Ecological dynamics of *Melanaphis sorghi* in forage sorghum: effects of climate, predators, and insecticide use

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ARTICLE INFO

ABSTRACT

Forage sorghum, valued for its high protein content and resilience to abiotic stress, is key component in livestock feed production. However, it faces challenges from various insect pests such as aphids, fall armyworms, and sugarcane borers. This study investigated insect dynamics, focusing on *Melanaphis sorghi*, and their interactions with natural enemies, weather patterns, and other pests in forage sorghum cultivation. Conducted over two seasons crop in Brazil, the research compared plots with and without insecticide treatment, employing weekly insect sampling and climate monitoring. Our findings revealed *M. sorghi* as the predominant pest, with populations peaking during the vegetative stage. Correlation analysis showed a positive relationship between *M. sorghi* and Syrphidae predators, with weaker associations observed for *Spodoptera frugiperda.* The prevalence of *Rhophalosiphum maidis* increases in the second season, influenced by rainfall. Predatory insects like Coccinellidae and Syrphidae contribute to pest population control. Untreated areas exhibit higher diversity and equitability, indicating a balanced pest-predator ecosystem. Principal component analysis (PCA) suggested that the climate and specific pests exert an influence on treated areas, suggesting potential resistance or the need for more refined control strategies. This study underscores the importance of understanding pest dynamics for sustainable agriculture, providing valuable insights for the integrated pest management strategies to mitigate economic losses.

Introduction

Forage sorghum is valuable nutritional source in livestock production, primarily due to its high protein content, which is comparable to that of corn, and its greater tolerance to abiotic stresses (Simões et al., 2022). Economically, sorghum silage offers a lower production cost when compared to other forage species, such as maize. This cost-effectiveness is mainly attributed to sorghum's higher green mass production and regrowth capacity. When planted during the rainy season (between September and November, in southwest Brazil region) forage sorghum allows for a second harvest from regrowth after the first cut, increasing yield (Assis, 2021; Barros et al., 2022).

This type of sorghum is frequently infested by insect pests, such as the aphids *Schizaphis graminum* (Rondani, 1852) (Hemiptera: Aphididae), *Rhopalosiphum maidis* (Fitch, 1856) (Hemiptera: Aphididae), the fall armyworm *Spodoptera frugiperda* (JE Smith, 1797)

(Lepidoptera: Noctuidae), the sugarcane borer *Diatraea saccharalis* (Fabricius, 1794) (Lepidoptera: Crambidae), and more recently, the aphid *Melanaphis sorghi* (Theobald, 1904) (Hemiptera: Aphididae). This aphid began to be reported in Brazil around 2019, when it started causing significant damage to sorghum crops, especially in the states of Goiás, São Paulo, and Minas Gerais (Mendes et al., 2020).

The sorghum aphid *M. sorghi* is found on the abaxial side of the leaves, where it causes damage by feeding on the sap, causing necrosis and characteristic aphid spots. Intense infestations lead to the production of honeydew, a sugary liquid that can compromise the quality of the silage, promote the development of fungi such as sooty mold, and reduce photosynthesis (Peña-Martínez et al., 2023).

Understanding the role of biotic and abiotic factors in pest mortality is crucial for effective management. For example, aphid population dynamics are influenced by climatic parameters such as temperature, relative humidity, rainfall, wind, and sunlight, with precipitation being an important factor in the natural mortality of aphids in the field

(Rodríguez Del Bosque et al., 2020). Natural enemies also play a crucial role in controlling pest insects, keeping phytophagous insect populations below economically damaging levels for the crop (Mendes et al., 2018).

Given the emergence of a new biotype of *M. sorghi* in sorghum cultivation in the country, characterized by increased reproductive capacity and dispersal potential, it is essential to understand the role of each insect in the production system, as well as the factors affecting its population dynamics. Therefore, we aim to answer the following questions: i) What insect pests are present in forage sorghum crops? ii) When does the population peak of *M. sorghi* occur in forage sorghum? iii) What is the correlation between the occurrence of *M. sorghi* and: natural enemies, climatic factors, and other pest insects? This study was conducted to assist in decision-making regarding management strategies.

Material and methods

The evaluations were conducted in a forage sorghum field at Farm True Type, located in the municipality of Inhaúma, MG, in the central region of the state, with geographic coordinates of 19° 26' 03" S and 44° 29' 48" W. This large-scale farm is a major producer of forage crops. Planting was carried out on November 26th 2020 and November 4th 2021.

Sampling was conducted weekly over two distinct annual crop seasons of forage sorghum: 2020/2021 and 2021/2022. In both sample years, the study was conducted on an area of 8.7 hectares planted with the sorghum cultivar Volumax®, divided into two plots: 6.2 hectares with insecticide application and 2.5 hectares without insecticide application. The products used in the chemically controlled area are listed in Table 1. These were applied at two stages: once during the vegetative stage, when six and seven leaves were fully developed, and once during the reproductive stage, when grain formation was occurring. Within each area, four sampling points were established, with one plot kept free of any insecticide application. This resulted in a total of eight points: four in the area with pest control using chemicals and four in the area without pest control.

Collections were performed starting from the fifth week after planting, when the plants had four to five fully formed leaves.

The method employed was the plastic bag technique proposed by Waquil (1997), in which the plant and the insects present on it were collected. Insect sorting from the plants in each cultivation area was conducted at the insect ecotoxicology laboratory of Embrapa Milho e Sorgo, in Sete Lagoas, MG. The sampled plants were placed in plastic trays, where, with the aid of a brush, magnifying glass, and counter, the main species and other individuals were classified and identified, down to the family level.

Data were recorded weekly, totaling the number of insects collected and climatic data for the first season (2020/2021) from December 30th 2020 to March 24th 2021, and for the second season (2021/2022) from December 9th 2021 to February 3rd 2022. The mean number of insects per collection date is accompanied by a 90% confidence interval. Temperature was calculated as the weekly average, and precipitation values were obtained by summing weekly precipitation. Weekly meteorological data, including Precipitation (mm), Average Temperature (°C), Maximum Temperature (°C), and Minimum Temperature (°C), were obtained from the INMET (National Institute of Meteorology) database - https://portal.inmet.gov.br/).

A simple correlation analysis was performed between the total values of *M. sorghi* and various evaluated parameters. Similarly, a simple correlation between the total values of aphids with predators was calculated. For diversity indices, the number of individuals per species was used. The relative abundance (%) of the species was calculated for each studied phase. The Shannon-Wiener (H'), 1st order jackknife, Pielou's evenness (J'), and Simpson's Dominance (D) indices were calculated using the DivEs – Species Diversity® software v. 4.15 (available at https://dives.ebras.bio.br/).

Principal Component Analysis (PCA) was conducted using the JAMOVI® software to group species occurrence profiles based on the two growing seasons (2020/2021 and 2021/2022) for areas with and without insecticide use.

Results

A total of 181,803 specimens from the Aphididae family were collected during the sampling period (Table 2). Two aphid species sampled were *R. maidis* and *M. sorghi*, with the latter being the most abundant

Table 1
Chemical products used for pest insect control in sorghum crops in Inhaúma- MG, including active ingredients, mode of action, dosage and formulation.

Product	A.I	Dosage/ha	Mode of Action	Formulation	Plant stage during application
Engeo Pleno™ S®	Thiamethoxam; Lambda-Cyhalothrin	0.3 l	Contact. Ingestion. Systemic	Suspension Concentrate (SC)	Grain Formation
Pirate®	Chlorfenapyr	1.09 l	Contact. Ingestion	Suspension Concentrate (SC)	V5/V6
Nuprid 700 WG®	Imidacloprid	0.4 kg	Systemic. Contact. Ingestion	Dispersible Granules (WG)	V6/V7 V8/V9

Table 2
Total abundance, relative frequency (RF%), richness and indices of Evenness (J), Shannon diversity (H') and dominance (D) of species present in forage sorghum cultivation in Inhaúma- MG, Brazil.

| Area	2020/2021				2021/2022				Total
	With insecticide		Without insecticide		With insecticide		Without insecticide		
Rate	Total	RF (%)	Total	RF (%)	Total	RF (%)	Total	RF (%)	
Melanaphis sorghi	14.599	75.74	155.919	97.41	877	40.51	642	40.48	172.037
Rhopalosiphum maidis	4.438	23.03	3.594	2.25	1.086	50.16	648	40.86	9.766
Spodoptera frugiperda	92	0.48	131	0.08	183	8.45	280	17.65	686
Coccinelidae	8	0.04	267	0.17	5	0.23	0	0.00	280
Dermaptera	56	0.29	76	0.05	12	0.55	16	1.01	160
Syrphidae	81	0.42	71	0.04	2	0.09	0	0.00	154
Abundance	19.274	100	160.058	100	2.165	100	1.586	100	183.083
Evenness (J)	0.34		0.08		0.54		0.78		–
Richness	6		6		6		4		–
Diversity (H')	0.89		0.19		1.40		1.56		4.05
Dominance (D)	0.63		0.95		0.42		0.36		–

(97.41% of individuals). Predatory insects totaled 594 specimens, including 280 Coccinellidae covering all developmental stages (larvae, pupae, and adults), 160 Dermaptera (nymphs and adults), and 154 Syrphidae (larvae). During both growing seasons, 2020/2021 and 2021/2022, six species/families of insects were identified in both the insecticide-treated area and the area without any agricultural chemicals.

In the insecticide-treated area in 2020, 14,599 specimens of *M. sorghi*, 4,438 specimens of *R. maidis*, 92 specimens of *S. frugiperda*, 8 specimens of Coccinellidae, 56 specimens of Dermaptera, and 81 specimens of Syrphidae were found (Table 2). In the area without insecticide application, 155,919 specimens of *M. sorghi*, 3,594 specimens of *R. maidis*, 131 specimens of *S. frugiperda*, 267 specimens of Coccinellidae, 76 specimens of Dermaptera, and 71 specimens of Syrphidae were found (Table 2).

These patterns persisted in the 2020/2021 growing season, with a reduction in insect abundance in the insecticide-treated area. There were 877 specimens of *M. sorghi*, 1,086 specimens of *R. maidis*, 183 specimens of *S. frugiperda*, 5 specimens of Coccinellidae, 12 specimens of Dermaptera, and 2 specimens of Syrphidae (Table 2). In the area without insecticide application, 642 specimens of *M. sorghi*, 648 specimens of *R. maidis*, 280 specimens of *S. frugiperda*, 0 specimens of Coccinellidae, 16 specimens of Dermaptera, and 0 specimens of Syrphidae were found (Table 2).

Population peaks of *M. sorghi* in sorghum crops revealed distinct patterns in areas with and without insecticide application. In the insecticide-treated area during the 2020/2021 season, a population peak was observed during the reproductive stage of grain formation, as shown in Figure 1B, with 7,397 insects. Conversely, in the area without chemical applied, the population peak of *M. sorghi* occurred during the vegetative stage V8/V9, with 88,904 insects (Figure 1C). Additionally, right after the peak of *M. sorghi* in the non-insecticide area, a corresponding increase in the predator population was observed (Figure 1C). The peak population of *S. frugiperda* occurred in both areas at the beginning of the crop cycle. This period coincides with the stage when the plants have formed the whorl.
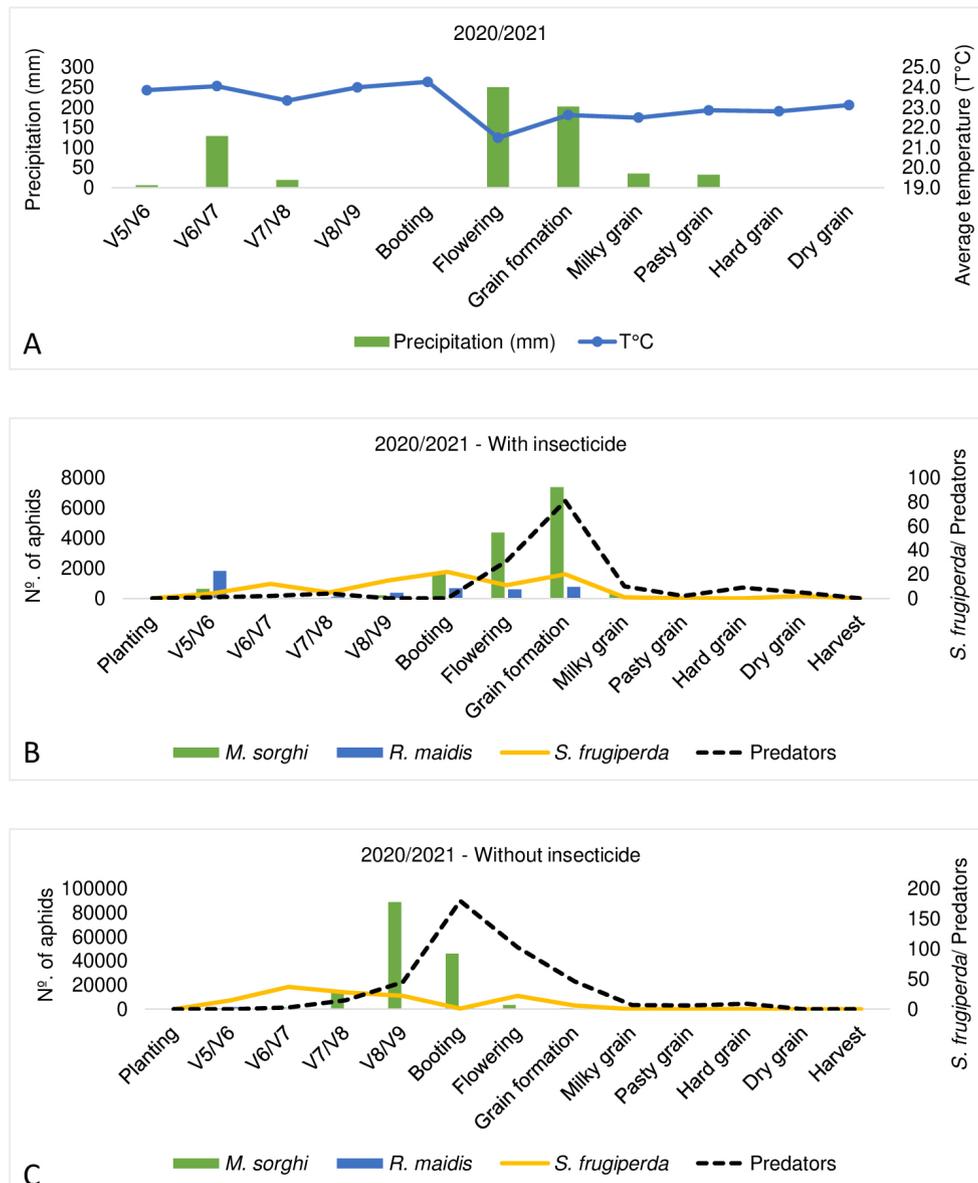
Figure 1 Weekly averages of temperature (°C) and precipitation (mm) during the 2020/2021 growing season in Inhaúma, Minas Gerais, based on historical data from local weather stations (A); population dynamics of pest insects and predators in sorghum fields treated with insecticide (B) and untreated (C), illustrating pest–predator interactions throughout the crop cycle.

In the 2021/2022 season, in both treatments, population peaks of *M. sorghi* occurred during the reproductive stage of the milky grain, with 743 specimens in the insecticide-treated area (Figure 2B) and 582 specimens in the area without insecticide (Figure 2C). For the non-insecticide area, *S. frugiperda* exhibited peaks with 88 specimens collected in the insecticide-treated area (Figure 2B) and 82 specimens in the area without insecticide (Figure 2C), both during the reproductive stages V7/V8.

The t-test proposed by Magurran (1988) for comparison between two estimated values of the Shannon diversity index showed significant differences between all diversity comparisons, according to the t-test for H' at a 5% probability level (Table 3).Correlation analysis showed a significant relationship between *M. sorghi* and Syrphidae predators (Table 4). A positive relationship was observed between all the predators found: Coccinellidae, Dermaptera, and Syrphidae, in both the insecticide-treated area and the area without insecticide application. Syrphidae is a significant group of predators in both areas, with a strong correlation of 0.993 in the insecticide-treated area and 0.892 in the area without insecticide (Table 5). It is important to note that only larval stages of

Syrphidae were collected, which are directly associated with aphid colonies and are the active predatory stage. Additionally, in the area without insecticide application, a correlation of 0.670 was observed between precipitation and the presence of *M. sorghi*.

A total of six species/families were collected in both the insecticide-treated area and the area without chemical applications. The lowest diversity (H=0.19) and evenness (J=0.08) indices for captured species were obtained in the area without insecticides during the first season (2020/2021). On the other hand, the area without chemical insecticides had higher diversity (H=0.63) and evenness (J=0.34). In the second growing season, the diversity (H=1.56) and evenness (J=0.78) indices were higher in the area where insecticides were applied. In the area without chemical applications, the diversity index was (H=1.40) and evenness (J=0.54) (Table 2).

In the 2021/2022 growing season, however, there was an inversion in dominance indices (D=0.42) for the area where chemical defenses were used (D=0.36) and for the area without insecticides. In the first season, dominance values were (D=0.63) and (D=0.95) for the areas with and without insecticides, respectively (Table 2). There was higher richness in the first year of cultivation; in the second year, richness was higher in the area with chemical defenses.

The first axis of the Principal Component Analysis (PCA) for the insecticide-treated area explained 81.2% of the total variation, and the second axis explained 16.1%. The total variation explained by the three axes was 100% (Table 6). The species/families correlated with the three components (in bold) were *M. sorghi* and Coccinellidae for the second component, and *S. frugiperda* for the third component, while the first component showed no correlation (Table 6). The abundance of *M. sorghi* and Coccinellidae was the factor in the second matrix with the highest positive weight on Component 2 (Figure 3), corresponding to the area without insecticide application. The species *M. sorghi* showed

Table 3
Comparison using the t-test (P = 0.05), of diversity values (H') in the two sampled areas (with and without insecticide) during the 2020/2021 and 2021/2022 agricultural harvests in Inhaúma - MG.

Year/ with and without insecticide	$t_{calculated}$
Comparison between H'$_{2020}$ and H'$_{2021\ without\ inseticide}$	0.0082*
Comparison between H'$_{2021}$ and H'$_{2022\ without\ inseticide}$	0.0266*
Comparison between H'$_{2020}$ and H'$_{2021\ with\ inseticide}$	0.0216*
Comparison between H'$_{2021}$ and H'$_{2022\ with\ inseticide}$	0.0174*

*Results marked with * indicate statistical significance at 5%*

Table 4
Pearson's simple correlation coefficients between *Melanaphis sorghi*, *Rhopalosiphum maidis*, *Spodoptera frugiperda*, predators, precipitation (mm), and temperature (°C) in the area with insecticide application in Inhaúma - MG, during the 2020/2021 and 2021/2022 agricultural harvests. The correlation coefficient values provide insights into the relationships between pest insect populations, predators, and the climatic variables studied.

WITH INSECTICIDE								
Species/Family	*Melanaphis sorghi*	*Rhopalosiphum maidis*	*Spodoptera frugiperda*	Coccinellidae	Dermaptera	Syrphidae	Preci. (mm)	T°C
Melanaphis sorghi	1							
Rhopalosiphum maidis	0.201	1						
Spodoptera frugiperda	0.318	0.515	1					
Coccinellidae	0.285	0.140	-0.261	1				
Dermaptera	0.228	-0.171	-0.308	0.529	1			
Syrphidae	0.993	0.165	0.286	0.293	0.301	1		
Prec. (mm)	0.001	0.160	0.165	0.628	0.595	0.035	1	
T°C	0.332	0.434	0.525	0.347	0.394	0.326	0.691	1

Table 5
Pearson's simple correlation coefficients between *Melanaphis sorghi*, *Rhopalosiphum maidis*, *Spodoptera frugiperda*, predators, precipitation (mm), and temperature (°C) in the area without insecticide application in Inhaúma- MG, during the 2020/2021 and 2021/2022 agricultural harvests. The correlation coefficient values provide insights into the relationships between pest insect populations, predators and the climatic variables studied.

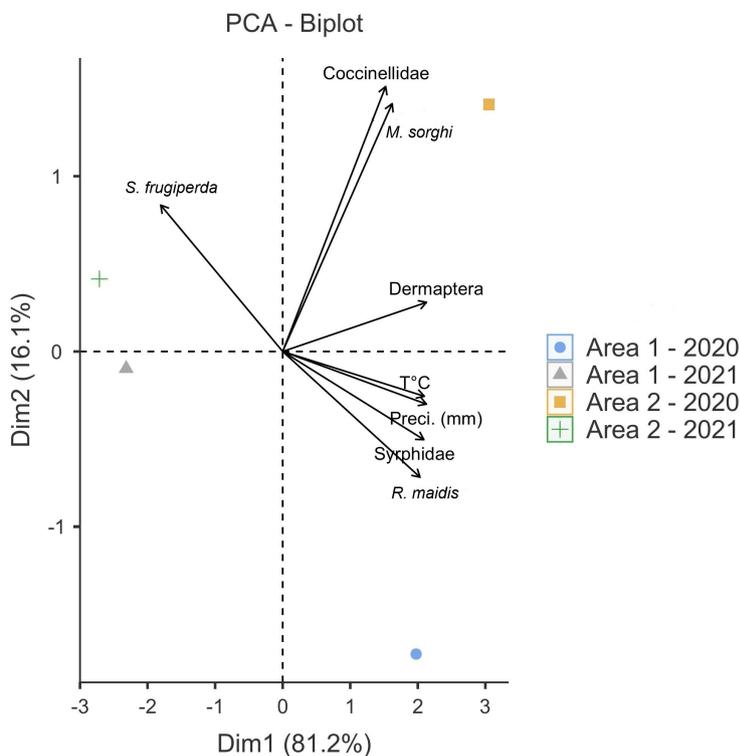| WITHOUT INSECTICIDE								
Species/Family	*Melanaphis sorghi*	*Rhopalosiphum maidis*	*Spodoptera frugiperda*	Coccinellidae	Dermaptera	Syrphidae	Preci. (mm)	T°C
Melanaphis sorghi	1							
Rhopalosiphum maidis	0.261	1						
Spodoptera frugiperda	-0.141	0.340	1					
Coccinellidae	0.049	0.309	0.333	1				
Dermaptera	0.635	-0.145	-0.397	-0.080	1			
Syrphidae	0.892	0.165	-0.086	0.150	0.372	1		
Prec. (mm)	0.670	0.333	0.123	-0.085	0.482	0.400	1	
T°C	0.371	0.563	0.517	0.412	0.115	0.214	0.691	1
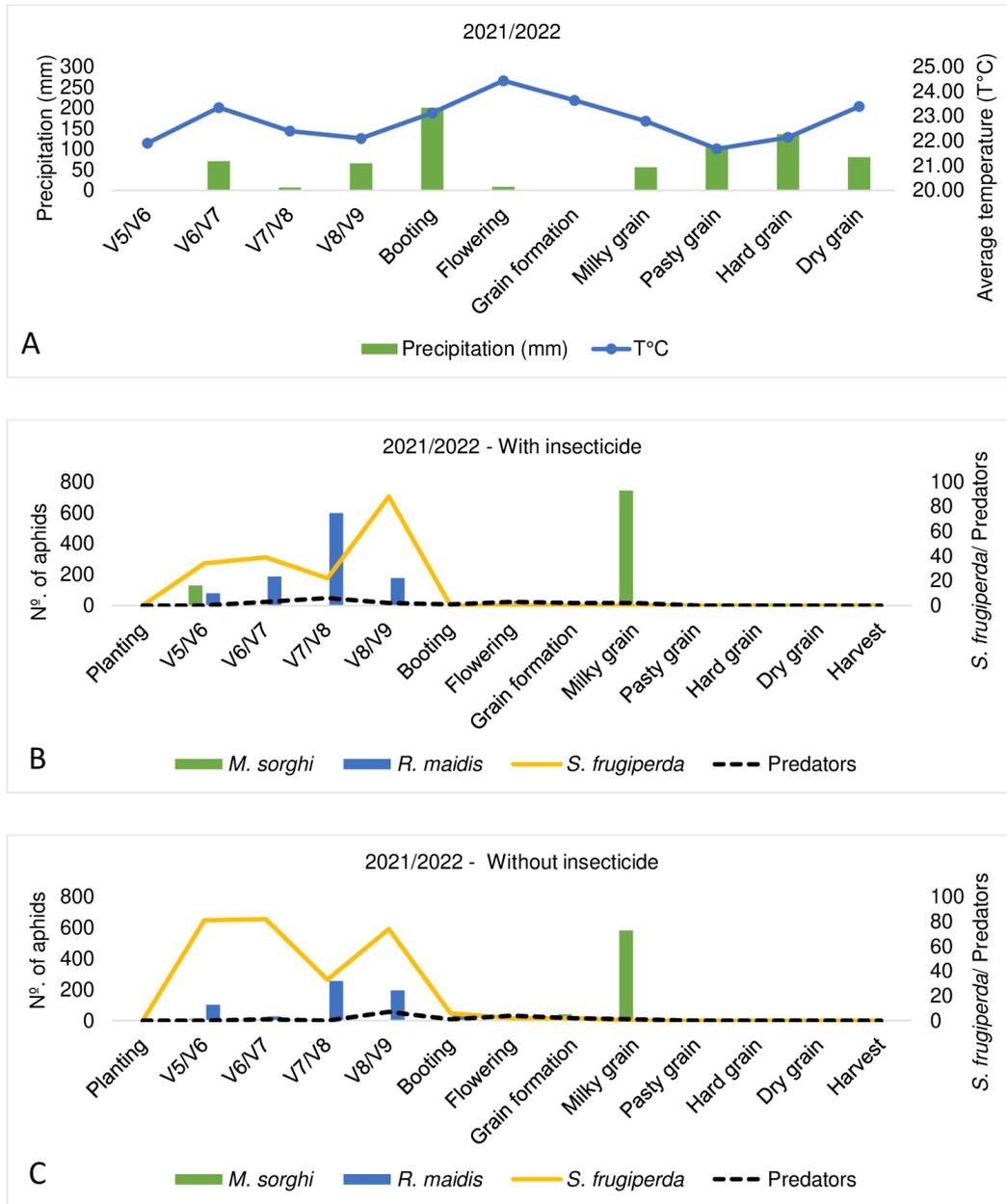
Figure 2 Weekly averages of temperature (°C) and precipitation (mm) during the 2021/2022 growing season in Inhaúma, Minas Gerais, based on historical data from local weather stations (A); population dynamics of pest insects and predators in sorghum fields treated with insecticide (B) and untreated (C), highlighting the impact of insecticide use on pest–predator relationships during the crop cycle.

Table 6

Principal Component Analysis (PCA). Percentage of cumulative variance explained and correlation coefficients of species and environmental variables with components.

	Component 1	Component 2	Component 3
% Variance	81.2	16.1	27.3
% Cumulative variance	81.2	97.3	124.6
	Correlation	Correlation	Correlation
Melanaphis sorghi	0.295	**0.578**	-0.140
Rhopalosiphum maidis	0.370	-0.293	0.019
Spodoptera frugiperda	-0.329	0.341	**0.822**
Coccinellidae	0.277	**0.618**	-0.192
Dermaptera	0.388	0.115	0.186
Syrphidae	0.381	-0.206	0.156
Prec. (mm)	0.387	-0.123	0.166
T °C	0.382	-0.104	0.425

Statistically significant values are in bold.

Figure 3 Principal Component Analysis (PCA) of pest insect species/families, sorghum predators, and environmental variables from the 2020/2021 and 2021/2022 growing seasons in areas with (Area 1) and without (Area 2) insecticide application at Fazenda True Type, Inhaúma, Minas Gerais.

a significant positive correlation with Component 1 (0.578), indicating a strong association with this component.

Similarly, the family Coccinellidae also exhibited a robust positive correlation with Component 1 (0.618), suggesting a significant relationship with this component. The species *S. frugiperda* showed a prominent positive correlation with Component 3 (0.822), indicating a strong association with this specific component.

The PCA (Figure 3) revealed three distinct groupings. Group 1 included *M. sorghi,* Syrphidae, and Coccinellidae. Group 2 comprised Dermaptera, temperature, and precipitation. Group 3 was represented solely by *S. frugiperda.*

All species and families, except *S. frugiperda*, were positioned on the positive side of axis 1. This indicates a general positive correlation among them. In contrast, *S. frugiperda* appeared on the negative side of axis 1, suggesting a negative correlation with the other insect populations and with climatic factors such as temperature and precipitation.

Dermaptera was located in a more isolated position, apart from the other groups. This suggests a weak or negligible correlation with both aphid populations and other predator families, as well as with the environmental variables analyzed. These results indicate that the dynamics of Dermaptera may be influenced by other factors not captured in this analysis.

Discussion

This study evaluated the presence of pest insects in forage sorghum crops, as well as the main groups of natural enemies. This survey updates the records of pest occurrences, population fluctuations, and the importance of pests, given that literature relies on field records of insects in sorghum from the 1990s, when insects such as *Contarinia sorghicola* (Coquillet, 1898) (Diptera: Cecidomyiidae) were still considered the key pest of the crop (Sharma and Nwanze, 1997),

or studies such as those by Kore et al. (2013) which evaluated major insect pests in sorghum crops in Maharashtra, a state in central-western India, which does not reflect agricultural conditions in Brazil. Since the 1990s, sorghum cultivation and agricultural production systems have undergone significant changes, highlighting the need for updated pest information as new insect groups attain key pest status.

Several groups of natural enemies are reported for the aphid *M. sorghi* worldwide (Colares et al., 2017). The population of predators from the family Syrphidae showed a close association with *M. sorghi*, regardless of insecticide use. This is due to the fact that it distinguished itself from other predator groups by being very frequent in the analyzed areas.

The observed association between *M. sorghi* and predators suggests a possible interaction between these organisms, with the presence of *M. sorghi* showing a significant positive correlation with Syrphidae predators, indicating an association between the presence of the predators Coccinellidae, Syrphidae and Dermaptera and the occurrences of the aphids *M. sorghi* and *R. maidis* in sorghum crops. An important point to note is the adaptation of native predators already present in sorghum cultivation areas to this newly introduced pest and their role in biological control. This was also highlighted by Colares et al. (2015), who showed the adaptation of native predators and parasitoids in Kansas to *M. sorghi*, providing natural biological control in sorghum-producing regions in the U.S.

Adult syrphids depend on flowers for nectar and pollen for energy and egg production (Haslett, 1989; Bugg et al., 2008), resources that become available when sorghum reaches the flowering stage, which coincides with the peak of predator abundance during the observation period. Meyer et al. (2009) found that syrphid density was influenced by the availability of local pollen and nectar for adults, as well as the presence of aphid-infested plants. Syrphids are rare in most field studies evaluating aphid mortality in cereals, likely due to the scarcity of essential resources for adult females (Colares et al., 2015). Our study shows a positive correlation between syrphids and *M. sorghi*, contributing to the maintenance of natural pest control in the field.

The presence of *S. frugiperda* was frequent and dominant in all evaluated situations. This was expected, as reported by Boregas et al. (2013), this caterpillar shows superior adaptation to maize, considered by Carvalho et al. (2022) as its main host, thus demonstrating adaptation to sorghum. Even the use of insecticides does not alter these ecological indices. This is evident in the PCA analysis, where *S. frugiperda* was inversely related to aphid populations and natural enemies, reinforcing the theory that *S. frugiperda* will always be present in sorghum crops, as sorghum provides the necessary condition for the pest's occurrence. Despite Montezano et al. (2018) reporting that this pest has over 350 host plant species, some authors (Moraes et al., 2020; Sisay et al., 2023) show that it has biological variables similar to maize, especially when compared to other host plants, indicating that sorghum is suitable for the pest's development. Authors such as Boregas et al. (2013); Dias et al. (2016); Mendes et al. (2018); and Carvalho et al. (2022) support this observation, showing that the pest survives better in sorghum than in maize (considered the main host). The observation of a population peak of *S. frugiperda* in the first crop year of this study, in the area without insecticide, followed by a marked reduction in the insect's occurrence, may indicate a response from the predator population to changes in prey availability, consistent with patterns observed in other studies (Gonzáles et al., 2002).

The occurrence of *R. maidis* in the area treated with insecticide was associated with *S. frugiperda* in the area treated with insecticide, while in the untreated area, its occurrence was more influenced by temperature. This difference may be explained by the fact that this pest is more common at the beginning of the crop cycle, when aphids prefer to feed on the plant's whorl, a location that offers protection to the individuals. Contact insecticides typically show significant efficacy only after the plants have flowered, a time when insects are more exposed.

Rodríguez-Vélez et al. (2021) performed a principal component analysis to find a relationship between predators and aphids in sorghum crops in Mexico. The collected species included *S. graminum, R. maidis*, and *M. sorghi*, with the latter being the most abundant and showing a strong correlation with the population of coccinellids.

In our PCA (Figure 3), *R. maidis* and *S. frugiperda* are positioned at opposite ends of axis 1, indicating a negative correlation between these species, which may reflect differing ecological preferences or temporal niche separation.

In our study, we observed a positive correlation between *M. sorghi* and predators for the area with insecticide application, and a null correlation between the aphid and precipitation for the area with insecticide.

These findings support the interpretation that natural enemies contributed to the reduction of *M. sorghi* populations, as when aphid infestations decreased, predator numbers also declined, indicating a reduction in prey availability in the field (Figures 1 and 2). Maxson et al. (2019) confirmed the development of adults of many coccinellid species fed with *M. sorghi* in the laboratory. Selected ladybug species were shown to suppress *M. sorghi* in small experimental arenas in a study by Hewlett et al. (2019).

Climatic factors significantly influence species' population growth. Specifically, rainfall followed by warm and dry periods can promote rapid pest multiplication. However, intense and frequent rains can lead to, natural control due to the direct action (Cunha Borges Filho et al., 2019). This pattern was evident in our study: a period of heavy rainfall resulted in a moderate association between precipitation and *M. sorghi*. Conversely, in areas where insecticides were applied, precipitation played a less critical role in aphid population dynamics. In the absence of insecticide, however, aphid populations showed a greater dependence on precipitation for control in the field.

On the other hand, we observed a consistent correlation between precipitation and a reduction in insect populations across both seasons. Aphid populations remained moderate until early March, but in observations at the end of the month, when rainfall volumes increased, revealed a significant reduction in population.

These studies highlight the complexity of interactions between aphids, climatic factors, agricultural management practices, and natural enemies in sorghum crops. Understanding these relationships is essential for developing effective and sustainable integrated pest management strategies. In our study, the area without insecticide application showed greater species diversity and lower dominance, indicating a more balanced ecological environment. Literature from countries where *M. sorghi* has been present for longer suggests that a broad diversity of predators and parasitoids may contribute to its biological control across its distribution range (Colares et al., 2015). However, no parasitized aphids were observed during field sampling, which may be due to specific local conditions or limitations in detection.

The Shannon index proved to be a useful tool for evaluating the structure of insect communities, revealing substantial differences likely influenced by insecticide use and high precipitation levels during the second crop year. These environmental and management-related factors appear to shape both pest and predator populations in the field.

The observed differences in species composition and abundance highlight how even subtle environmental variations can influence local biodiversity. Monitoring these changes is crucial for the conservation of natural enemies and for refining pest management strategies.

The PCA results helped elucidate relationships between insect groups and environmental variables, reinforcing the ecological role of natural enemies in regulating aphid populations. Overall, our findings demonstrate that natural enemies play a key role in maintaining *M. sorghi* infestations at low levels. This strongly supports the development of Integrated Pest Management (IPM) programs that incorporate biological control and climate factors. Given these insights it's essential to adopt management strategies for forage sorghum crops, that consider broader ecological interactions, moving beyond sole reliance on direct chemical control. Sustainable pest control fundamentally depends on understanding the dynamic relationships among pests, predators, and environmental conditions.

Future research in this area could significantly contribute to improving the productivity of forage sorghum crops in Brazil.

Conclusion

This study identified *Melanaphis sorghi* (sorghum aphid), *Rhopalosiphum maidis* (corn aphid), and *Spodoptera frugiperda* (fall armyworm) as the main pest insects in forage sorghum crops.

Population peaks of *M. sorghi* varied between crop stages and insecticide treatments: in the first year, the peak occurred during the reproductive stage in treated areas and earlier during the vegetative stage in untreated areas. In the second year, peaks occurred during the reproductive period in both areas.

A significant association was found between *M. sorghi* and predators from the Syrphidae family, suggesting these predators play an important role in controlling aphid populations.

Acknowledgments

Conflicts of interest

The authors declare no conflicts of interest.

Author contribution statement

GSA Investigation (equal); methodology (equal); analysis (equal); and writing of original draft (equal). SMM Methodology (equal); funding acquisition (equal); project and laboratory administration (equal); resources (equal); writing and editing (equal). IEM Writing, review, and editing (equal). NMS Methodology (equal); writing of review and editing (equal). DGS Methodology (equal). AVF: methodology (equal).

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