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ORIGINAL RESEARCH ARTICLE

Evaluation of insect diversity and prospects for pest management in agriculture

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Abstract

Insects, when harnessed as part of an agricultural sustainability initiative, can reduce reliance on chemical pesticides and fertilizers. However, their full potential has yet to be realized. Understanding the impact of these factors on insect communities is imperative for agricultural systems. The task gets complicated because of changing weather patterns, which can increase and decrease abiotic variables (e.g., climate), and biotic variables (e.g., food resources). These factors, and their effect on insect diversity, must be understood before insects can be widely used in agricultural operations. This study, conducted in Faisalabad, Pakistan, aims to add to existing knowledge of insect assemblage in an agricultural setting. Insects were collected on a monthly basis over a period of one year using yellow sticky traps, pitfall traps, sweep nets, forceps, and by direct handpicking. A total of 1503 insect specimens were collected, representing 91 species, 74 genera, and 36 families. We assessed variations in abundance, diversity, and species richness over the different months of study. We evaluate the effects of environmental factors on insects' composition using a Principal Component Analysis. In our samples, pest species were the most abundant and they were strongly influenced by temperature. There was a significant negative association of richness with wind speed, and relative humidity for herbivore insects. Overall, insect diversity mostly varied in April and October. The results revealed that relative humidity had a significant effect on the composition of insect assemblages in January, November, and December; whereas temperature had a significant effect on insects examined in May and June. The findings of this research will contribute to the further development of agricultural management systems aimed at reducing pernicious species through biological control elements.

Keywords Agricultural management · Trophic structure · Abiotic factors · Integrated pest management · Biodiversity conservation · Pesticides · Sustainable farming

Introduction

Insects serve an essential role within a thriving agricultural sector by contributing to overall ecosystem health in a variety of ways. Depending on the species, insects act as herbivores, decomposers, prey, predators, and pollinators (Scudder 2017). Furthermore, managing biodiversity on agricultural land is important from both conservational and commercial perspectives, as insects can positively impact ecosystems through prey-predator interaction, soil enrichment, and bio-indicative behaviors (Dislich et al. 2017; Luke et al. 2020). Given the value insects stand to provide, it is critical to study their communities in agricultural land, to improve crop production and conserve beneficial species (Mahmoud and Shebl 2014). The first step in this process is to conduct biodiversity assessments. This will provide commercial farmers with some of the requisite information needed to implement integrated pest management (IPM) strategies. Integration of IPM is an important sustainability initiative as it may help to curb over-reliance on pesticides by achieving a more harmonious ratio of pest-to-predator species, rather than practicing a strategy of complete eradication by chemical means.

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Utilizing predator insects to control pest species naturally is one of the exciting prospects for the future of sustainable agriculture management. As such, this idea is a central component of IPM (Stenberg 2017). Novel methods of pest control, such as those presented in IPM, can better help regulate pesticide use and guide active pest monitoring. No matter the strategy, though, understanding species diversity is key. In addition to this, the relationship between seasonality and habitats must also be evaluated to improve data usability. These factors significantly influence insect diversity, abundance, and evenness (Liu et al. 2013). Even a minor disturbance in the environment, such as unusually warm weather, can affect insect diversity and distribution. Biodiversity assessment is thus especially important for agricultural areas significantly affected by climate change, as the species density of a given community can be altered by irregular abiotic factors (Kingsolver et al. 2011; McMahon et al. 2011; Lemoine et al. 2014). It is important to associate climatic data with diversity patterns, so insect assemblage studies can reveal deeper ecosystem insights.

Indicator species have been deliberately utilized over time to monitor the health of natural habitats in response to environmental changes (Caro 2010; Carvalho et al. 2020). For example, environmental contamination can be tracked by examining changes in insect species, such as their growth inhibition, developmental abnormalities, reduced reproduction, and decreased hatchability (Iqra et al. 2015). In agricultural lands, insects commonly interact with contaminants in soil and water because of toxic pesticide use. In instances such as these, certain orders of insects are especially useful for monitoring purposes. Insects such as beetles, ants, honeybees, and butterflies are considered particularly sensitive to environmental changes (Garvita et al. 2020). Hymenoptera, including 150,000 living species of ants, bees, sawflies, and wasps (Wong et al. 2019), and Formicidae, can likewise be used as valuable bioindicators from a conservation perspective (Bution et al. 2010). Lepidoptera is also excellent for assessing biodiversity in agricultural lands (Nair 2014). Therefore, countries that derive a large portion of their GDP from agriculture could see tremendous benefits from programmatically integrating bioindication into regular practice.

Pakistan is a high agriculture producing country. Its varied topography and climatic conditions support a vast range of plants and animals. Pakistan's enormous agricultural sector uses 368,440 km^2 of land (The World Bank n.d.). This sector is responsible for 18.5% of Pakistan's GDP, and most of the nation's population depends on it for their livelihood, whether directly or indirectly. With such a heavy reliance on this industry, crop viability is crucial. Pest species, either larval or mature, pose a hazard to crop output in all farming locations, typically resulting in financial losses for farmers. To protect crops and livelihoods, farmers use chemical pesticides excessively, especially in developing countries where they are unregulated. While pesticides are generally effective at destroying pest species, they also cause a decline of non-pest species, including natural predators of pests (Khan et al. 2016). Fortunately, there are alternatives to chemical pesticides for pest management. Biological controls, such as those described in IPM literature, are effective in controlling pest infestations. However, a lack of technical knowledge regarding the implementation of such strategies results in continued chemical control reliance (Fahad et al. 2015). In addition, continual exposure to chemical pesticides is responsible for poor health outcomes in Pakistani farmers and the surrounding communities (Tariq et al. 2007). Thus, those involved with environmental pollution research are increasingly interested in insects as both a pest management and bioindication tool, to track ecosystem restoration efforts (Quigley et al. 2019).

With environmental concerns at the forefront of global development, interest in studying insect diversity through fauna collection has grown. Many researchers of biodiversity conservation have been advocating for the standardization of assessments (Ritter et al. 2017). It is imperative to identify important ecosystems from a singular and systematic perspective, to estimate insect diversity and distribution on those sites (Langor 2019). Additionally, regular studies of this nature can determine if fauna occurrences fluctuate over longer periods. Studies of this nature previously conducted in Pakistan have been limited in scope and concentrated on small areas with a few species (Majeed et al. 2019; Rana et al. 2019; Maqsood et al. 2020; Naseem et al. 2020; Ramzan et al. 2020). Building on these studies, this research further adds to available insect records that support Pakistan's agricultural industry through the development of IPM and sustainable farming strategies. Due to the lack of knowledge regarding major insect groups (Coleoptera, Hemiptera, Hymenoptera, and Lepidoptera) in Pakistan, this study aims to evaluate insect diversity within an agroecosystem in Faisalabad, Pakistan. Adequate knowledge of diversity patterns in the area will assist in managing pest, predator, and prey species. The resultant data from this study will be fundamental for understanding species presence, pest-to-predator ratios, and the impact of external factors on Faisalabad's agricultural lands. With this information, IPM may be strategized to modify the use of agrochemicals. The long-term goal in all of this is to augment sustainability efforts by utilizing insects' beneficial functions.

Materials and methods

Study area

The study area is located in Faisalabad, Pakistan, on agricultural land (Fig. 1). The Faisalabad region is situated at an elevation of 604 feet above sea level, with latitudes ranging from 30° to 31.5o N and longitudes ranging from 73° to 74o E (Nawaz et al. 2017). It is part of the alluvial plains of Punjab, with a mean annual temperature of 24.8 °C, humidity of 52.9%, and precipitation of 25.5 mm (Farid et al. 2013). An agricultural field measuring five hectares in size was selected as the sampling area. The soil in the selected study area has a sandy loam texture (Baig et al. 1990). The vegetation in the area consists primarily of crops, grasses, bushes, herbs, and shrubs. Wheat, rice, and fodder crops are the primary farming activity of the area. The abiotic conditions considered during the study were temperature, humidity, and wind speed, and the data was obtained from the Meteorology Department, University of Agriculture, Faisalabad. A large area of agricultural land in Faisalabad is largely affected by contaminants and climate change; as such, the crops are susceptible to damage (Bouraoui et al. 2019). With such vulnerabilities in perspective, this study improves on the knowledge of optimum crop cultivation and the prioritization of IPM programs for crop damage reduction in the area.

Insects sampling and identification

From January through December of 2018, samples were collected once a month. On each sampling day, 20 quadrats (each $3m^2$) were selected randomly, and insects were collected for 2 h from 08:00 to 10:00, as insects are most active during this time. Sweep nets, direct handpicking, and forceps were used for direct sampling of vegetation and crops. Simultaneously, yellow sticky traps and pitfall traps were deployed for 48 h. Yellow sticky traps were hung on small trees, primarily to capture the Hemiptera species and other flying insects. Pitfall traps were dug into the ground, cresting the surface, and filled with a formalin solution (Triplehorn and Johnson 2005). This method is mainly used for the collection of ants and sometimes beetles. Insects at rest or on shrubs were handpicked. Finally, the sampling day's temperature, relative humidity, and wind speed were recorded to verify the meteorological department's data.

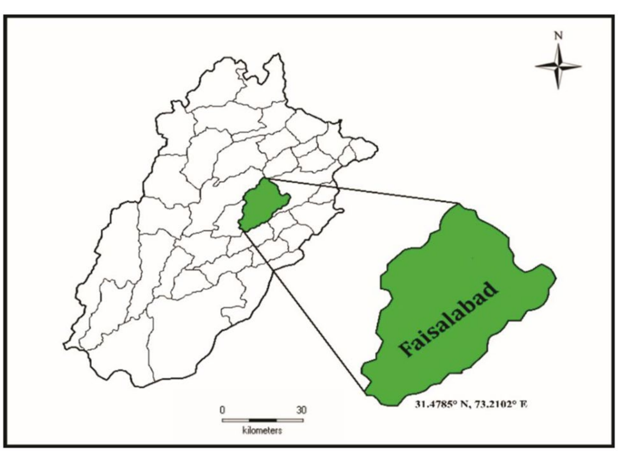

Fig. 1 Map of the sampling study area

Upon collection, each specimen was placed in a killing jar containing a 10% formalin solution. Samples were then transported to the laboratory where they were rinsed with distilled water and allowed to air dry. Based upon their orders and morphological characteristics, each specimen was placed in a separate vial to await species level identification, which was performed using microscopes accompanied by taxonomic literature (Rafi et al. 2005; Triplehorn and Johnson 2005) and taxonomic keys (www.antweb.com; www.bugnet.com). Specimens were preserved in an alcohol glycerin solution (70:30 ratio) and labeled with their corresponding scientific names. Finally, identified specimens were organized into a tabular arrangement based on their taxonomy (order, family, genus, and species).

Statistical analysis

Values obtained from each quadrat were pooled and treated as a monthly sample for statistical analysis purposes. To determine the relationship between environmental variables (temperature, relative humidity, and wind speed) and insect composition (abundance and richness of insects according to order), Generalized Linear Models (GLM) were used. A Poisson distribution was selected for this analysis as the insect diversity data relates to an integer count within a specified timeframe. A similarity dendrogram was created using the Jaccard Distance measure (Kosub 2019), which enabled the assessment of insect community patterns in the different months. Additionally, Principal Component Analysis (PCA) was used to assess the relationship between the community of insects and the environmental variables (temperature, relative humidity, and wind speed). The statistical analyses were conducted using R v. 3.6.2 (R Development Core Team 2019) and the package 'vegan' (Oksanen et al. 2018).

Results

A total of 1503 insect specimens were collected from the orders Coleoptera, Hemiptera, Hymenoptera, and Lepidoptera. These were classified into 91 species, 74 genera, and 36 families. The most commonly found order was Hemiptera (37.92% of all individuals, 31 species), followed by Coleoptera (31.87% of all individuals, 29 species), and Hymenoptera (17.96% of all individuals, 18 species). The lowest values were recorded for Lepidoptera (12.24% of all individuals,13 species) (Table S1). In the sampling of the first month (January) we collected just 11 species, while *Apis mellifera* (Linnaeus 1758) and *Exitianus spp.* (Distant 1908) were recorded mostly in the eleventh month (November) of collection. Other insect species recorded in the tenth month of collection (Oct) include *Chrysolina cerealis*, *Myzocallis* spp., *Adalia* spp. and *Camponotus* spp. (Table S1).

March, April, September, and October had the highest insect richness, whereas January, February, June, July, and December had the lowest (Fig. 2A). The same pattern was observed when comparing the abundance of insects; however, the peaks were in March and September (Fig. 2B). A significant positive relationship of abundance was found with relative humidity and temperature, while a significant positive correlation was found between richness and relative humidity (Table 1).

The increase in insect diversity was observed until April, while a declining trend was visible between November, December, and January (Fig. 3A). We observed maximum similarity in insect communities between March and April, while less similarity was observed in December and January (Fig. 3B). Relative humidity was found to have a significant effect on the composition of insect assemblages examined in November, December, and January, whereas temperature had a significant effect on insects sampled in June and July (Fig. 4).

Within specific periods, species richness varied according to the order (Fig. 5). Hemiptera is the only order that did not see a sharp decline in species richness in June, whereas Coleoptera was the only order to see a considerable rise in December. We found a significant relationship between the richness of Coleoptera, Hymenoptera, and Lepidoptera with temperature, relative humidity, and wind speed. However, for the Hemiptera species, we found a significant negative relationship between species richness and wind speed (Table 1). We observed significant positive relationships between the abundance of insects and temperature, and a significant negative relationship with relative humidity. Wind speed also showed a significant positive relationship with Coleoptera and Hymenoptera abundance (Table 1).

Based on microscopic observations and taxonomic data, we organized species into different categories. We observed that pests (37 species; 611 specimens) represented 41% of the samples collected, nearly half of all the recorded communities; followed by predators (16 spp.; 19.2%), herbivores (11 spp.; 20.56%), pollinators, polyphagous, omnivores (five spp.; 7.25% each), nectarivores, detritivores, fluid feeders (three species and less than 2% of the total fauna, each), coprophagous, parasites, and scavengers (one species and less than 1% of the total fauna, each) (Table S1). Coleoptera species represent 30% of insects classified as pests, with 9% of those classified as herbivores, and 50% as predators. Hemiptera species represent 48% of the insects classified as pests, with 45% of those classified as herbivores, and 12% as predators. Hymenoptera species represent 2.7% of insects classified

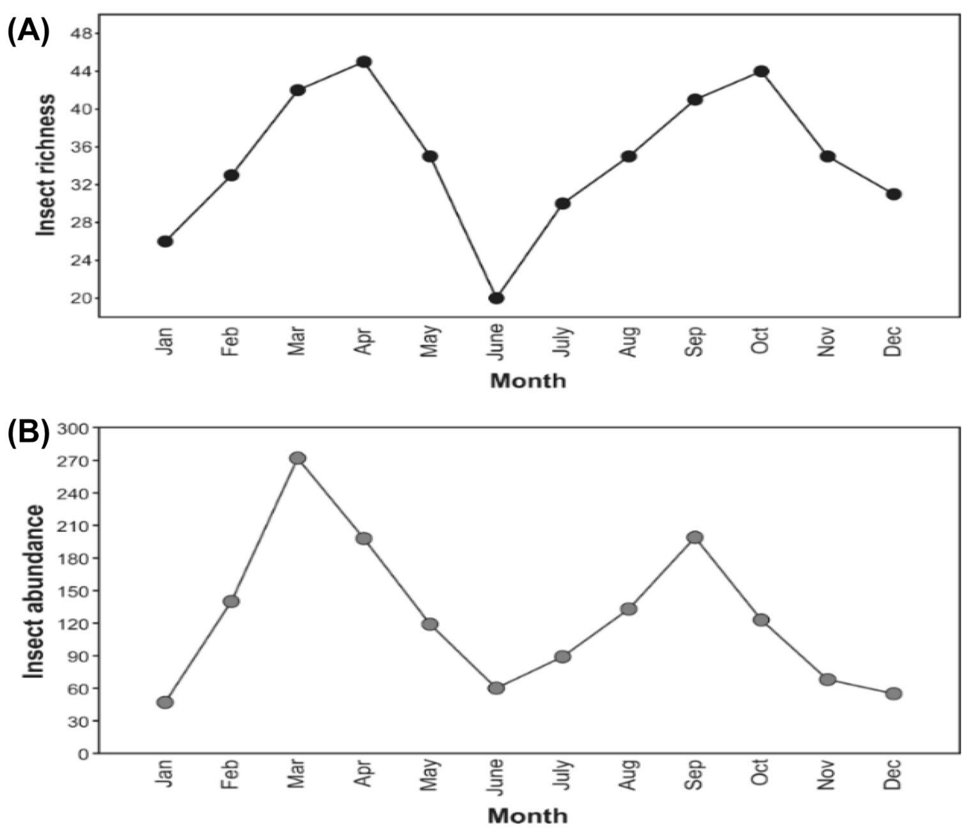

Fig. 2 Variation in (**A**) insect species richness and (**B**) insect species abundance over different sampling months

Table 1 Relationship between environmental variables and richness/abundance of insects for different classifications (Values highlighted in bold are significant. * = $p < 0.05$; ** = $p < 0.005$; *** = $p < 0.001$)

Group	Metric	Variable	*G* value	*p* value
All species	Richness	Temperature	1.701	0.192
		Relative humidity	**6.211**	**0.012***
		Wind speed	0.214	0.643
	Abundance	Temperature	**7.328**	**0.007****
		Relative humidity	**16.68**	**< 0.001*****
		Wind speed	0.663	0.415
Coleoptera	Richness	Temperature	0.284	0.593
		Relative humidity	1.175	0.278
		Wind speed	0.178	0.672
	Abundance	Temperature	**19.91**	**< 0.001*****
		Relative humidity	**39.47**	**< 0.001*****
		Wind speed	**12.30**	**< 0.001*****
Hemiptera	Richness	Temperature	0.093	0.759
		Relative humidity	0.001	0.995
		Wind speed	**5.603**	**0.018***
	Abundance	Temperature	**63.82**	**< 0.001*****
		Relative humidity	**57.19**	**< 0.001*****
		Wind speed	3.023	0.082
Hymenoptera	Richness	Temperature	0.402	0.525
		Relative humidity	1.088	0.296
		Wind speed	3.282	0.071
	Abundance	Temperature	**18.958**	**< 0.001*****
		Relative humidity	**31.31**	**< 0.001*****
		Wind speed	**37.82**	**< 0.001*****
Lepidoptera	Richness	Temperature	0.553	0.456
		Relative humidity	0.166	0.683
		Wind speed	0.004	0.948
	Abundance	Temperature	**12.687**	**< 0.001*****
		Relative humidity	**11.43**	**< 0.001*****
		Wind speed	1.795	0.180
Herbivore species	Richness	Temperature	**4.001**	**0.045***
		Relative humidity	**9.866**	**0.002****
		Wind speed	3.464	0.062
	Abundance	Temperature	7.091	0.007*
		Relative humidity	**22.22**	**< 0.001*****
		Wind speed	0.223	0.636
Pest species	Richness	Temperature	**7.778**	**0.005****
		Relative humidity	2.007	0.156
		Wind speed	0.532	0.465
	Abundance	Temperature	**22.03**	**< 0.001*****
		Relative humidity	**11.45**	**< 0.001*****
		Wind speed	0.223	0.636
Predator species	Richness	Temperature	0.089	0.764
		Relative humidity	3.710	0.054
		Wind speed	0.001	0.994
	Abundance	Temperature	0.228	0.633
		Relative humidity	**10.51**	**0.001****
		Wind speed	0.631	0.427

as pests [represented only by a single record of *Formica* spp. (Linnaeus 1761)] and 37.5% of those were classified as predators. Meanwhile, species of the order Hemiptera represented 19% of insects classified as pests and 45% of those were classified as herbivores. The trophic status coprophagous, detritivore, and scavenger were represented only in Coleoptera. In comparison, pollinators were exclusively found in the order of Hymenoptera. Fluid feeders and parasites were represented solely in Hemiptera (Table S1).

Richness for species considered pests was greatest in April, August, and October, whereas the lowest richness for this category was observed in January, February, May, and June. The observed richness was high and practically constant between February-May and September–November for predator and herbivore species. In June, only one species considered to be predatory was recorded (Fig. 6A). We observed that fluctuations in abundance recorded for the main trophic levels follow the general pattern of diversity observed for all insect species. The abundance observed for herbivore and predator species in the first peak was about twice that of the second (Fig. 6B). However, pest species showed similar values in the two peaks. For herbivores, a significant relationship of richness was found with temperature and relative humidity, while for abundance, a significant association was found with relative humidity. For pest insects, a significant relationship of abundance was found with temperature and relative humidity, while for richness, a significant association was found only with temperature. We also discovered a significant relationship between species richness and relative humidity in the predator insects (Table 1).

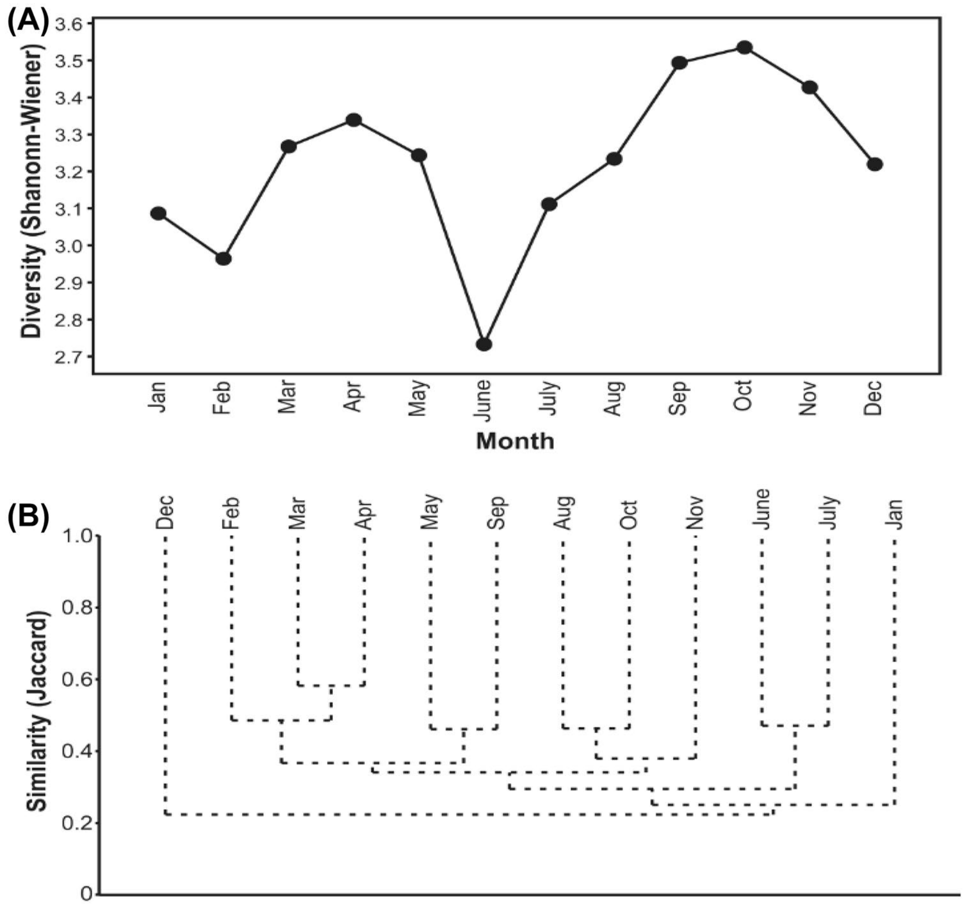

Fig. 3 (**A**) Variation in (**A**) insect diversity and (**B**) similarity in insect assemblages over the study months

Discussion

In the study area, the most prevalent orders were Coleoptera, Hemiptera, Hymenoptera, and Lepidoptera; this corresponds to research findings by Ruby et al. (2010), Niba (2011), and Roy (2014). These four insect orders are generally considered critical for agricultural ecosystems. Harihar (2013) also reported a similar pattern of insect diversity, richness, and abundance. Furthermore, as previously discussed, some insect groups may help to mitigate other harmful insects' impacts and aid biological control (Liu et al. 2019). Beetles, for instance, fulfill this role well, and they were found to have the highest richness among all groups. In addition, they function as decomposers, and are useful bioindicators predicting changes to the environment (Korasaki et al. 2013). Beetles also create microhabitats that allow other insect species to flourish (Liu et al. 2019) and promote biodiversity. Given these benefits, the findings of this study are noteworthy for this agricultural area. Future research may focus on beetles to gather more in-depth information about their uses in ecosystem management and sustainability.

Furthermore, our findings indicated that pest species were the most prevalent group across all orders within the agricultural study area. This was followed by predators, herbivores, pollinators, polyphagous, omnivores, and nectarivores. The high pest population can be attributed to the intense use of pesticides. The effects of pesticides are not limited to pests, as these chemicals also kill natural predator species due to direct chemical contact (Krauss et al. 2011; Michalko and Pekár 2017; Jacobsen et al. 2019). The use of pesticides in agriculture has increased globally during the last few decades. Thus, we can surmise that pesticide usage has likely increased in the agricultural land under study as well, potentially shifting the pest-to-predator ratio (Popp et al. 2013). Maintaining a harmonious pest-to-predator ratio is crucial to ecosystem productivity (Inayat et al. 2011; Ghosh and Kar 2014). Pest abundance varies with environmental conditions (Ahmed et al. 2016), especially with temperature, as it directly affects insect physiology and behavior (Régnière et al. 2012). The changes documented in this study also showed that the pest population is highest during the cool and dry times of the year, which was also found by Azrag et al. (2018). Given these findings, it may be possible to adjust strategies for pest management in response to changing weather conditions. Future climate change could potentially influence pest populations, altering agricultural activity in this area. Environmental changes and their impact on pest

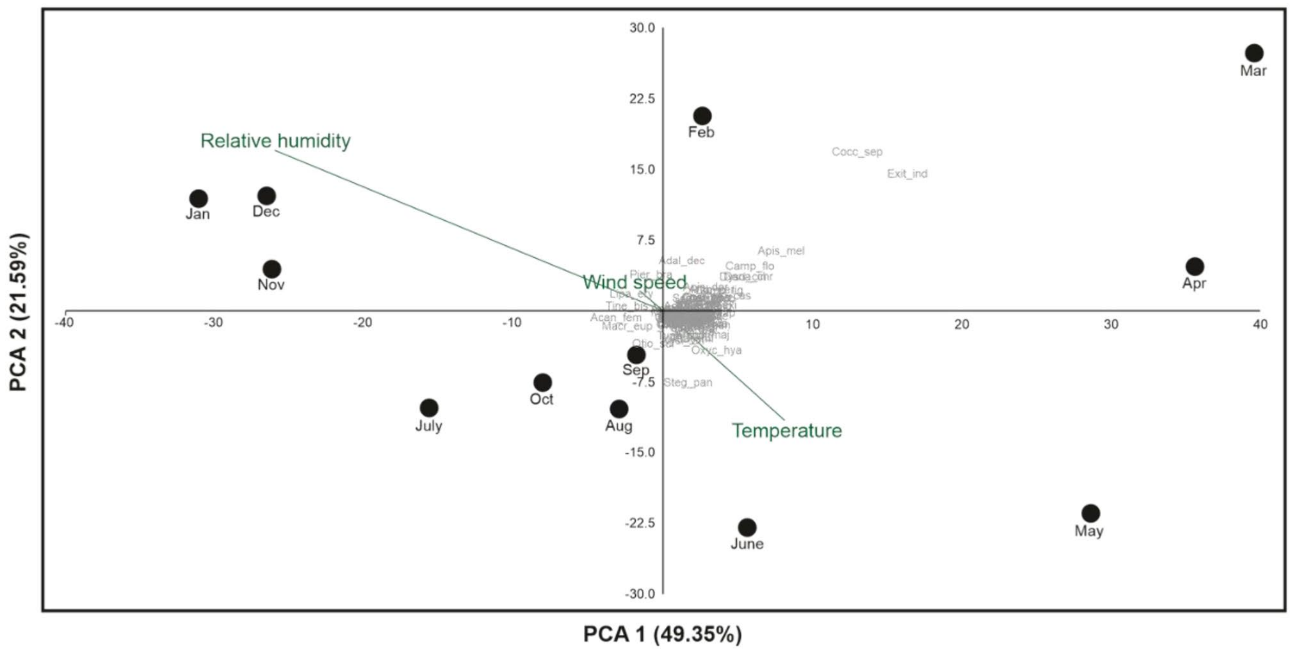

Fig. 4 Principal Component Analysis (PCA) illustrating relationship between environmental variables and insect assemblages

species need to be further researched to promote sustainable agriculture management.

The findings of this study showed that insect diversity altered with changes in temperature, precipitation, and humidity. Since factors such as temperature affect the dispersal of more discrete phenotypes in insect populations by polyphenisms, shifts in the ecosystem can occur. In past studies, it was also observed that insect communities' diversity patterns shift due to lower humidity and increased temperature (Andrew et al. 2012; Xu et al. 2013; Majeed et al. 2021). The reduction in insect diversity as temperature rises (34–36 °C) suggests that species tolerant to heat were inactive, or not present, and therefore unable to be collected. These results, along with other recent studies of insect diversity, showed that the interaction of abiotic factors has a major effect on insect diversity and distribution (de Sassi et al. 2012; Kyrö et al. 2018; Anderson et al. 2019). This is significant when forming IPM strategies, as the balance of predator and prey species will also vary according to these abiotic factors. With the data gathered from this study and others, we know that abiotic variables such as temperature and relative humidity can also be used to accurately predict insect diversity. Additionally, these findings suggest that the incidence of pest infestation could be lowered in environments where humidity can be controlled, such as greenhouses.

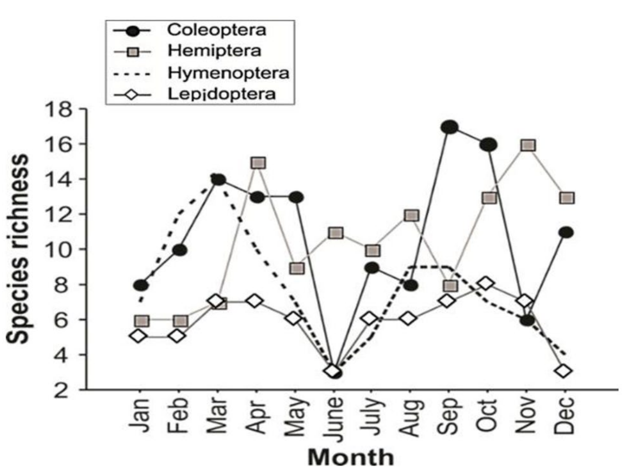

Fig. 5 Variation in species richness over the study months

This study recorded many insect families with bioindicative uses in agriculture. For instance, areas heavily affected by pollutants could be diagnosed and monitored using indicator species, such as beetles. These results may be used to begin restoration efforts surrounding our study area in the future. Wang et al. (2008) have also described in detail the abundance of insect (pest) diversity as a key factor in understanding the long-term environmental and agricultural sustainability of a given area. Moreover, as delineated in some other study results, Coleoptera species, especially those belonging to the families Elmiindae, Scarabaeidae, Gyrinidae, and Haliplidae, have been recognized as good indicators for changes in soil structure (Menta and Remelli 2020). These species play a fundamental role in maintaining ecosystem functionality by contributing to nutrient cycling, soil aeration, parasite control, and seed dispersal (Scudder 2017). Overall, the records demonstrated by this

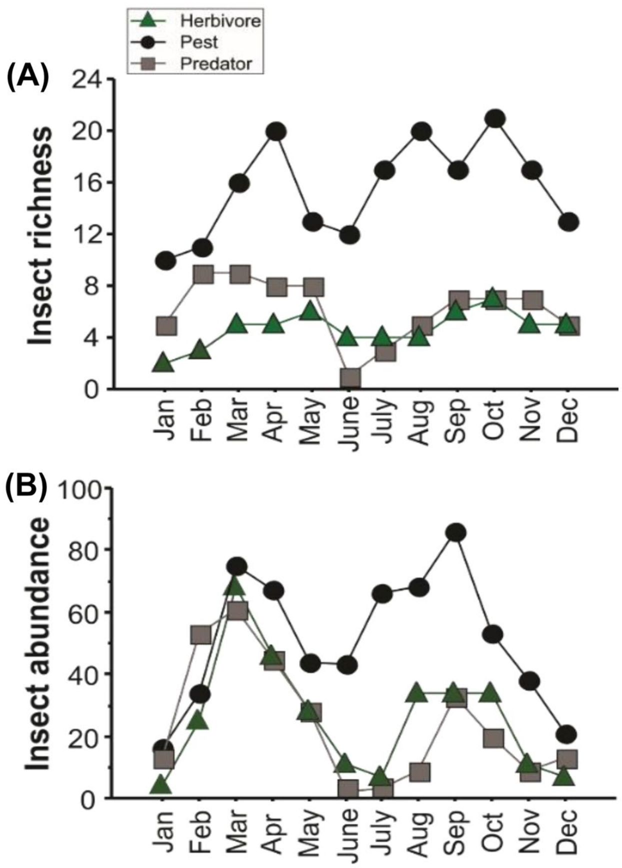

Fig. 6 Variation in (**A**) species richness and (**B**) insect abundance according to trophic classification over the study months

research can be an important step for implementing alternative agricultural techniques for pest management and soil fertility in Faisalabad's agricultural lands.

Conclusion

Through the findings of this research, a more holistic approach to pest management can be developed in the future by integrating both biological and chemical controls. The pest population was much greater than the predator population within the study area. This uneven pest-to-predator ratio is most likely due to heavy pesticide usage, as discussed previously. However, additional studies must be performed in this area to validate these conclusions. This should include a detailed evaluation of pesticide usage in these agricultural lands and its effects on the environment, insect communities, and human health. Future studies must also identify the ideal pest-to-predator ratio to optimize crop production. While this is no small task, understanding the impact of various abiotic factors is an extremely useful foundation. Though the results of this research suggest that abiotic variables strongly affect insect diversity, more studies regarding the impact of climate change and pest populations are imperative. This is especially true for areas expected to face severe effects of climate change in the coming years. Finally, gathering this information can help vulnerable countries avert food insecurity issues. While insects are traditionally viewed unfavorably in agricultural areas, changing this perspective will open new opportunities for pest management and crop production. Rather than dismissing all insects as pernicious, we must regard them as valuable tools with untapped potential. In doing so, benefits to human health and food security may be realized more efficiently.

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Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Conflicts of interest All authors declare that they have no conflict of interest.

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