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ORIGINAL ARTICLE

Insects in Sorghum and comparative studies on the population dynamics of some main species

Ivelina Nikolova*

Department Selection and Technology, Institute of Forage Crops, General Vladimir Vazov, Pleven, Bulgaria

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*Corresponding address:
imnikolova@abv.bg

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Abstract

At the current level of applied entomology, comprehensive research on the species composition and population dynamics of the insect community in crops is of the utmost importance. Comprehensive studies on sorghum agroecosystems in Bulgaria have been scarce and have necessitated, necessitating a need for new and up-to-date developments. The study investigated the species composition and population dynamics of the main insect species in Bulgaria's sorghum. Insect diversity was represented by 51 insect species belonging to 17 families and 46 genera. Harmful species made up 70.6% of the total population density of insect representatives, while beneficial (predators) – 29.4%. The insect composition included two aphid species, 17 species of cicadas, 11 species of bugs, 17 species of beetles, and four thrips species. Aphids and cicadas were some of the most important insect pests of sorghums in Bulgaria. Temperature changes affected the life characteristics of insects and ultimately determined population growth rates. Various factors like global warming, changing cropping patterns, and adoption of technologies alter insect abundance, distribution, and pest-associated losses. Work, related to the survey and surveillance of sorghum insect pests should be regularly conducted to gain proper knowledge of changing trends of insect pests, associated losses, and timely management.

Keywords: climatic parameters, entomofauna, population dynamics, *Sorghum bicolor*

Introduction

In recent years, several factors, such as global warming, the application of new agricultural technologies, agricultural practice modification, and the introduction of intensive high-yielding varieties/high-yielding hybrids, have been associated with changes in the insect pest entomofauna of cereal grains, including sorghum. Excessive and uncontrolled use of plant protection products has resulted in several issues, such as pest outbreaks, pesticide resistance, and environmental pollution. These problems have also contributed to the emergence and multiplication of certain insect pests in specific regions.

In the context of climate change, sorghum offered distinct advantages. Around 80% of arable agricultural land in Europe is not irrigated, and sorghum's resilience during droughts makes it an important crop for many farmers. Additionally, sorghum is a versatile cereal crop with worldwide importance, cultivated for food, fiber, forage, ethanol, and sugar production (Liu *et al.* 2009).

Numerous researchers have studied the entomofauna of sorghum in various geographic locations. Their research has revealed around 150–200 species of insects and mites that negatively impacted the quality and productivity of *Sorghum bicolor* L. Moench. Nearly 20 insect pests among these, have been identified as economically considerable (Kumar and Jakhar 2018; Nibouche *et al.* 2018; Kerns *et al.* 2023). Some of the most numerous and harmful pests reported were aphids: *Rhopalosiphum padi* L., *Schizaphis graminum*

Rondani, *Sitobion* sp. *Melanaphis* sp. (Hemiptera: Aphididae) (Chunming *et al*. 2018; Nibouche *et al*. 2018; Uyi *et al*. 2022), the Elateridae family (*Agriotes* sp.), and several stink bugs from Pentatomidae (Heteroptera) (*Nezara viridula* L., *Oebalus pugnax* F.) (Knutson *et al*. 2018; Okosun *et al*. 2021). In addition, *Leptocorisa acuta* Thunberg, commonly known as earhead bugs, was reported as a considerable insect pest for sorghum plants in India (Poul *et al*. 2020). Other insect pests that attacked sorghum were cicadas (*Pyrilla perpusilla* Walker, *Zignidia manaliensis* Singh, *Empoasca* sp., *Nephotettix verescence* Distant) (Hemiptera: Auchenorrhyncha) (Kalaisekar *et al*. 2017; Arora 2017), *Helicoverpa armigera* Hübner, *Spodoptera frugiperda* J.E. Smith, *Ostrinia nubilalis* Hübner (Lepidoptera: Noctuidae, Crambidae) (Chunming *et al*. 2018; Padmaja and Aruna 2019), thrips (*Thrips tabaci* L., *Haplothrips* sp., *Florithrips* sp.) (Thysanoptera) (Arora 2017; El-Gepaly *et al*. 2021) and others.

From the sucking insects, aphids, thrips, and cicadas are some of the most important insect pests of grain and forage sorghums in production regions in the United States, India, Europe, the Philippines, and other areas (Limaje *et al*. 2018; Niebres and Alviar 2023). These insects have mouth parts that pierce and suck juices from plants. This process causes a yellowish spot to develop around the feeding area due to the injection of toxins and saliva into the plant tissue. The damaged tissue quickly loses its green color on the leaf surface and gradually enlarges. As feeding continues, the leaves start to brown and eventually die.

Aphid species commonly found in grain sorghum fields can transmit the Maize Dwarf Mosaic Virus (MDMV), according to a study conducted by Munson *et al.* in 1993. The virus can be a threat in fields, where aphids are abundant since the grass serves as the perennial host during winter. The virus caused distinct mottling of the leaf tissues, with infected leaves turning yellow with light green islands. In highly susceptible varieties, symptoms of red leaves may manifest during cool weather. Cicadas and thrips were vectors of dangerous viral diseases, which can also compromise the harvest and deteriorate the production quality.

Losses in sorghum caused by pests have increased by 26.5% since the early 2000s (Dhaliwal *et al*. 2015).

Diverse factors such as global warming, abnormal weather patterns, changing crop patterns, and technological advancements can all affect insect populations, distribution, and pest-related losses (Kumar and Jakhar 2018). It is necessary to conduct regular surveys and surveillance of insect pests in sorghum to gain proper knowledge of their changing trends and associated losses. Furthermore, developing topical management practices for new crop pests in advance is necessary.

Past research on economically important insects affecting sorghum in Bulgaria has been limited and insufficient, with most studies conducted in the last century. Aphids qua insect pests of cereal crops, including sorghum, were commonly mentioned, but there was a lack of in-depth studies (Maneva 2010). This necessitated the need to complement the existing information and obtain new data on the quantitative and qualitative composition and seasonal dynamics of dominant insects, which induced the present study.

Materials and Methods

Between 2021 and 2023, the species composition and population dynamics of the main insect species in *Sorghum bicolor* (L.) Moench was studied. The experiment was conducted annually with a sowing density of 18–22,000 plants per hectare, a row spacing of 45–50 cm, and a sowing depth of 3–5 cm. The experimental area covered an area of 0.1 ha.

Chemical control was not used for insect pests during the growing season. Insect species were collected once or twice a week with an entomological net along the diagonals of the crop. Sweeping was made in the morning shortly after plant emergence until the above-ground mass began to dry. The samples were taken from the middle of May to the end of August in the 2021, 2022 and 2023 seasons. Fourteen samples were obtained for each season. During the initial stages of plant development, permanent monitoring was performed in May.

After sweeping, the species were placed in dark glass vials filled with 70% ethyl alcohol. Species identification was carried out under laboratory conditions using a stereomicroscope of the "Amplyval" type.

Accurate insect identification from the various orders, families, and genera was made by taxonomic classification of morphological characters. Rich personal collections and collections of insect species determined by relevant entomological systematists were used. Some of the identified taxa were compared and confirmed with their description in definition species tables from relevant Bulgarian and foreign systematists. Adult insects (imago) were used to determine the species.

The route survey method and visual observations were used to identify parasitized aphids, which were distinguishable from non-parasitized ones by their oval shape and lighter, straw-yellow color. Once a week, larval and adult forms were collected, along with the leaves. The material was then placed in cloth bags, transferred to a laboratory, and grown in glass Petri dishes covered with cheesecloth until adults of the parasitoid emerged from the host's body, and identified.

The analysis focused on the climatic parameters between April and August to study the occurrence of aphids in the field. Canonical correspondence analysis (CCA) was conducted to determine the impact of selected climatic variables on the population density of the species. The calculation was performed using the Paleontological Statistics Software Package (PAST) (Hammer *et al*. 2001).

Species classification was made according to Boychev (1975), where: * – dominant species have more than 15% participation, ** – subdominant – from 5 to 15%, *** – secondary – from 1 to 5%, **** – tertiary – less than 1% participation relative to the total population density of insects.

Results

Insect pest damage represented a substantial threat to reducing sorghum productivity. Pests attack through various stages of plant development, from sowing to seed ripening. About 150 species of insects from 29 families affect sorghum worldwide (Guo *et al.* 2011), and can be primary, secondary, or occasional pests.

The study included insect species from three orders, five suborders, 17 families, 46 genera, and 51 species, as listed in Table 1. The insect composition included two aphid species, 17 leafhopper species, 11 bedbug species, 17 beetle species, and four thrips species.

During the growing season, 12 insect species belonging to different orders and families were established with a minimal presence of two to three individuals (Table 2).

Of the 51 insect species, 70.6% were herbivores, and 29.4% were predators. Harmful species belonged to six orders: Coleoptera (suborder Polyphaga), Hemiptera (including three suborders: Cicadomorpha, Heteroptera, and Sternorrhyncha), Thysanoptera (suborder Terebrantia), Orthoptera (suborder Caelifera), and Diptera (suborder Brachycera).

The Hemiptera order (30 species) was the most numerous and diverse, followed by Coleoptera (17). The useful entomofauna consisted of four orders – Coleoptera, Hemiptera, Diptera, and Thysanoptera. *Coccinella septempunctata* Linnaeus (Coleoptera, Coccinellidae) and *Nabis ferus* Linnaeus (Hemiptera, Heteroptera) were dominant.

During the study period, only a few accidental species were observed to visit the sorghum. Those species were found in too low numbers and belonged to the orders Coleoptera, Hemiptera, Thysanoptera, and Diptera (Table 2), with the lowest participation from the latter. Only *Aphidius ervi* Hal. was found among the parasitoids but in negligible amounts.

Hemiptera: suborder Sternorrhyncha, Aphididae

Schizaphis graminum and *Sitobion avenae* Fabricius were the most common insect pests from the Sternorrhyncha suborder, Aphidoidae family. *Sitobion avenae* was the dominant species occupying 89.1% of the total aphid population density.

The life cycle of aphids is based on two main factors – food and climate. As for weather conditions, the even distribution of precipitation combined with optimal humidity and temperature in 2021 favored the migration, development, and fecundity of aphids (Fig. 1). Conversely, the high precipitation levels in the spring, coinciding with the start of migration and the vegetative period of 2023, significantly curtailed the mass reproduction of aphids. The agroclimatic conditions in 2022 also contributed to the species' abundance.

The species migrated to the sorghum crop after May 20th, with winged and wingless forms appearing (Fig. 2). In early June, the wingless forms became dominant, reaching up to a mean of 34 individuals per square meter for the 2021–2023 period. Their numbers peaked during the first 15 days of the month, particularly between June 6th and 10th, with an average of 63 individuals per square meter. Also, during this period mass reproduction of this species was observed. Over the years, that period slightly changed, depending on the specific agrometeorological conditions. There was a considerable increase in the aphid population around mid-June, with an average of 45 individual wingless aphids per square meter. However, towards the end of the month, the number gradually decreased, and by July, the aphid population was significantly lower, with only three individual aphids per square meter. A considerably increased number of winged forms was found on June 6–10 (10 individuals/m^2) and June 21–25 (11 individuals/m^2), with relatively high participation remaining until the end of the month, after which the population declined. A less pronounced new increase in the winged form amount was observed during the second 10 days of July (7–8 individuals · m^{-2}). They were present for a longer time during the entire studied period, while the wingless forms were mainly present in the crops from the end of May to the middle of June, but in many times higher numbers.

During the 3-year study, similar trends were observed. The highest population total density of aphids was in 2021, followed by 2022 and 2023 (Table 1: $F_{2,9} = 33.273$; $p < 0.031$).

The *S. graminum* and *S. avenae* populations were low during the early growth stages of the plants (principle growth stage 2 – tillering). However, their density

Table 1. Species composition and insect species number in *Sorghum bicolor* (L.) Moench

Order, suborder, family, species	2021	2022	2023	Total
Hemiptera: suborder Sternorrhyncha, Aphididae				
Schizaphis graminum Rondani, 1852	86	31	3	120
Sitobion avenae Fabricius, 1775	479	394	109	982
Hemiptera: Auchenorrhyncha, family Cicadellidae				
Allygidius (Allygidius) atomarius Fabricius, 1794	9	0	0	9
Anaceratagallia laevis Ribaut, 1935	11	0	0	11
Balclutha punctata Fabricius 1775	4	3	0	7
Cicadella viridis Linnaeus, 1758	13	1	0	14
Empoasca pteridis Dahlbom, 1850	82	10	7	99
Eupteryx atropunctata Goeze, 1778	10	0	0	10
Euscelis plebeia Fallén	5	1	0	6
Hyalesthes obsoletus Signoret, 1865	14	0	0	14
Macrosteles laevis Ribaut, 1927	42	6	2	50
Metalimnus steini Fieber, 1869	4	0	0	4
Philaenus spumarius Linnaeus, 1758	14	4	0	18
Psammotettix striatus Linnaeus, 1758	621	226	59	906
Reptalus panzeri Low, 1883	49	7	0	56
Scaphoideus titanus Ball, 1932	1	0	0	1
Tibicina haematodes Scopoli, 1763	10	0	0	10
Zyginidia (Zyginidia) scutellaris (Herrich-Schäffer	987	704	289	1980
Hemiptera: Fulgoromorpha, Delphacidae				
Laodelphax striatellus Fallen, 1826	68	60	55	183
Hemiptera: Heteroptera				
Anthocoridae family				
Orius (Orius) niger (Wolff, 1811)	0	2	0	2
Lygaeidae family				
Geocoris ater Fabricius, 1787 *	7	0	0	7
Nysius senecionis subsp. senecionis Schilling, 1829	7	2	0	9
Miridae family				
Adelphocoris lineolatus Goeze, 1778	10	2	0	12
Campylomma verbasci Meyer-Dür, 1843 *	5	0	0	5
Deraeocoris serenus Douglas & Scott, 1868 *	6	0	0	6
Deraeocoris ruber (Linnaeus, 1758) *	0	2	0	2
Lygus rugulipennis Poppius, 1911	26	23	6	55
Trigonotylus coelestialium Kirkaldy, 1902	34	31	4	69
Nabidae family			0	
Nabis ferus Linnaeus, 1758*	64	12	3	79
Pentatomidae family				
Dolycoris baccarum Linnaeus, 1758	5	0	0	5
Coleoptera, Polyphaga suborder				
Cantharidae family				
Malthinus frontalis Marsham, 1802*	5	0	0	5
Rhagonycha (Rhagonycha) fulva Scopoli, 1763*	14	4	23	41
Chrysomelidae family				
Altica lythri Aube, 1843	22	3	2	27
Oulema melanopus Linnaeus, 1758	6	3	3	12
Phyllotreta atra Fabricius, 1775	38	30	6	74

Table 1. Species composition and insect species number in *Sorghum bicolor* (L.) Moench – continuation

Order, suborder, family, species	2021	2022	2023	Total
Phyllotreta cruciferae Goeze, 1777	14	10	1	25
Spermophagus sericeus Geoffroy, 1785	16	2	0	18
Сем. Coccinellidae:				
Coccinella (*Coccinella*) *septempunctata* Linnaeus, 1758*	80	24	3	107
Coccinula quatuordecimpustulata Linnaeus, 1758*	5	3	0	8
Harmonia axyridis Pallas, 1773*	12	0	3	15
Hippodamia (Hippodamia) variegata Goeze, 1777*	9	0	0	9
Thea vigintiduopunctata Linnaeus, 1758*	6	1	0	7
Scymnus femoralis Gyllenhal, 1827*	24	10	3	37
Scymnus frontalis quadrimaculatus Hrbst, 1783*	5	0	0	5
Curculionidae family				
Lixus cardui Olivier, 1807	3	0	0	3
Elateridae family				
Agriotes (Agriotes) ustulatus Schaller, 1783	4	21	1	26
Mordellidae family				
Mordellistena variegata (Fabricius, 1798).	0	3	0	3
Thysanoptera order				
Aeolothripidae family				
Aeolothrips intermedius Bagnall, 1934*	82	31	9	122
Phlaeothripidae family				
Thrips atratus Priesner, 1920	5	16	52	73
Haplothrips tritici Kurdjumov, 1912	17	27	3	47
Thrips atratus Priesner, 1920	5	16	52	73
Haplothrips tritici Kurdjumov, 1912	17	27	3	47
Thripidae family				
Odontothrips confusus Priesner, 1926	13	4	0	17
Total	**2992**	**1753**	**646**	**5412**

*useul species

Table 2. Species composition of random insect species on *Sorghum bicolor* (L.) Moench

Species, order, suborder, family
Aphidius ervi Haliday (Hymenoptera, Braconidae) *
Callimoxys gracilis Brullé, 1832 (Coleoptera, Cerambycidae)
Catapion seniculus Kirby, W., 1808 (Coleoptera, Apionidae)
Spermophagus sericeus Geoffroy, 1785 (Coleoptera: Bruchidae)
Syrphus ribesii Linnaeus, 1758 (Diptera: Syrphidae) *
Latematium cypriacum Dlabola, 1982 (Hemiptera, Fulgoromorpha, сем. Issidae)
Polymerus cognatus Fieber, 1858 (Hemiptera, Heteroptera, Miridae)
Therioaphis trifolii Monell, 1882 (Hemiptera, Sternorrhyncha, Aphidoidea, Aphididae)
Dociostaurus maroccanus Thunberg, 1815 (Orthoptera, Acrididae)
Tettigonia viridissima Linnaeus, 1758 (Orthoptera, Tettigoniidae)
Thrips atratus Haliday, 1836 (Thysanoptera, Thripidae)
Thrips tabaci Lindeman, 1889 (Thysanoptera, Thripidae)
Stenothrips graminum Uzel, 1895 (Thysanoptera, Thripidae)

*useful species

increased rapidly as the plants entered the budding stage and reached the highest density at the flowering stage. As the sorghum seeds matured (at the end of August and September), the number of aphids decreased considerably due to deteriorating nutritional conditions. Aphids were one of the most important insect pests of sorghum in Bulgaria, as temperature changes affected the life characteristics of insects and ultimately determined population growth rates.

Species of the Coccinellidae family had a decisive influence on the aphid density and control. It was represented by seven species (Table 1), with *C. septempunctata* being the most important and dominant species among predators. Ladybugs were the most abundant predators in sorghum, being associated with high levels of predation, mainly in June. The most pronounced participation over the years was observed in 2021 when the species occupied 74.8% of the total population density for the study period.

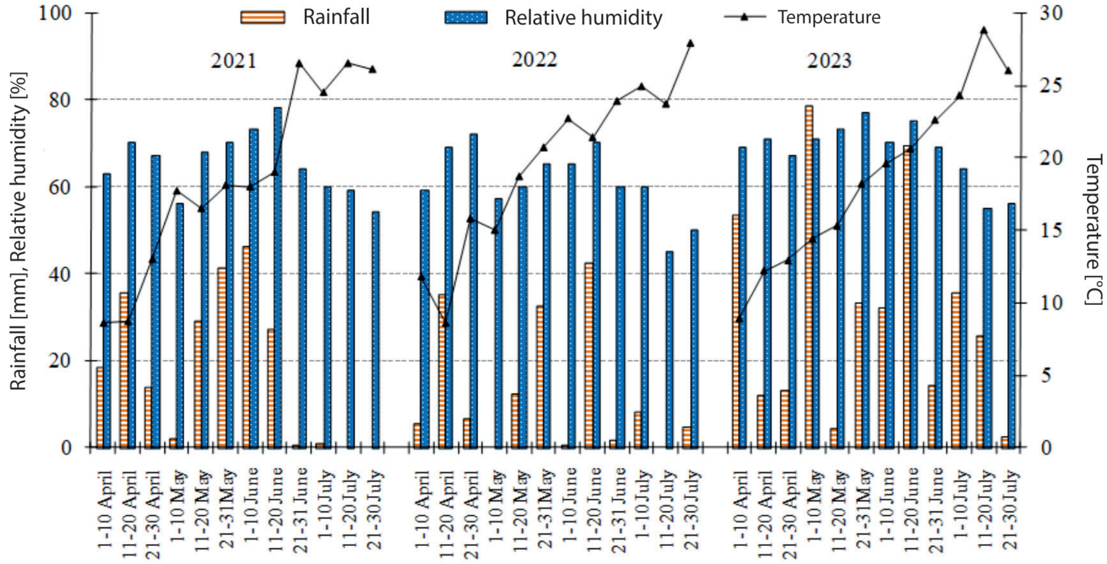

Fig. 1. Meteorological characteristics for the Pleven region

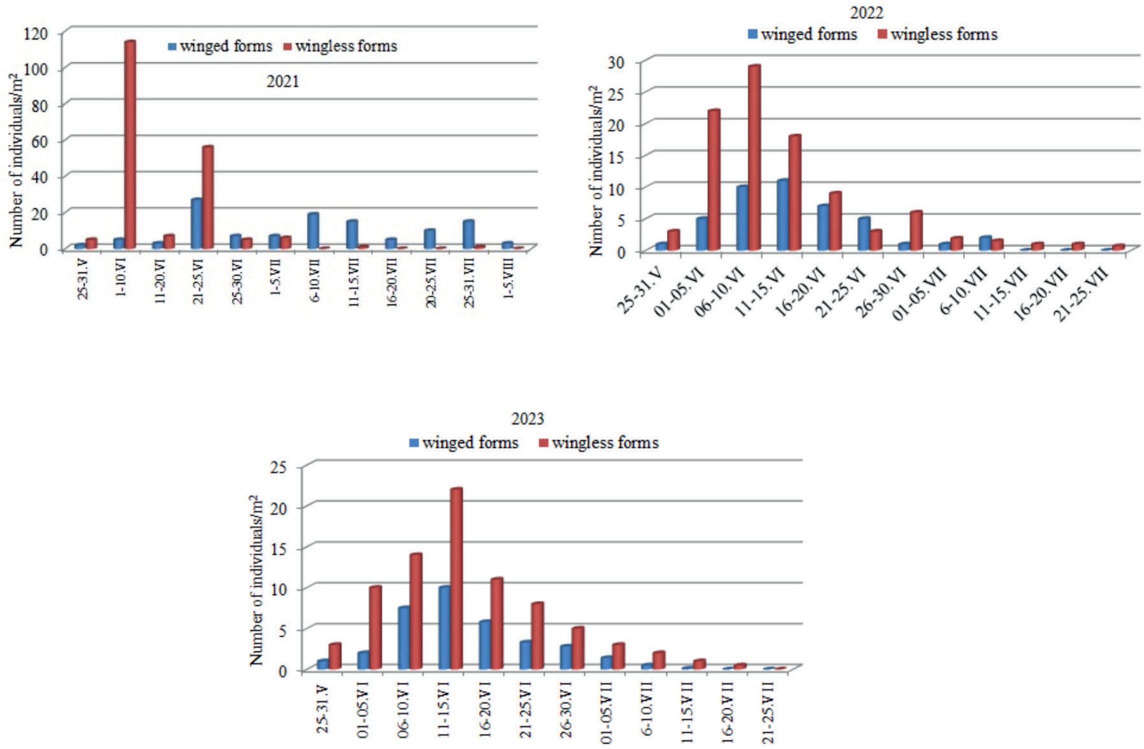

Fig. 2. Population dynamics of *Sitobion avenae* Fabricius, 1775 on sorghum *Sorghum bicolor* (L.) Moench, (number of individuals · m^{-2})

In early June, a 7-point ladybird was observed and was sighted until the end of the month or the beginning of July (Fig. 3). During June 6-10, there was a synchronicity in the numbers between the predator and prey, and the maximum value for *C. septempunctata* (25 individuals · m^{-2}) completely coincided with the abundance of its prey (73 winged and wingless forms · m^{-2}). From June 11 to 15, a pronounced synchronicity was also observed with the dynamics of the aphid population. When the prey number increases considerably, larvae and adult predators usually multiply and leave the sites when the presence of aphids is negligible. Thus, ladybirds may cause an immediate decline in aphid numbers.

Schizaphis graminum (common wheat aphid) had a holocyclic developmental cycle and reproduced sexually to overwinter (as an egg). In June, aphids were found in much lower numbers than grain aphids, and the wingless forms were mainly present in the crops.

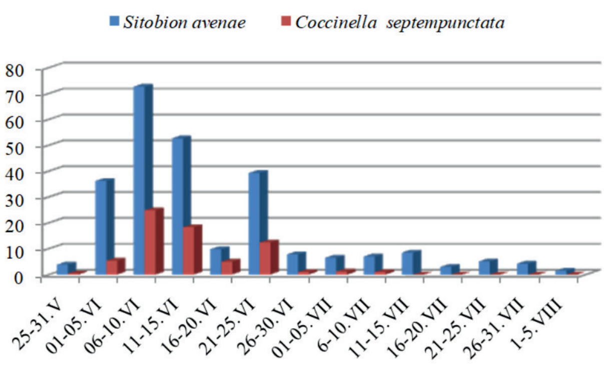

Fig. 3. Population dynamics of *Sitobion avenae* Fabricius, 1775 and the predatory species *Coccinella septempunctata* Linnaeus, 1758 on sorghum *Sorghum bicolor* (L.) Moench (number of individuals · m^{-2}), average for 2021–2023

Hemiptera: Cicadellidae and Delphacidae families

The cicadas belonging to the suborders Auchenorrhyncha and Fulgoromorpha were the most numerous and diverse species of the Hemiptera order. Cicadellidae was the most diversified family of 16 genera and 16 species identified (Table 1). From the Delphacidae family, only one species was found. Among the cicadas, *Zyginidia scutellaris* Herrich-Schäffer (58.6%) and *Psammotettix striatus* Linnaeus (26.8%) were the dominant species, with over 15% participation in the total population density. The subdominant species was *Laodelphax striatellus* Fallen, accounting for 5.4% of the cicada's total population.

Zyginidia scutellaris was an oligophage on cereal plants. It caused damage to the leaves of the plants, particularly on the underside along the major veins. That damage appeared as white dots at the site where the insect had punctured the leaf and injected its juice. In severe cases, the leaves can dry up. The species was first spotted in the crops towards the end of May, with its numbers slightly increasing until mid-June, moving in the range of 1.4–5.1 individuals per mean square meter for 2021–2023 (Fig. 4). During that period, the species had a low presence and did not cause considerable damage due to its spring migration from wintering sites, mainly *Sorghum halepense* (L.), to their hosts. However, at the end of June, a considerable increase in density of 11.8 individuals per square meter was observed as the species entered the generative period of sorghum in the flowering and seed-pouring stages. The abundance peaked at 18.9 individuals/square meter from July 6–10. Following that, there was a gradual decrease in density throughout July, with a slight increase at the end of the month, after which, the cicada participation dropped sharply and left the sorghum crops by mid-August.

Throughout the 3-year study, the population dynamics of the dominant species, *Z. scutellaris* followed a definite pattern. The highest density of this species was recorded from July 6 to 10. In 2022, the value peak was between July 21st and 25th. During the growing season, the highest density was in 2021, followed by 2023 (Table 1: $F_{2,9} = 60.184$; $p < 0.021$).

Psammotettix striatus was noticed in sorghum crops at the beginning of June, but its presence was

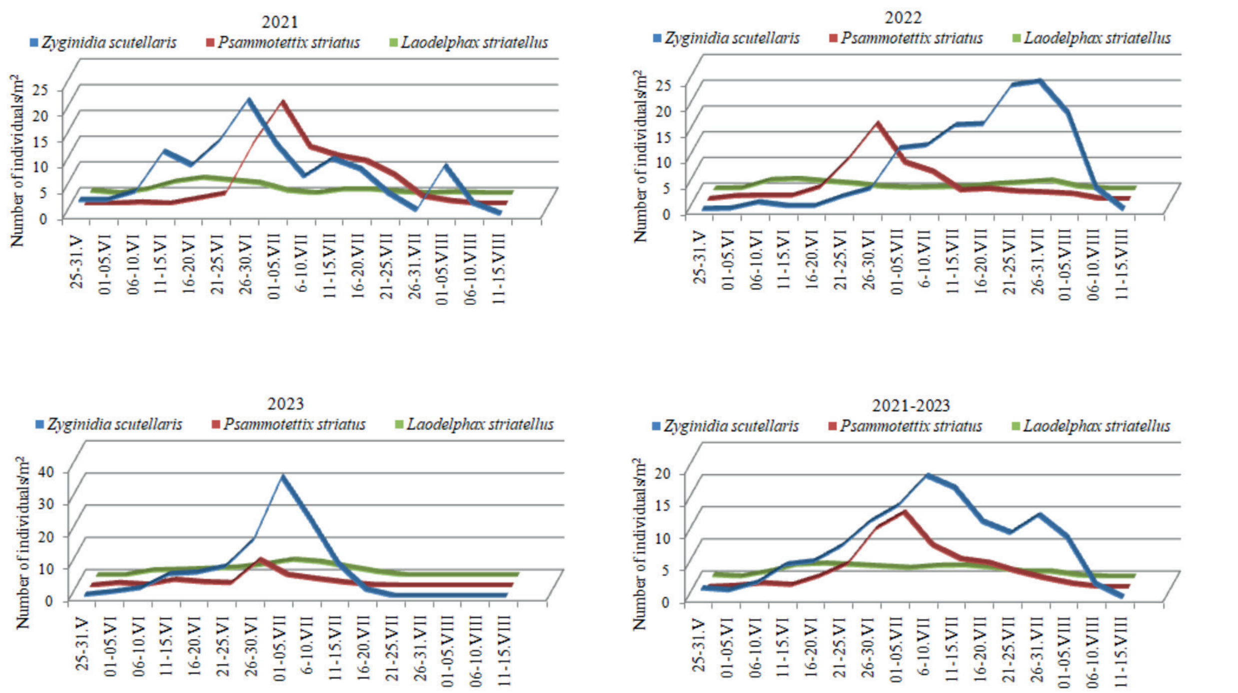

Fig. 4. Population dynamics of dominant and minor leafhopper species in sorghum *Sorghum bicolor* (L.) Moench (number of individuals · m^{-2})

weak until the second 10 days of the month. Its density increased pronouncedly towards the end of June, reaching a maximum of 11.6 individuals per square meter at the beginning of July (July 1–5). As the vegetation days in July increased, the *P. striatus* density gradually decreased from an average of 6.5 to 1.4 individuals per square meter. By the beginning of August, only a few individuals were found. The highest density was in 2021, followed by 2022 and 2023 (Table 1: $F_{2,9} = 41.093$; $p < 0.040$).

Laodelphax striatellus, a subdominant species, was observed in higher numbers during the second 10 days of June, reaching a maximum of 2.0 individuals · m^{-2} in the middle of the month. The species participation was considerably less pronounced than the previous two species but covered almost the entire studied period (May 25 – August 10). Species participation was similar over the study period (Table 1: $F_{2,9} = 18.106$; $p < 0.064$).

Empoasca pteridis Dahlbom, *Macrosteles laevis* Ribaut, *Reptalus panzeri* Low and *Philaenus spumarius* Linnaeus had a minor presence.

In summary, leafhoppers mainly participate in sorghum from mid-June to mid-July.

Cicadas, like *Z. scutellarisand* and other insects, are hypothermic and cannot regulate their internal temperature effectively. The results showed that the cicada development and reproduction regulated by temperature, was most pronounced in 2021 when their density reached the highest values for the vegetation period (Table 1).

Hemiptera: Heteroptera

Throughout the growing season, plant bugs were present in *Sorghum*. By sucking plant sap, bugs damage the youngest plant parts, stop the growth, and cause the seeds to deform.

There were 11 species from 10 different genera and five families of Heteroptera. Dominant harmful species were *Trigonotylus coelestialium* Kirkaldy (27.5%) and *Lygus rugulipennis* Poppius (21.9%), while *Nabis ferus* (31.5%) was among the useful ones. *Trigonotylus coelestialium* was present in crops from the beginning of June to the second 10 days of August, depending on the specific agrometeorological conditions in the respective year. The highest density was observed in the seed-pouring stage at the end of July 2021, followed by 2022 (Table 1: $F_{2,9} = 2.818$; $p < 0.025$) (Fig. 5). *Lygus rugulipennis* dynamics were similar.

Piercing and juice-sucking by *T. coelestialium* damaged *Sorghum*. Initially, the damaged areas of leaves displayed small, irregular yellow spots, which gradually turned white. When the number of insects was high and the damage severe (like in 2021), small spots on the plant expanded and became flakes, ultimately affecting normal plant growth. Adult and immature bugs feed on the juices in stems, leaves, or other plant parts. Young plants were highly susceptible to attack, while older plants could withstand the offense better, although they became weakened and stunted. Sorghum plant bugs prefer hot and dry weather and therefore often migrate in large numbers from wild bunch grasses into sorghum fields.

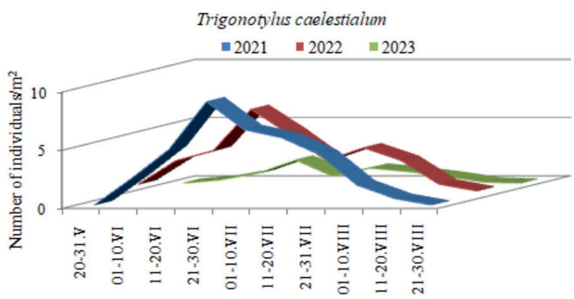

Fig. 5. Population dynamics of *Trigonotylus coelestialium* Kirkaldy, 1902 on sorghum *Sorghum bicolor* (L.) Moench, (number of individuals · m^{-2})

Several types of beneficial insects commonly occur in *Sorghum*. Generally, the entomophagous insects found in grain sorghum were the same as those in maize and other crops. Common, useful species included *N. ferus, Geocoris ater* Fabricius*, C. septempunctata, Harmonia axyridis* Pallas*, Scymnus femoralis* Gyllenhal. The predatory species *N. ferus* dominated during the third 10 days of July – the beginning of August and followed the dynamics of true bugs.

Coleoptera order

Within the Coleoptera order, specifically the Polyphaga suborder, six families, fourteen genera, and sixteen species were established, with nine being predators, primarily belonging to the family Coccinellidae. The most prevalent species were the predatory ladybird *Coccinella septempunctata*, which accounted for 25.4% of the total population density of the representatives of the order Coleoptera, and the phytophagous *Phyllotreta atra* Fabricius, which accounted for 17.5%. The subdominant predators were *Rhagonycha fulva* Scopoli (9.7%) and *S. femoralis* (8.8%), while the harmful species were *Altica lythri* Aube (6.4%), *Agriotes ustulatus* Schaller (6.2%), and *Phyllotreta cruciferae* Goeze (5.9%).

According to the study results, 55.5% of Coleoptera species exhibited a predatory lifestyle and dominated over the harmful ones. During June, predatory ladybirds, mostly *C. septempunctata*, appeared in large numbers (Fig. 3), which coincided with the reproduction of *S. avenae.* Biological control agents could successfully suppress pest populations at every sorghum growth stage.

Phyllotreta atra, by chewing numerous tiny holes in leaves, inflicted substantial damage that impaired crop growth and worsened the quality. The flea beetle appeared at the end of May and occurred until the first 10 days of August (Fig. 6). The species density increased in the second half of June and reached a maximum value of 8.8 and 2.7 individuals/m^2 during the first 10 days of July in 2021 and 2023, respectively. The maximum population value of 6.6 individuals · m^{-2} was recorded during the second 10 days of July 2022. By the end of July and the beginning of August, the participation of the species decreased. In the middle of the month, only single individuals were observed. In 2021 and 2022, a higher cabbage flea beetle number was discovered (Table 1: $F_{2,9}$ = 12.354; p < 0.010).

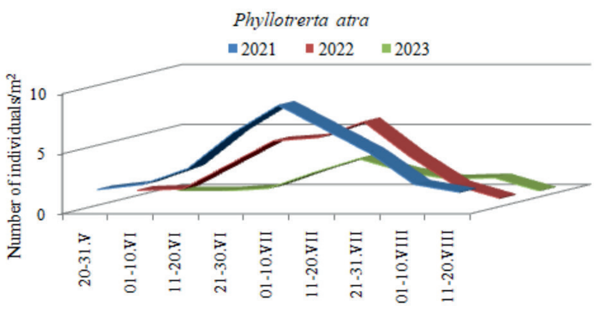

Fig. 6. Population dynamics of *Phyllotreta cruciferae* Goeze, 1777 on sorghum *Sorghum bicolor* (L.) Moench, (number of individuals · m^{-2})

Another pest from Coleoptera was *A. ustulatus*. Wireworm larvae stay underground during daylight and emerge at night to feed, cutting plants just below or above the soil surface. *Agriotes ustulatus* was a subdominant species with a lower population than *Ph. cruciferae*. There was a 3-year development that took place over 4 calendar years. The species overwintered as larvae of various ages. Adult individuals were observed from the middle of June to the beginning of July, with a higher number during the second 10 days of June (0.5 individuals · m^{-2}).

Thysanoptera order

Thysanoptera was represented by three families and four species, of which the predatory species *Aeolothrips intermedius* Bagnall had the highest numerical participation (47.1% of the total population density of representatives of the order Thysanoptera), followed by the dominant phytophagous *Thrips atratus* Priesner (28.2%) and *Haplothrips tritici* Kurdjumov (18.1%). The percent of harmful species (total 52.9%) slightly exceeded the predator *A. intermedius*, where female individuals had numerical superiority and the sex index was 0.93. Thrips were most predominant in the soft-dough stage during the second half of July. There was synchrony in the dynamics of harmful and beneficial species which revealed a potential for regulating the numbers of phytophagous thrips.

Discussion

Aphids are one of the main insect pests that suck the juice from the upper and lower leaf surfaces and stems. After head emergence, *S. avenae* moves along the panicles in separate rare columns and concentrates on classes. With mass occurrence, 50–100 larvae and adult aphids are found per class. When present in smaller numbers, aphids are typically found on the upper sides of leaves. During a massive attack, aphids cover the entire petiole. The tissue fades and later turns yellow in places where *S. avenae* suck the juice. In the case of a high attack, the leaves twist, dry, and acquire a red-brown color (Grigorov 1980). By the time discoloration symptoms are visible, plants have been injured considerably. Damage often leads to delayed maturity and plant lodging. In Bulgaria, the species was found generally in the highest density in cereal crops and is one of the main vectors for BYDV transmission (Barley Yellow Dwarf Virus) (Grigorov 1980).

Aphids feed on xylem tissues in leaves, causing changes in the host plant metabolism, upset photosynthesis, speed up tissue aging, cause morphological deformations, delay flowering, and prevent head emergence (Wilkaniec 1990; Bowling *et al*. 2016; Brewer *et al*. 2017). As per Royer *et al*. (2015), when seedlings are injured, it often leads to loss of stand, stunted growth, and delayed maturity. On the other hand, injury to larger plants causes stunted growth, smaller kernel size, and lower grain quality. The nitrogen deficiency and moisture stress symptoms are similar to damage caused by green bugs.

Sitobion avenae is a non-migratory aphid that lays eggs on plants of the Poaceae family in autumn. It has an alternating cycle of wingless forms mainly adapted to exploit aphid host plants and winged forms, displacing the species over long distances, similar to various other aphid species. Spring and summer generations reproduce parthenogenetically (without fecundation), without laying eggs through viviparous ones. Similar to the present results on population dynamics Marshall (2006) reported that *S. avenae* was frequently present in June but of short duration in most cases.

After cereal plants are harvested, the aphids move to the graminaceous grasses and move to self-seeding plants. They lay their winter eggs on fall crops and perennial wheat grasses after passing from the self-sowing plants to cereal that emerges in autumn (Grigorov 1976, 1980).

Temperature changes affect insects' life history traits, development period, and fecundity, finally determining population growth rates. *Sitobion avenae* tended to grow and reproduce at a temperature range of 5 to 30°C, whereas the optimal temperature for increasing its density was around 20–22.5°C. According to Grigorov (1976, 1980), the larvae hatched when the average daily temperature reached 5°C in the April initial days in Bulgaria. When the spring season was cooler larvae tended to hatch later. The generation's development took around 8–14 days. The parthenogenetic forms endure cold temperatures up to −10°C, as per Williams' findings in 1980. Jeffs and Leather (2014), and De Souza *et al*. (2019) found that the survival aphid rate was significantly lower when exposed to cold (1.33 h at −15°C) because of an elongated development period. On the other hand, heat stress (16 h at 30°C) significantly decreased aphid fecundity and increased the physiological development period, resulting in a reduced population growth rate.

Schizaphis graminum (common wheat aphid) was widespread throughout the country but occurred in low densities (Grigorov 1980). Aphids were found in much lower numbers than *S. avenae*. According to Maneva (2010), wheat aphids had high variability and ability to develop on different hosts and sources of resistance, including sorghum.

Canonical correlation analysis was utilized to illustrate the various relationships between the density of aphid populations and climatic variables (Fig. 7). Whereas the population was positively related to average temperature, precipitation, and humidity negatively impacted its density. It is important to note that the temperature was unequivocally associated with warmer weather in Environment 1 in 2021. In Environmental 1, temperatures varied within normal limits which favored aphid development and fecundity, with density reaching the highest values. The density was in direct contrast to rain and humidity during the wet periods in Environment 3 in 2023.

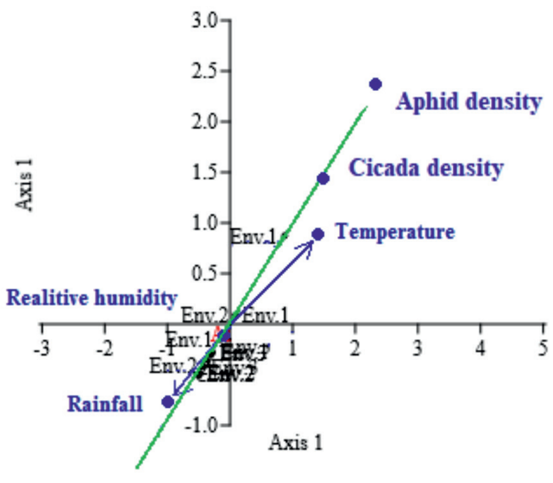

Fig. 7. CCA graph based on the correlation of population density of *Sitobion avenae* Fabricius, 1775 and cicadas for *Sorghum bicolor* (L.) Moench according to several climatic parameters. The period analyzed was from April to August

The arrow for a quantitative variable ran from the origin (center) of the diagram to an arrowhead, the coordinates of which are the correlations of the variable with the axes. The place of each element in the diagram made ample scope for interpretation. The positioning of the environmental variables in Figure 2 showed that the synthetic gradient (i.e. the explainable variation in the aphid density) was positively correlated with the temperature and negatively with rainfall and relative humidity. The second axis was strongly negatively correlated with the rainfall (ca. – 0.90) and weakly with the relative humidity (ca. – 0.1). Based on the arrow for temperature (t°C), it was inferred that Environment 1 had the highest weighted averages for t°C and density, leading to the massive occurrence of aphids at high-temperature values. Meanwhile, Environment 3 had the lowest weighted average for temperature. That was because frequent heavy rains washed the aphids off the plant leaves, and a considerable part of the *S. avenae* died. On the other hand, the varying temperatures within normal limits during the study period favored aphid development and fecundity, and its density increased.

The origin point (0.0) indicated the global average of the variable, and *S. avenae* occurred largely in Environment 1 at above-average t°C values, and nominally at lower-than-average values in Environment 3. Environment 2 had a middle-weighted average for t°C, and the aphid population took second place for the study period.

Environment 3 had the highest weighted averages for rainfall and humidity. They showed a negative effect on the *S. avenae* density, and the amount of precipitation affected the aphid development and reproduction to a higher degree. On the other hand, the length of an environmental arrow in a biplot indicated the importance of the variable and how well its values were displayed. It was equal to the maximum rate of change of the variable. Short arrows represented variables with little effect on aphid density, such as relative humidity. The variable having the highest effect on the population was temperature, followed by rainfall.

In the spring, as the weather warms, *S. avenae* larvae hatch and suck sap from the plant stems and leaves.

Species were observed only during daylight hours concerning their temporal patterns. Researchers studied the relationships between aphids and aphidophages of the Coccinellidae family and revealed that changes in their seasonal dynamics were more or less synchronized (Soleimani and Madadi 2015). Effective biocontrol of aphids required an increase in native coccinellid populations in sorghum fields before the arrival of aphids at sorghum panicle emergence, as noted in a study by Royer *et al.* (2015). According to Herrera (2012), the migration and movement of predatory ladybirds were modulated by the agricultural landscape, existing habitats, and adjacent crops that favor their population. It is important to note that usually, the ratio between aphids and predatory ladybirds was in favor of the first, which supported the statement of Grigorov (1980) that aphidophagous coccinellids played only a modifying role and were not able to regulate the population of those pests during a period of aphid mass reproduction. However, in that specific case, the control of the aphid population by aphidophagous species was efficient, as the changes in the number of predatory ladybirds were in sync with the dynamics of the aphid population. Consequently, oat aphid calamity was not observed during the study period**.**

The relationship of the cicada group with host plants is crucial since they use the plant organism not only as a food source but also as a suitable environment for fertilization and oviposition, as well as a means of communication (Holzinger *et al.* 2003). The damage from the feeding activity of cicadas is related not only to a decrease in the productivity of the above-ground biomass but also to a change in the forage quality (Kastalyeva *et al.* 2016). According to several authors, *Z. scutellaris* is a harmful, widely distributed leafhopper, found in cereal crops, including wheat, barley, and maize (Mutlu and Sertkaya 2015; Mutlu *et al*. 2017; Ardanuy *et al*. 2018).

According to a report by Mutlu and Sertkaya (2015), there was a strong *Zyginidia* species (*Z. sohrab* Zatchvakin) preference for Sorghum. As in the present studies, the authors found that the species appeared in nature as early as the middle of April, especially feeding on *Sorghum halepense* (L.) Pers. which they preferred. At the beginning of June, the leafhopper transitioned to feed on the nearby main crop of maize. Furthermore, Madeira (2014) noted that maize and other similar cereal crops had an abundance of maize leafhoppers, particularly *Z. scutellaris*, and the attendance of the predator *Orius* spp. was typically related to the leafhopper *Z. presence*.

Psammotettix striatus is a harmful insect that can cause serious damage to wheat and other cereals such as barley, oats, and sorghum and is a vector of the stolbur phytoplasma on the plants (Kastalyeva *et al*. 2016). In Bulgaria, this species is known to be a permanent pest of corn and sunflowers (Dimitrova 2010).

Canonical correlation analysis also showed an interaction between cicada population density and climate variables (Fig. 7). Like aphids, higher temperatures favored cicada numbers, while rainfall and humidity had a negative effect. Environment 1 was characterized by the highest mean temperature values and density correlated with the highest cicada participation (2021). On the other hand, Environment 3 had the highest mean values for precipitation and humidity and strongly inhibited cicada development and reproduction. Additionally, the precipitation amount had a higher negative effect on density. Cicadas had a lower weighted average for temperature than aphids. The temperature arrow is pointed in the direction of maximum change in the value of the associated variable, and the arrow length is proportional to this maximum rate of change. The population density increased markedly and was the strongest in the direction indicated by the arrow. Thus, temperature impacted the cicada population's lower range more than the aphid one.

The environmental temperature impacted the speed of all chemical reactions in the cicada life cycle. Therefore, the temperature was a crucial factor that determined the development, fecundity, population growth, and survival of cicadas (Wang *et al*. 2021), and thus cicada numbers were highest in 2021.

Another group, which damages sorghum plants is the Heteroptera species, which may not impact plant physiology significantly but gains economic importance as the reproductive stages of plant development progress. It is the most important insect pest of seed production, feeding on reproductive organs and reducing seed yield (El-Gepaly 2019; Okosun *et al*. 2021). Grain sorghum seeds are vulnerable to attack by various plant bugs. Bugs can cause considerable damage by feeding on the developing seed within the panicle during the soft and milk dough stages, leading to seed size and quality reduction, and ultimately affecting grain weight, grain size, and seed germination (Okosun *et al*. 2021).

The Coleoptera order includes beneficial and harmful species. The flea beetle, *Phyllotreta* spp., is among the most damaging insects to sorghum, affecting various plant organs during different stages of growth and development. *Phyllotreta* species impact leaf photosynthesis, according to Chunming *et al*. (2018). By chewing numerous tiny holes in leaves, they inflict substantial damage that impairs crop growth and worsens the quality. True wireworms reduce the plant's vigor, resulting in patchy seedlings and low plant density (Knutson *et al*. 2018). On the other hand, lady beetles, especially *C. septempunctata*, dominated among useful insects in the present study. According to Buntin (2012), lady beetles (Coccinellidae), syrphid larvae, big-eyed bugs (*Geocoris* spp.), Damsel bugs (*Nabis* sp.), minute pirate bugs (*Orius*), lacewings (Chrysoperla), ground beetles (*Calosoma* spp.), spiders, and numerous parasitic wasps and flies primarily dominated in sorghum plants. Ichikawa *et al*. (2016) studied the seasonal abundance of predators and their potential role in sorghum. The authors noted that syrphid and coccinellid predators were predominant and reached their peak abundance in the late summer consistent with the current study findings. These insects were successful aphidophagous predators of aphids.

From the Thysanoptera order, the predatory species *A. intermedius* had the highest numerical participation, followed by the phytophagous *T. atratus* and *H. tritici*. In contrast, Ananthakrishnan (2010) reported that *H. ganglbaueri* Schmutz and *Florithrips tragardhi* Trybom were in the highest populations infecting sorghum plants. Thrips (harmful and beneficial) prevailed mainly in the second half of July, consistent with the findings of El-Gepaly *et al.* (2019), indicating the potential of predators to regulate the number of phytophagous thrips, which is important for maintaining a stable ecosystem.

Conclusions

In sorghum, insect diversity was represented by 51 insect species belonging to 17 families and 46 genera. Harmful species made up 70.6% of the total population density of insect representatives, while beneficial (predators) – 29.4%. The insect composition included two aphid species, 17 species of cicadas, 11 species of bugs, 17 species of beetles, and four thrips species. Aphids and cicadas were some of the most important insect pests of sorghums in Bulgaria, as temperature changes affected the life characteristics of insects and ultimately determined population growth rates.

Various factors like global warming, aberrant weather, changing cropping patterns, and adoption of technologies alter insect abundance, distribution, and pest-associated losses. Work, related to the survey and surveillance of sorghum insect pests across the country should be regularly conducted to gain proper knowledge of changing trends of insect pests and associated losses. Additionally, the management practices for emerging insect pests of sorghum need to be devised or modified well in advance.

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