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Functional diversity of the cotton crops arthrofauna

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Abstract. Brazil stands out as the fourth-largest global producer of cotton, benefiting from favorable climatic conditions for crop development. However, these same conditions promote diverse arthropod fauna, encompassing pests and beneficial organisms that contribute ecological services to agroecosystems. This study investigated the functional diversity of arthropods in cotton cultivation under alternative management practices. For two growing seasons, arthropods were sampled and classified into functional groups: pollinators, predators, parasitoids, and detritivores. In addition, parasitized insects were recorded separately. The first season revealed low functional group richness, with only pollinators and predators observed. Diversity indices, such as Shannon and Simpson, were low across all phenological stages, with greater richness during reproductive phases. In contrast, the second season demonstrated increased richness and balance, with all five functional groups represented and higher diversity during reproductive stages. Indices reflected improved functional group distribution, indicating reduced dominance of specific groups and stabilization of the agroecosystem. The findings emphasize the significant influence of phenological stages on arthropod diversity, with reproductive phases offering critical resources for functional groups. Sustainable practices facilitated recovery and stabilization of the agroecosystem, improving richness and abundance of beneficial arthropods. These results highlight the potential of integrated, sustainable management practices in promoting ecosystem in cotton fields.

Keywords: Arthropod fauna; Cotton agroecosystem; Functional diversity; Sustainable management.

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Brazil is the fourth-largest cotton producer in the world, with production distributed across the entire country, particularly in the Midwest region of the country (CONAB 2021). The country's climatic conditions favor the development and high productivity of the crop, establishing adequate parameters for planting in 3,590 municipalities, although climate variability and the impact of water stress on productivity culminate in the decrease of these numbers (Aparecido *et al.* 2022). However, these same conditions also contribute to a diverse range of arthropods with various ecological services associated with cotton farming (Naeem-Ullah *et al.* 2020; Wilson 2020; Weigmann 2021).

Arthropods play different roles in agroecosystems, acting as pests, pollinators, predators, detritivores, parasitoids, and other functional groups (Cardoso *et al.* 2024). Pests, which are herbivorous arthropods, feed on plants, causing damage and/or transmitting entomopathogens to crops, thereby harming the health and productivity of the fields (Mahas *et al.* 2023; Leite *et al.* 2024).

According to Torres *et al.* (2022), more than 58 species of arthropods have the potential to reach pest status in cotton cultivation, which, along with factors such as field history and climatic conditions, explains the current challenges in managing these organisms.

Currently, there are different options for pest management in cotton, such as the use of biopesticides like *Bacillus thuringiensis* (Berliner, 1915) to control the caterpillar complex, the use of predatory or parasitoid bioagents, and the most widely adopted, which is the use of organosynthetic insecticides (Ahmad *et al.* 2020; Denguine *et al.* 2009). However, these substances harm other organisms within the arthropod fauna, leading to imbalances in agroecosystems (Sánchez-Bayo 2021; Ziółkowska *et al.* 2021; Cutler *et al.* 2022).

Beneficial insects such as bees, flies, earwigs, ladybugs, beetles, and true bugs, belonging to functional groups like pollinators, detritivores, parasitoids, and predators, provide essential ecosystem services but are also affected by the use of insecticides (Follett 2020; Schowalter 2022).

Insects play essential roles in agricultural ecosystems, contributing to the maintenance of biodiversity and ecological balance. They can be organized into functional groups, which are categories of organisms that share similar ecological functions, regardless of their phylogenetic relationships. These groups directly influence processes such as pollination, biological pest control, and nutrient cycling, and are affected by environmental factors and agricultural practices (Blondel 2003).

Pollinators form a functional group composed of birds, bats, small rodents, and other animals, as well as insects and other arthropods responsible for pollination interactions, which are particularly crucial for plants dependent on cross-pollination. These organisms transfer pollen grains from anthers to the androecium and gynoecium, enabling fertilization and plant reproduction (Rech *et al.* 2014). Although other animals may be included in this group, insects represent the majority, with the orders Hymenoptera, Diptera, Lepidoptera, and Coleoptera being the most representative (Wolowski *et al.* 2019).

Predators belong to a functional group of carnivorous arthropods that feed on other insects, arthropods, invertebrates, and also vertebrates, playing a fundamental role in biological pest control. They are widely used in agriculture as an alternative to synthetic pesticides, helping to regulate pest populations in crops. The main orders of predatory arthropods include Mantodea, Dermaptera, Neuroptera, Coleoptera, and Araneae (Martinez & Rocha-Lima 2020; Salustino *et al.* 2021).

Detritivorous insects, also known as saprophages, make up a functional group that feeds on decomposing organic matter, playing a key role in decomposition, nutrient recycling, and soil fertility. They are also used as bioindicators of agroecosystem health, as their presence and abundance reflect soil conditions and potential environmental disturbances (Coulis 2021; Constantino 2024).

Parasitoid insects belong to a functional group that parasitizes other organisms, developing inside or on their hosts and eventually leading to their death. Like predators, parasitoids are widely used in biological pest control, particularly in crops such as cotton. The main orders in this group are Hymenoptera and Diptera (Polaszek & Vilhemsen 2023; Parra *et al.* 2024).

The presence and abundance of functional groups in agroecosystems are determined by multiple factors. The use of synthetic organic insecticides is not the only element affecting their populations. Other crucial factors include the history of the cultivated area, such as crop succession, the implementation of polycultures or monocultures, and soil management practices.

Therefore, this study aims: 1) characterize which functional groups the arthropods associated with the cotton plant belong to, 2) evaluate the richness of these individuals and functional groups, 3) estimate the abundance of these individuals and functional groups in the 2022/2023 and 2023/2024 during the 2022/2023 and 2023/2024 growing seasons.

MATERIALS AND METHODS

The experiment was carried out at the Universidade Federal de São Carlos - Lagoa do Sino *Campus*, Buri - SP, Brazil (-23.600403, -48.531372). The weather classified as high-altitude tropical with characteristics of a humid temperate climate with dry winter and hot summer, with an average annual rainfall of 1,253 mm, and an average maximum temperature of 27.2 °C (February) and average minimum of 14.7 °C (July) (Fritzsons *et al.* 2012).

The data were collected within the *Campus* in an experimental crop area of 1 ha of cotton cultivation. The planting of the area was carried out in the 2022/2023 and 2023/2024 harvest windows. The variety sown was FM 944GL, at 1.00 m spacing between rows with a density of 8 plants per linear meter, without the application of insecticides and fungicides. Fertilization was carried out using the 04-27-10 formulation at the time of planting, and after fifteen days topdressing was carried out with urea, potassium chloride and boron. Applications of the herbicides glyphosate® were carried out; 1.6 to 2.0 L/ha, and glufosinate®; 2.0 to 2.5 L b.w./ha, for the control of weeds. Growth regulator applications were carried out from the emission of the first reproductive structures of the plant.

Arthropod sampling was carried out forty days after planting every two weeks. In each sampling, sixty georeferenced plants were evaluated, where it was sought to evaluate the same plants throughout the experiment. The evaluation period comprised the morning, from 7 am to 12 pm, and the evaluation method used was the direct counting of the insects on the plant. For each identified individual, the representatives were collected using entomological forceps and fine bristle brushes with a number 4 jar, and stored in 2 mL Eppendorf tubes with 70% alcohol. Sampling was carried out from the bottom up in order to prevent the escape of the target individuals. During the evaluations, the phenological stages of the cotton plant were also registered: vegetative, square, bloom, boll and boll opening were also determined, according to the progression of plant development.

All specimens identified in the entomofauna associated with cotton were quantified. Individuals belonging to the class Insecta were identified at the genus level whenever possible, with the exception of individuals of the order Odonata who were kept at the order level. Individuals of the Arachnida class were identified at the order level. Each arthropod accounted for in the plants was identified by comparison with previously identified individuals. When it was not possible to identify by comparison, the individual was collected and preserved in 70% alcohol, and taken for later identification in the laboratory with the aid of electronic magnifying glasses and identification keys (Kim 2017; Rafael *et al.* 2024). The classification of specimens into functional groups was based on interactions with plants and feeding habits described in the literature. The indications of functional groups follow Oliveira-Rebouças *et al.* (2022); Grandez-Rios *et al.* (2024); Reynolds *et al.* (2024).

The data collected during the evaluations were subjected to biodiversity index analyses applied to the different phenological stages of cotton, using RStudio software version 2024.09.1 (RStudio Team 2024). Diversity indices were calculated by assessing the richness of functional groups and applying the Shannon index to quantify arthropod diversity across harvests. The Simpson index was used to assess dominance by estimating the probability that two randomly selected arthropods belong to the same functional group. To better analyze the abundance distribution among groups, the Hill Series was applied, incorporating a pre-determined Hill parameter to account for different levels of sensitivity to species rarity and dominance. In addition, the Pielou evenness index was used to assess the evenness of the abundance distribution among functional groups (Jost 2006).

The dataset was analyzed separately, considering two distinct sets of data, where the first set referred to the 2022/2023 harvest data, and the second set referred to the 2023/2024 harvest data.

RESULTS

A total of one thousand six hundred and forty-five arthropods were recorded during the two season crop, being: six hundred and twenty-four individuals in the 2022/2023 season crop and eight hundred and six individuals in the 2023/2024 season crop.

Arthropods from four functional groups were recorded: predators, parasitoids, pollinators, and detritivores. In addition to the main functional groups, insects showing symptoms of parasitism caused by parasitoids were recorded as a separate observational category, rather than being classified as a functional group. This distinction was made to better capture the ecological interactions without conflating parasitized insects with established functional groups.

Arthropods from the families Coccinellidae, Anthocoridae, Anisolabididae, Chrysopidae, Anthicidae, Thripidae, Dolichopodidae, Reduviidae, Formicidae, as well as those from the order Odonata and Araneae, were assigned to the functional group "predators". Insects from the families Apidae and Syrphidae were allocated to the "pollinators" group. Individuals from the families Sarcophagidae and Braconidae were placed in the "parasitoids" group. Insects from the Tenebrionidae family were classified as "detritivores." Individuals from the Aphididae and Noctuidae families, which exhibited symptoms of parasitism, were recorded as parasitized insects, without classification into a functional group.

Ants can be considered predators due to their hunting and foraging behavior, which varies widely among species. Many are active hunters, using vision, smell, and even vibrations to detect prey, while others adopt ambush strategies or form coordinated attacks, as observed in species of the army ant group. However, the family Formicidae presents significant functional diversity, with some species being predators, while others feed on nectar, fungi, or practice kleptoparasitism, stealing prey from other colonies. This diversity reflects the broad ecological plasticity of ants and their fundamental role in ecosystems (Jauharlina *et al.* 2024).

Within the families and orders of arthropods, individuals belonging to different functional groups can be found. Since the highest taxonomic level of this research is only the genus of the individuals counted, the habit observed in the captures and/or the most prominent habit of the genera or family was taken into account.

In the 2022/2023 (first) and 2023/2024 (second) growing seasons, the functional richness was, respectively, 2 functional groups (pollinators and predators) and 5 functional groups (pollinators, predators, parasitoids, detritivores, and parasitized). For the Shannon index, the values for the first and second seasons were H = 0.26 and H = 0.91, respectively. For the Simpson index, the values were 0.13 and 0.54, respectively. For the Pielou index, the values were P = 0.38 and P = 0.56, respectively.

The Shannon, Simpson, Pielou, and Hill series indices applied to the vegetative phenological stage of cotton in the first season were, respectively, H = 0 ; 0; P = 0 and q=1. Applied to the square phenological stage, the values were H = 0 ; 0; P = 0 and q=1. Applied to the bloom phenological stage, the values were H = 0.33 ; 0.18; P = 0.48 and q=1.78. Applied to the boll phenological stage, the values were H = 0.28 ; 0.15; P = 0.41 and q=1.73. Applied to theboll opening stage, the values were H = 0.19 ; 0.09; P = 0.28 and q=1.65.

The Shannon, Simpson, Pielou, and Hill series indices applied to the vegetative phenological stage of cotton in the second season were, respectively, H = 0.54; 0.35; P = 0.78 and q = 1.92. Applied to the square phenological stage, the values were H = 0.52; 0.25; P = 0.37 and q = 2.90. Applied to the bloom phenological stage, the values were H = 0.72; 0.40; P = 0.66 and q = 2.70. Applied to the boll phenological stage, the values were H = 0.72; 0.41; P = 0.52 and q = 3.15. Applied to the boll opening stage, the values were H = 0.78; 0.78; P = 0.56 and q = 3.10.

DISCUSSION

The first crop season (2022/2023) showed low richness of functional groups, with individuals identified from only two groups: pollinators and predators. Diversity indices were low across all reproductive stages, indicating a dominance of arthropods classified as predators and low functional diversity. Regarding richness during phenological stages,

Table 1. Arthropods identified in cotton crops, classified by order, family, genus (when applicable), and assigned functional group based on ecological habits described in the literature*.

Order	Family	Genus	Functional Group
Coleoptera	Coccinellidae	*Cycloneda* Crotch, 1871	Predators
Coleoptera	Coccinellidae	*Eriopis* Mulsant, 1850	
Coleoptera	Coccinellidae	*Hippodamia* Dejean, 1837	
Hemiptera	Anthocoridae	*Orius* Wolff, 1811	
Hemiptera	Anthocoridae	*Xylocoris* Dufour, 1831	
Dermaptera	Anisolabididae	*Doru* Burr, 1907	
Neuroptera	Chrysopidae	–	
Coleoptera	Anthicidae		
Thysanoptera	Thripidae		
Diptera	Dolichopodidae		
Hemiptera	Reduviidae		
Hymenoptera	Formicidae		
Odonata	–		
Araneae			
Acari			
Hymenoptera	Apidae	–	Pollinators
Diptera	Syrphidae	*Allograpta* Osten Sacken, 1875	
Diptera	Sarcophagidae	–	Parasitoids
Hymenoptera	Braconidae		
Coleoptera	Tenebrionidae	*Lagria* Fabricius, 1775	Detritivores
Hemiptera	Aphididae	–	Parasitized
Lepidoptera	Noctuidae		

*The dash (–) indicates that the genus was not identified for that taxon.

higher richness was observed during the reproductive stages of cotton – flowering, boll formation, and open boll stages.

The results suggest that species richness and abundance are directly related to phenological stages, as the availability of food resources is greater during the reproductive period, providing more essential resources for the survival of arthropods associated with cotton plants. The management practices and history of the area also directly affected the diversity observed in the first crop season. The planting area had no prior history of cotton in the crop succession and was surrounded by fields managed with chemical agricultural pesticides.

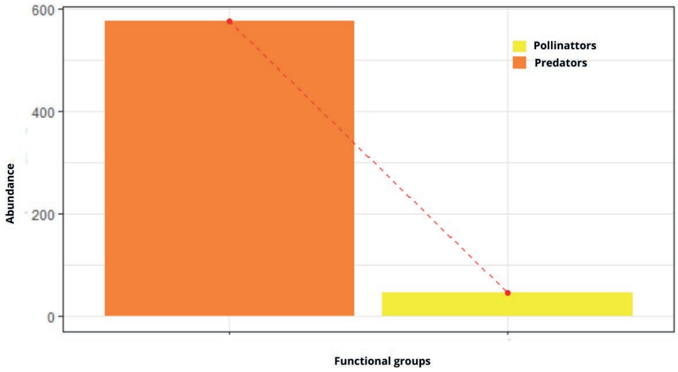

Figure 1. Abundance of functional groups 2022/2023. Collections carried out at the Lagoa do Sino Campus, Universidade Federal de São Carlos, between 2022 and 2023.

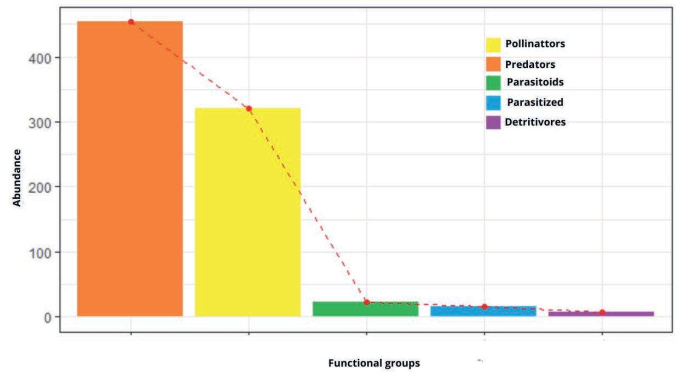

Figure 2. Abundance of functional groups 2023/2024. Collections carried out at the Lagoa do Sino Campus, Universidade Federal de São Carlos, between 2023 and 2024.

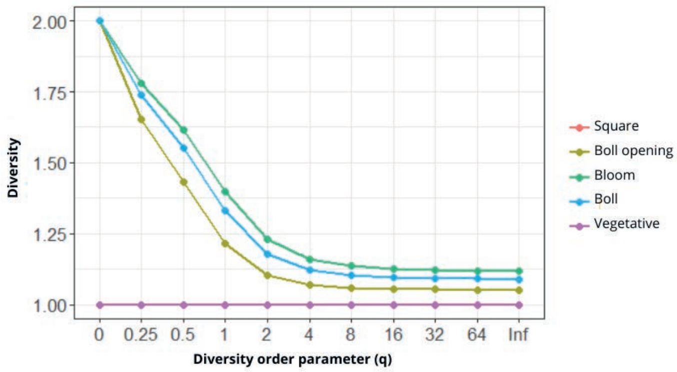

Figure 3. Diversity parameter of functional groups throughout the phenological stages 2022/2023.

The second crop season (2023/2024) showed a significant difference in the richness of functional groups. Individuals from five functional groups were identified: predators, pollinators, parasitoids, detritivores, and parasitized insects.

Diversity indices indicated greater diversity and balance in the agroecosystem's arthropod fauna during the second season. The highest functional group diversity was again observed in the reproductive stages, particularly during flowering and open boll stages. A more uniform distribution of functional groups, especially during the vegetative stage, indicated less dominance by a specific functional group.

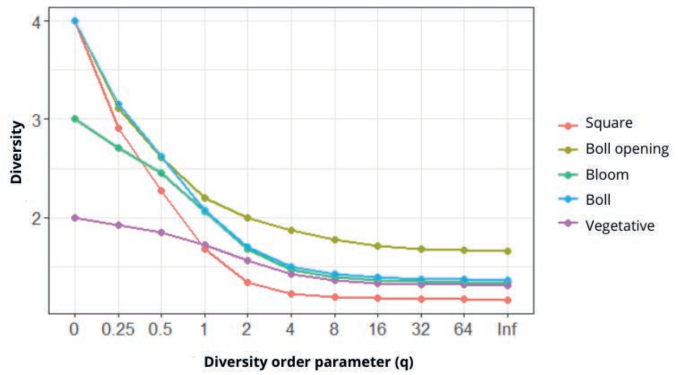

Figure 4. Diversity parameter of functional groups throughout the phenological stages 2023/2024.

The presence of phytophagous insects showing signs of parasitism indicates not only the presence of parasitoid insects but also their effective activity within the agroecosystem. Both crop seasons shared the presence of predators and pollinators as functional groups, and in both cases, they represented the most abundant groups throughout the cotton plant's cycle.

The establishment of the crop in the area using an alternative management approach without insecticides for a second consecutive season resulted in a significant increase in richness, abundance, and diversity of functional groups. This indicates that the agroecosystem tends to stabilize and further enrich functional group diversity, potentially integrating additional functional groups as well.

The adoption of alternative management practices, without the use of chemical insecticides, significantly influenced the increase in the richness, diversity, and balance of functional groups associated with cotton cultivation observed from the first to the second crop season. The impact of integrated and alternative management practices is positive for the functional diversity of agroecosystems.

Groups such as pollinators, predators, parasitoids, and detritivores play a fundamental role in establishing a healthy agroecosystem, and the conscious use of less toxic practices promotes the presence of arthropods in these groups.

The reproductive phenological stages of cotton proved to be critical for the greater richness and abundance of species, highlighting the importance of food resource availability during specific periods to support the associated entomofauna. The absence of a history of cotton cultivation and the surrounding environment managed with chemical pesticides in the first season limited the observed diversity. In contrast, the continuation of sustainable management in the second season enabled a gradual recovery and stabilization of the agroecosystem.

The greater abundance of pollinators and predators during the reproductive phases of cotton highlights the need for caution in the use of agricultural pesticides, particularly broad-spectrum insecticides, as these groups play a key role in alternative pest control and plant reproduction.

Therefore, the results indicate that sustainable management practices, aligned with phenological monitoring and the conservation of ecosystem services provided by arthropods, are promising strategies for developing more balanced and productive agricultural systems.

AUTHORS CONTRIBUTION

GBBI: Data curation; Formal analysis; Writing – original draft; Writing – review & editing; JBAB: Data curation; Methodology; PPC: Data curation; IVFF: Data curation; REPP: Data curation; CSB: Resources; DOF: Formal analysis, Software; TAA: Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

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CONFLICT OF INTEREST STATEMENT

We declare that there is no conflict of interest related to the publication of this article.

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