and had a larger space (F:Ö:T $p<0.001$).

3.3. The results of fruit testing from 2019

76.8% of the fruits of the Red Trinidad Scorpion Butch T (F1) variety remained healthy. *H. armigera* and thrips damage was negligible. 11.5% of the fruits were damaged by Pentatomidae. Among the fruits of the Yellow Scotch Bonnet (F2) variety, we found 80.2% healthy. We found Pentatomidae damage on 6.8%. 6% were damaged by thrips. 81.4% of the fruits harvested from plots irrigated daily (Ö1) remained healthy. *H. armigera* damage was negligible. 5% was damaged by Pentatomidae and 6.8% was damaged by thrips. We found 76.7% of the fruits picked from blocks irrigated every other day (Ö2) were healthy. We found Pentatomidae damage on 11.7%. 4.8% were damaged by thrips. 79.1% of the fruits of the plants planted with a larger plant spacing (T1) remained healthy. 8% was damaged by Pentatomidae and 5% were sucked by thrips. 78.8% of the fruits collected from plots with a smaller space (T2) were healthy. The damage caused by *H. armigera* was negligible, but at the same time, significantly more damaged fruits were found in the more irrigated plots (Ö1). We found symptoms caused by Pentatomidae in 8.9%. 6.4% was damaged by thrips. The Pentatomidae damage was significantly higher on the fruits of less watered plants (Ö2).

3.4. The results of individual plant testing from 2021

Significantly more female ladybirds chose the Red Scorpion Butch T variety (F1) plants in the less irrigated plots (Ö2) for egg laying. At the same time, more eggs were laid on the leaves of the Yellow Scotch Bonnet variety (F2) in the more frequently watered plots (Ö1) (F:Ö $p=0.0236$). Furthermore, we found significantly more eggs in the less irrigated plots (Ö2), with an increased plant spacing (T1) (Ö:T $p=0.0265$).There was a general significant effect of irrigation (Ö $p<0.001$), and there were more eggs on the more frequently irrigated plants (Ö1) on the Red Scorpion Butch T variety (F: Ö $p=0.0314$).In addition, it can be shown that there were significantly more Neuroptera eggs in the Red Scorpion Butch T variety (F1) in the larger plots (F:T $p<0.001$). In the larger plant spaced plots (T1) we found more ladybird larvae on the Yellow Scotch Bonnet variety (F2), while in the smaller plots (T2) there were more individuals on the Red Scorpion Butch T variety (F:T p=0 ,0026). In the case of ladybird pupae, there was no statistically detectable difference between the factors. At the same time, we can state that more larvae pupated in the less irrigated (Ö2) areas. The number of Neuroptera larvae was significantly higher on the F2 variety in the less frequently irrigated area (Ö2) (F:Ö $p=0.0225$). The same can be said for Syrphidae larvae (F:Ö $p=0.0143$). Significantly more ladybugs were found in less irrigated areas (Ö2) (Ö $p=0.0192$). Regarding the other settings and the interaction of the factors, no statistical difference can be shown. Significantly more Thomisidae individuals were found in the more irrigated plots (Ö1), with a larger plant spacing (T1), and less irrigated (Ö2) areas with shorter plant spacing (T2) (Ö:T $p=0.0434$). On the Yellow Scotch Bonnet variety (F2), we found significantly more *H.*

axiridis individuals (F p=0.033). In the case of the sixteen-spotted ladybug, the interaction of the three factors showed a significant difference. More individuals were located on the Yellow Scotch Bonnet variety (F2) irrigated less (Ö2), planted with a greater distance (T1) (F:Ö:T p=0.0186). We found significantly more seven-spotted ladybugs on the Yellow Scotch Bonnet variety (F2) (F p=0.0153) and in the less irrigated plots (Ö2) where the space ratio was greater (T1) (Ö:T p=0.015). In the less irrigated areas (Ö2) we found significantly more eye-spotted ladybird adults (Ö p<0.001), and there were significantly more individuals on the Yellow Scotch Bonnet plants (F2) (F p=0.0011). Based on the total number of larvae and adults of the *H. halys,* there was a significant difference for all settings. Also, the variety - irrigation and the interaction of the three factors also showed a significant difference. The number of individuals was significantly higher on the less watered (Ö2) Red Scorpion Butch T plants (F1) and on the more irrigated (Ö1) Yellow Scotch Bonnet variety (F2). Furthermore, in terms of the triple interaction, the Yellow Scotch Bonnet variety (F2), which was irrigated more often (Ö1) and had a smaller plant spacing (T2), had the most *H. halys* (F p<0.001; Ö p=0.0015; T p<0.001; F: Ö p<0.001; F:Ö:T p<0.001).

3.5. The results of flower testing from 2021

Significantly more phytophagous thrips larvae were found in the less frequently irrigated (Ö2) plots with smaller plant spacing (T2) (Ö p=0.0138; Ö:T p=0.0155). Regarding the number of *Orius* individuals, the variety - irrigation and also the interaction of variety - irrigation - plant spacing showed a statistical difference. In the case of the former, several individuals appeared on the more frequently watered (Ö1) Yellow Scotch Bonnet variety (F2). In the case of the triple interaction, the most individuals were found on the Yellow Scotch Bonnet variety (F2), which was irrigated more often (Ö1) and planted with a larger plant spacing (T1) (F:Ö p=0.0396; F:Ö:T p=0.0378). Regarding *Orius* larvae, no statistical differences could be detected between the settings and their interactions. Significantly more phytophagous thrips adults and larvae were found in the less frequently irrigated (Ö2) and larger plots (T1) (Ö p=0.0146; Ö:T p=0.0412). Regarding the total number of *Orius* flower bugs, no statistical difference could be detected between the settings and their interactions.

3.6. The results of fruit testing from 2021

44.1% of the fruits of the Trinidad Scorpion Butch-T (F1) variety remained healthy. 10.8% were damaged by the *H. armigera*. 7.5% were bitten by *Pentatomidae individuals* and 37.6% were sucked by thrips. Stink bug damage was significantly higher on the fruits of the Yellow Scotch Bonnet variety (F2) (F p=0.001) and in the less irrigated (Ö2) plots (F:Ö p=0.044). Among the fruits of the F2 variety, 76.5% were healthy. Yellow S. B. fruits were significantly damaged by *H. armigera* larvae (F p<0.001), 10.4% of the fruits were chewed by H. armigera larvae. We found *Pentatomidae* damage on 4.3%. We experienced thrips damage on 8.8%. 74.5% of the fruits harvested from plots irrigated daily (Ö1) remained healthy. 8.6% were damaged by the *H. armigera*. 13.4% were sucked by thrips. The damage caused by stink bug was insignificant. The fruits picked from blocks irrigated every other day (Ö2), 65.2% were healthy. 12.7% were chewed by *H. armigera* larvae. We found Pentatomidae damage on 6.5%. 15.5% were affected by thrips. 69.9% of the fruits of the plants planted with a larger plant spacing (T1) remained healthy, 10.7% were damaged by the *H. armigera*, 5.2% were damaged by stink bugs, and 14.2% were sucked by thrips. 70.5% of the fruits collected from the decreased plant spaced plots (T2) were healthy, 10.3% was damaged by H. armigera larvae, 4.6% was found to be damaged by stink bugs, and 14.6% was damaged by thrips.

3.7. The results of the individual plant testing and flower testing combined for the two years

In the following, I highlight the results that were the same in both years, regardless of whether the difference in the number of individuals was significant or not.

Female ladybugs laid several eggs on plants of the Trinidad Scorpion Butch-T (F1) variety. Neuroptera females laid more eggs in plots set up with greater plant spacing (T1). Most of the ladybug larvae pupated in plots irrigated every two days (Ö2). Aphids appeared in greater numbers in the less irrigated plots (Ö2) and on Trinidad Scorpion Butch-T (F1) plants and where the plant to plant distance (T1) was larger. The abundance of Syrphidae larvae was higher on the plants planted with wider spacing (T1). The total number of adults and larvae of ladybugs was higher in the less irrigated plots (Ö2) and with a larger tree spacing (T1). The most Thomisidae individual appeared on the Trinidad Scorpion Butch-T (F1) variety, and in the plots where watering was done daily (Ö1) and the space was larger (T1). *H. halys* females laid more eggs on the more frequently watered Yellow Scotch Bonnet variety (F2). *N. viridula* females laid eggs in greater numbers on the plants of the more frequently watered (Ö1) plots. The total number of adults and larvae of *N. viridula* was higher in the plots planted with a larger spacing (T1). The total number of adults and larvae of *H. halys* was higher in the plots set with smaller plant spacing (T2), and we found more on the Yellow Scotch Bonnet (F2) plants. The abundance of *Orius* adults was higher in the flowers of plants planted with wider spacing (T1). More *Orius* larvae appeared in the flowers of the Yellow Scotch Bonnet (F2) and on the plants that were watered less (Ö2) and planted with smaller plant spacing (T2). The total number of adults and larvae of phytophagous thrips was higher in the plots set with a larger plant spacing (T1). The total number of adults and larvae of *Orius* individuals was higher in the plots set with a smaller plant spacing (T2), and we found more on the less watered (Ö2) Yellow Scotch Bonnet (F2) plants. More *Aeolothrips* adults were found in the plots irrigated every two days (Ö2), and the number of *Aeolothrips* larvae was higher in the Trinidad Scorpion Butch-T (F1) flowers planted with a larger plant spacing (T1).

3.8. The results of the trophic tests based on the aggregated data of the two years

The number of the Theridiidae cocoons and Thomisidae individuals was negatively correlated with the number of all *Orius* individuals (adults and larvae). The sum of Theridiidae cocoons and Thomisidae individuals was positively correlated with phytophagous thrips larvae. The sum of Theridiidae cocoons and Thomisidae individuals was negatively correlated with phytophagous thrips adults. The sum of Theridiidae cocoons and Thomisidae individuals was positively correlated with fruits damaged by thrips. In the case of spiders and *Aeolothrips* individuals, I found negative correlations. Aggregated number of Theridiidae cocoons and Thomisidae individuals were negatively correlated with *Aeolothrips* larvae. Aggregated number of Theridiidae cocoons and Thomisidae individuals were negatively correlated with *Aeolothrips* adults. Thomisidae individuals were negatively correlated with Neuroptera eggs. Thomisidae individuals were positively correlated with Neuroptera larvae. Theridiidae cocoons were positively correlated with Neuroptera larvae. Aggregated number of Theridiidae cocoons and Thomisidae individuals were positively correlated with Neuroptera larvae. Aggregated Theridiidae cocoons and Thomisidae individuals were negatively correlated with Coccinellidae eggs. The sum of Theridiidae cocoons and Thomisidae individuals was positively correlated with the sum of ladybug adults and larvae. The sum of Theridiidae cocoons and Thomisidae individuals were positively correlated with the L3, L4, and L5 larvae of *N. viridula*, and with the sum of *N. viridula* adults and larvae. Ladybug eggs were negatively correlated with the sum of phytophagous thrips adults and larvae. There is a positive correlation between the total number of ladybug adults and larvae and the number of aphids. There is a positive correlation between the Neuroptera and Syrphidae larvae. In the case of *Orius* individuals and phytophagous thrips individuals, I found negative correlations. The sum of *Orius* adults and larvae was negatively correlated with the sum of phytophagous thrips adults and larvae. There was a negative correlation between *Orius* larvae and *H. armigera* damage. *Aeolothrips* larvae were negatively correlated with phytophagous thrips larvae. *Aeolothrips* larvae were positively correlated with phytophagous thrips adults. *Aeolothrips* adults were negatively correlated with phytophagous thrips larvae. *Aeolothrips* adults were positively correlated with phytophagous thrips adults. *Aeolothrips* larvae were positively correlated with sum of *Orius* adults and larvae. *Aeolothrips* adults were positively correlated with *Orius* larvae.

4. Conclusion and recommendations

4.1. Individual plant testing

In 2019, aphids appeared in greater numbers on Yellow Scotch Bonnet (F2Ö2T2) plants, which were watered less often and planted with smaller spacing. This relationship was not only shown in the factor 3 interaction, but also in the pairwise comparison. Therefore, plants of the F2 variety were preferred if they were treated with less frequent irrigation (Ö2) and the plant spacing was smaller (T2). In 2021, the examination of interaction 3 showed that the abundance of aphids was higher on the less irrigated Red Scorpion Butch T variety with a larger plant space (F1Ö2T1). Interaction 2 showed the same results. According to the 2019 results Aphididae species occur to a greater extent on the Yellow Scotch Bonnet variety (F2) with yellow fruits, as aphids are attracted to the yellow color (Basky 2005). In contrast, in 2021, more individuals of aphids appeared on the F1 variety. At the same time, contrary to our expectations, aphids preferred less watered plants in both years. This observation can be paralleled by Hluchy et al. (2007), according to which the aphid species *Aphis grossulariae, Aphis schneideri, Aphis idaei* and *Cryptomyzus ribis* appear in greater numbers in less irrigated areas. However, during an irrigation experiment set up in an almond orchard, they could not demonstrate a correlation between the level of irrigation and aphid infestation (González-Zamora et al. 2021).

If we examine the number of Pentatomidae eggs and the interaction of all the settings, we can conclude that in both years, both of the two Pentatomidae species' females laid the eggs on the plants planted with the smaller plant spacing (T2). Female *N. viridula* preferred the more watered Red Scorpion Butch T variety (F1Ö1) in both years. In relation to irrigation and plant spacing, in both years the females of both Pentatomidae species laid their eggs in the more irrigated areas with a smaller plant spacing (Ö1T2), presumably because more irrigation and the bushier vegetation resulted higher relative humidity. Chanthy et al. (2015) says it is more optimal condition for the eggs.

On the Yellow Scotch Bonnet variety (F2) in the 2021, the higher Pentatomidae infestation resulted in higher damage on the fruits. Also, this year, more individuals appeared in the less frequently irrigated plots (Ö2) and this resulted in greater damage on the fruits collected here. I could not show a significant correlation regarding the number of Pentatomidae individuals and fruit weight.

In 2021, damage by *H. armigera* was significantly higher on the Yellow S. B. variety (F2) with a lower capsaicin content. This was also the case in 2019, but the difference could not be shown statistically. In the future, it would be advisable to compare these results with the actual capsaicin content of the fruits.

In 2019, the ladybugs preferred the Yellow Scotch Bonnet variety (F2Ö1T2), which was watered more often and planted in a smaller space, for laying eggs. In the second test year, the Red Scorpion Butch T variety (F1Ö2T1), which was irrigated less frequently and had a longer plant spacing, was chosen for laying eggs. Examining the three settings together, we cannot state that the female ladybugs laid their eggs on plants more heavily infested by aphids. In 2021, the Coccinellidae females preferred the F1 variety, which was more infested with aphids and watered less often (Ö2). Based on the pairwise analysis of cultivar and plant spacing, there was no match with aphids, and only in the case of irrigation and plant spacing in 2021, when the less frequently irrigated plants planted with larger plant spacing (Ö2T1) laid their eggs in greater numbers on the less frequently irrigated plants (Ö2T1), where there was greater aphid pressure. Based on the different results obtained in individual years, it is difficult to draw a conclusion regarding the spatial position setting. We can observe that in 2019, the highest number of Coccinellidae eggs during the season is compatible with the population peak of aphids on 24.07. Female ladybugs lay their eggs near aphid colonies, so the larvae can get food shortly after hatching (Budai and Hataláné 2006). Furthermore, Thangjam et al. (2020) also observed the coincidence of the population peaks of aphids and ladybugs. However, ladybug larvae did not appear in greater numbers in the plots where the density of aphids was higher in any of the study years. When comparing the irrigation and plant spacing settings, in both years more Coccinellidae larvae occurred on the more frequently irrigated plants with increased plant spacing (Ö1T1). In wheat, Pérez-Fuertes et al. (2015) made similar observations that more Coccinellidae larvae appeared in the irrigated culture compared to non-irrigated areas. The place where the ladybugs laid their eggs and the location of the larvae did not match in any of the years. It is noteworthy that, on the other hand, in several cases the larvae chose the plants to pupate on which more aphids were present. In 2019, these were the Yellow Scotch Bonnet plants (F2Ö2; F2T2), which were watered less often and with a smaller spacing, and in 2021, the plants of the Red Scorpion Butch T variety, which were watered less frequently and planted with greater plant spacing (F1Ö2T1).

In the reflection of the interaction of irrigation and plant spacing settings, in 2019 the Neuroptera females preferred the less frequently watered, more densely spaced plants (Ö2T2), while in 2021 the plants of the Red Scorpion Butch T variety (F1T1) planted with a larger plant spacing were preferred for oviposition, where there was a greater aphid pressure. In 2019, this can also be seen on the basis of the population dynamics, according to which the density of aphids coincided with the majority of the found Neuroptera eggs. Nasreen et al. (2000) observed more Neuroptera eggs in cotton set with decreased plant spacing. The occurrence of Neuroptera larvae differed from the location of the eggs in each year. Regarding the interaction of cultivar-irrigation and irrigation-spatial condition, the Neuroptera larvae appeared in larger numbers in plots of the same type in both years. We found more larvae on the less frequently watered Yellow Scotch Bonnet variety (F2Ö2) and on the less frequently watered plants planted with greater plant spacing (Ö2T1), presumably because e.g. In 2019, more aphids occurred in plot F2Ö2 and in plot Ö2T1 in 2021, and the density of Neuroptera larvae could not have been directly influenced by irrigation. González-Zamora et al. (2021) also found no correlation between the abundance of Neuroptera larvae and the level of irrigation.

With regard to the distribution of Thomisidae spiders, by examining the interaction of the three settings, we can conclude that in 2019, plants of the Red Scorpion Butch T variety (F1Ö1T2), which were irrigated more often and planted with a denser spacing, were preferred, on which the most *N. viridula* eggs were found in the same year. In 2021, the more frequently irrigated F1 variety (F1Ö1T1), which was planted with greater plant spacing, had the highest abundance of Thomisidae individuals, in which plots the most *N. viridula* larvae and adults occurred in the same year. Based on the pairwise analysis of the factors, more Thomisidae spiders appeared on the more frequently watered Red Scorpion Butch T variety (F1Ö1) in both years, where also in both years the most *N. viridula* eggs were present. Analyzing the data of the cultivar and plant spacing together, in 2019 the number of Thomisidae species was the highest in the F1 variety (F1T2) with a smaller plant spacing, on which plants the most *H. halys* eggs and the most *N. viridula* adults and larvae were found. It is noteworthy that if we examine the data on irrigation and plant spacing, the number of Thomisidae individuals and the eggs of the two Pentatomidae species was the highest in the more frequently irrigated plots with smaller plant spacing (Ö1T2) in both years, and in 2021 in these plots the abundance of *H. halys* larvae and adults was the highest. Based on these, we can draw the conclusion that during the time of Pentatomidae species egg-laying, the individual density of Pentatomidae adults on the plants, which could have been preyed upon by Thomisidae individuals in large numbers, could have been high. That is why Thomisidae individuals were present in the same plots in both years. In the case of other examined phytophagous organisms, I did not experience similar correlations with the Thomisidae species. Based on the above, in the case of a correlation between the Thomisidae species and the two Pentatomidae species, the correlation is greater between *N. viridula* and spiders. The *H. halys* individuals may have avoid the spiders, as it is known that the presence of hunting spiders on a plant can stimulate phytophagous species to leave (Sunderland 1999). If we examine the population dynamics of spiders, we can conclude that although it was fluctuating, a stable density of individuals always returns within two months. This supports the observation that generalist predators are less affected by a rapid decline in the number of individuals of a prey species than a specialist predator (Maloney et al. 2003).

4.2. Flower testing

Phytophagous thrips adults were present in larger numbers on the less frequently watered, larger Red Scorpion Butch T plants (F1Ö2T1) in both years. The temperature may be higher in less irrigated plots with greater plant spacing, however, e.g. *Thrips tabaci*, which typically damages pepper (Whitfield et al. 2005), adapts well to high temperatures (Safaei et al. 2015). In temperate regions, the number of individuals of most thrips species increases in summer when the weather is sunny, dry and warm (Lewis 1973). Setiawati et al. (2022) says in chili pepper plant spacing has an effect on thrips damage and crop quality. The flower, as a primary feeding site, can protect thrips from rain, unfavorable temperatures, excessive sunlight, and higher humidity from drying out (Kirk 1997).

If we examine the population dynamics of phytophagous thrips in 2019 and the amount of precipitation, we can conclude that the air cooled before the rain and the number of thrips increased. This may also be due to the fact that before the rainy season, thrips move to hiding places (e.g. flowers) at a height of 1-2 m from the ground level, so in such weather there may be more individuals in the flowers (Lewis 1973). However, there was more persistent rain at the beginning of August, and this probably reduced the number of thrips. According to Harding's (1961) recordings, heavy rains can cause a drop in the number of thrips. From the middle of August, there was three weeks of drier weather, and thus the number of phytophagous thrips increased. As the number of thrips decreased, the abundance of *Orius* individuals increased. The reverse was also true at the end of sampling. This can be explained by the fact that the locally increased prey population is followed by an increase in the predator population, which ultimately creates a state of equilibrium (Maloney et al. 2003).

In the second study year, the collection of flower samples also began in a rainy period. After that, the number of phytophagous thrips also decreased, and after the drier period of almost a month, their number increased at the beginning of October. This can be related to the fact that *Thrips tabaci* does not have a photoperiod-induced reproductive diapause (Sobhy et al. 2010).

In 2019, *Orius* adults preferred the flowers of Yellow Scotch Bonnet plants (F2Ö2T2) with decreased plant space and less irrigation, while in 2021, the number of individuals was highest in the flowers of the less watered F2 variety, but in plots with a larger space (F2Ö2T1). *Orius* females lay their eggs on a thinner epidermis in which intracellular vesicular transport allows larval development and survival (Lundgen et al. 2008). The abundance of larvae was highest in the F2T2Ö2 plot in 2019, and in the F1Ö2T2 plot in 2021. If the total number of phytophagous thrips and *Orius* individuals is compared, it can be seen that the *Orius* individuals chose the exact opposite setting in both years than the phytophagous thrips. In contrast to 2019, in 2021 the number of *Orius* followed the population dynamics of thrips. In both years, it was observed that the number of thrips began to rise again during the two rain-free weeks after the rainy period.

The seasonal effect changes the number and occurrence of *Orius* species (Saulich and Musolin 2009), the temperature and precipitation conditions, and indirectly the amount of food (Rácz 1989). In the 2021 vegetation, the average daily temperature was lower, and this probably induced slower development and a lower reproduction rate. Cocuzza et al. (1997), temperature also affects the feeding activity of *Orius* species.

4.3. Trophic relationships

The spread of aphids could fundamentally determine the spread of predatory species. In the case of low food density, predatory species switch to other food species or look for an area where more food is found (Maloney et al. 2003).

Neuroptera and Coccinellidae females laid their eggs on bases where there were fewer spiders. The presence of spiders affected the oviposition behavior of other predatory species. However, after hatching from the egg, the Neuroptera and Coccinellidae larvae migrated in order to achieve a higher density of prey animals (e.g.: aphids, thrips).

The spiders probably fed on phytophagous thrips, which is why there is a positive correlation between the individuals. Some studies have shown that in certain crops (e.g. peppers) thrips can partially form the diet of spiders (Ghavami 2008). In maize, Lycosidae individuals have been able to control populations of thrips, aphids and cicadas (Lang et al. 1999). In the longer term, however, they are not able to follow the changes of the prey animal at the population level, since the life cycle of spiders is relatively long, and their generalist nature does not allow their number of individuals to be limited to the abundance of a specific arthropod species (Riechert 1999). This may result from the positive correlation between all Theridiidae cocoons and Thomisidae individuals and thrips damage. Also, the fact that spiders are not able to permanently influence the density of pests is also proven by the fact that, based on statistical tests, they had no effect on Pentatomidae damage. However, based on our results, we can assume that the spiders preyed on *N. viridula*, mainly on larvae in L-3, L4 and L5 stages. Correlation studies show that *Orius* species and predatory thrips avoided spiders.

The majority Coccinellidae species are predators, feeding on aphids (Triltisch 1999). This is proven by the positive correlation between aggregated ladybird larvae and adults and aphid individuals. Where more aphids were present, more ladybugs occurred. According to other research, Coccinellidae species also feed on phytophagous thrips (Ricci et al. 2005).

Many other arthropods can also prey on phytophagous thrips. Pedro et al. (2021) recorded in field melons, *Orius* and *Aeolothrips* species were the main predators of phytophagous thrips.

It is noteworthy that when we examine the correlations between predatory thrips and pest thrips, negative correlations are observed for phytophagous thrips larvae, while positive correlations are observed for adults. Since the development of phytophagous thrips adults is dependent on the plant and soil (females lay their eggs in plant tissues; the mature larvae migrate to the soil and transform into a non-feeding pronymph and then into a nymph (Budai and Hataláné 2006), so we can notice a certain degree of preference in their occurrence for the phytophagous compared to thrips larvae. That is why we could observe that the adults appeared in the same treatments in both years, while the larvae did not. The presence of predatory thrips may make the phytophagous thrips larvae migrate, as according to Lewis (1973) the larvae are very mobile. In 2021, *Aeolothrips* individuals appeared in the same settings as the phytophagous thrips larvae, but in both years the *Aeolothrips* larvae predated the arthropods hiding in the flowers of the Red Scorpion Butch T variety (F1) planted with greater spacing species. *Aeolothrips* and *Orius* species have the same food spectrum, however, we know from research that *Orius* species prey on thrips species too belonging to the Thripidae family (Baez et al. 2004), other research confirms predation between two predatory arthropods. El-Serwiy et al. (1985) says *Orius albidipennis* was able to reduce the number of *Aeolothrips fasciatus* in open field conditions. Furthermore, according to Fathi et al. (2008), *Orius niger* preys on *Aeolothrips intermedius*.

According to the correlation test significantly less *H. armigera* damage was observed where more *Orius* larva was present (Ö2). According to Ali et al. (2020), *Orius* species can also feed on the eggs and on young larvae of butterflies.

Based on research, the population of *Orius tantillus* in sorghum affected the young larvae of *H. armigera* (Sigsgaard and Esbjerg 1997).

4.4. Recommendations

Based on the results of the experiment, the following recommendations can be made:

Regarding the varieties, Yellow Scotch Bonnet (F2) can clearly be recommended, as it produced more fruits, and fewer phytophagous thrips appeared on this cultivar, while the predatory arthropods on both cultivars and some predatory taxa preferred the F2. However, more additional studies are needed to clearly state the success of the F2 variety. Considering the irrigation setting, it is not possible to unequivocally state any irrigation frequency recommendation. The harvest amounts were different in each year, and the damage rates were also different. In case of stronger Pentatomidae pressure experienced in previous years, a higher irrigation intensity (Ö1) should be considered. In the case of less irrigation, we can expect a higher phytophagous thrips and Pentatomidae damage. It is important to avoid long-term high humidity in pepper plantation, as the eggs of pests survive such conditions more effectively, not to mention the possible infection of diseases. If we aim an even higher capsaicin content produced in the fruits, we may set a deliberately induced water stress. In the case of plant space setting, the yield of each year shows different results. Phytophagous arthropods appeared in greater numbers in the plots with smaller plant spacing (T2), while the abundance of predatory organisms was mostly higher on plants planted with a larger spacing (T1). In order to promote predators, an increased plant to plant distance can be recommended, and a less dense plantation may also be justified due to the bushy habit of the chili pepper. Considering all the results, since the number of phytophagous arthropods occurred in the plots in which the Red Scorpion Butch T variety was planted with a smaller plant spacing and was less irrigated (F1Ö2T2), it can be recommended to grow the Yellow Scotch Bonnet variety with a larger plant spacing and more frequent irrigation.

It is important to note that, due to the 2-year interval of the experiment, further investigations are necessary in order to formulate the conclusions that can be drawn on the basis of the results and the recommendations made based on them.

5. New scientific results

1) We found that Pentatomidae damage was greater on the berries of less frequently watered plants.

2) We found that aphids occurred in greater numbers on less watered plants.

3) We found that the females of *Nezara viridula* preferred plants that were watered more often and planted with a smaller distance between plants for laying eggs.

4) We found that *Helicoverpa armigera* damage was greater on the berries of the Yellow Scotch Bonnet variety.

5) We found that Thomisidae individuals occured in greater numbers on plants with a higher abundance of *Nezara viridula.*

6) We found that the damage caused by *Helicoverpa armigera* was decreased, where the Anthocoridae individuals occured in greater numbers.

7) We found that the two types of plant spacing and irrigation frequency used did not affect the yield.

6. References

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