ESTIMATION OF ARTHROPODS DISTRIBUTIONAL PATTERN OCCURS WITH RESPECT TO SPATIOTEMPORAL FACTOR IN CITRUS ORCHARDS OF DIFFERENT LANDSCAPES

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ABSTRACT

Decisions on land management and conservation should consider how the taxonomic and functional diversity of animal species react to land management in various locations. This study examined arthropod species diversity over space and time in four different regions (Faisalabad, Layyah, Vehari and Sahiwal) of Punjab, Pakistan. We sampled the arthropod fauna fortnightly for two years, January 2020- December 2021. A total of 16794 specimens were collected from all the sites. The highest abundance was found from Faisalabad 32.99% (n = 5542), followed by Sahiwal 26.01% (n = 4369), Vehari 23.73% (n = 3986) and the least was recorded from Layyah 17.25% (n = 2897). Diversity and abundance were greatest in Faisalabad and lowest in Layyah, while Vehari and Sahiwal had nearly similar diversity, likely because of similar environmental conditions. The highest abundance was recorded from Faisalabad orchards for *Diaphorina citri* Kuwayama, 1908 (Liviidae: Hemiptera) 5.88% (n=326), Layyah: *Coccinella septempunctata* Linnaeus, 1758 (Coccinellidae: Coleoptera) 3.97% (n=115), Vehari: *Culex quinquefasciatus* Say, 1823 (Culicidae: Diptera) 4.11% (n=164), Sahiwal: *Bactrocera dorsalis* Hendel, 1912 (Tephritidae: Diptera) 4.44% (n=194). Diversity (H) was recorded from Faisalabad 4.52 and Evenness was maximum in Layyah 0.813. Species diversity and abundance in Layyah are likely mainly affected by severe weather with fluctuating temperatures and humidity. The species richness varied along the latitudinal gradient and lower abundance was found at higher latitudes. A non-metric multidimensional scaling (NMDS) ordination showed clear clusters of regional assemblages that varied along a clear gradient. This research will assist future management and conservation of arthropods in Pakistan by providing a baseline for the diversity and abundance.

Keywords: Abundance; arthropods; diversity; ecological community; richness.

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INTRODUCTION

Arthropods seems to be undergoing a multicontinental crisis in the decline of their biomass, abundance and diversity as shown by recent regional reports and biomonitoring agents (Forister *et al.*, 2019) and keeping this decline in arthropods species needs to study in the region's sustainability of species. Both local and landscape-scale services influence the development of local communities (Adams *et al.*, 2020). They are influenced by plant diversity, habitat structural complexity, density, population dynamics, size, natural enemies and environmental factors (Ramzan *et al.*, 2021). These patterns lead to the disappearance of species-rich and diverse ecosystems, which serve as crucial habitats for many species (Cardinale *et al.*, 2018).

Arthropods perform ecosystem services such as nutrient recycling, trophic structures, decomposition, plant pollination, habitat provision and predation (Botha *et al.*, 2018; Amala and Subaharan, 2022; Chowdhury *et al.*, 2023; Nath *et al.*, 2023). Any alteration in environmental factors significantly impacts the feeding habits of arthropods and their population occurrence (Callis-Duehl *et al.*, 2017). Mainly, spatial factors have been useful for assessing the effect of climatic factors on any alteration in faunal diversity and pest interaction with predators (Defossez *et al.*, 2018). Determining the interaction of environmental gradients and their impacts on the dispersal of arthropods may provide useful information to augment biological control. The estimation of arthropods' distribution and their feeding habits in farmlands along spatial gradients remains a fundamental concern for ecologists (Descombes *et al.*, 2017; Ghahramani *et al.*, 2019).

Spatio-temporal dynamics and geographical variations in species communities are the cumulative results of habitat structure, intrinsic population dynamics and moving strategies (Cours *et al.*, 2023). The critical problem in arthropod ecology is understanding the distribution patterns of arthropod species and the underlying maintenance processes. However, there are still gaps in our understanding of the environmental conditions that shape the distribution of distinct spatial gradients in arthropod species (Guo *et al*., 2019). Lehmann et al. (2020) observed that temperature and relative humidity are considered the main factors in determining arthropods' diversity and species distribution; they may alter the species composition and community structures.

Making informed management decisions about the steps required to preserve arthropods and associated ecosystem processes at various spatial scales in agricultural landscapes requires a knowledge of how arthropods vary in response to plant variety (Mori *et al*., 2018). Dianzinga et al. (2020) revealed that arthropods' alpha and beta diversity impacts agroecosystem seasonal changes and habitat structure. The fragmentation of farmland has led to a dispersed distribution of resources at the landscape level, which significantly increases the significance of landscape structure in defining the final spatial pattern of a pest within and outside a crop field. The short-distance foraging flights of herbivores, as well as the dispersion of predators and parasitoids, are really influenced by the distribution of host plants, including alternate hosts (Sciarretta and Trematerra, 2014). Possible effects of global change on soil fauna abundance and diversity and the consequences of land use change and soil disturbance have all been examined in worldwide experiments (Wale and Yesuf, 2022). However, the temporal and spatial interspecific interactions as well as the feeding sources of insects on citrus canopies remain unclear.

In the citrus ecosystem, arthropods carry out different ecological functions that may affect the dynamics of citrus production (Pekas *et al*., 2011). It is complex ecosystems where plants have adjacent associations with inhabiting fauna because of modification in plant communities (Paudel and Tiwari, 2022; de Paz *et al*., 2023). Mansour et al. (2018) observed arthropods' diversity in citrus orchards and found pests to be the most common limiting factor in citrus production. Citrus (Rutaceae) includes diverse species of major economic importance, providing high nutritional value but also serving as hosts to numerous insect pests (Mushtaq *et al*., 2022). Pakistan produces more than 30 different fruit varieties, of which citrus makes up around 30 percent of the total fruit production in the region (Bangulzai *et al*., 2022). Punjab province produces more than 95% of citrus fruits sold through various value chains in international and domestic markets. Without much value addition, a significant portion of production is consumed locally; however, 10-12% of the total supply is exported after value addition (Siddique and Garnevska, 2018). Given the ecological and economic significance of citrus orchards in Punjab, this study aimed to quantify the Spatio-temporal diversity and abundance of arthropods across different agro-climatic regions.

MATERIALS AND METHODS

Study sites: Pakistan encompasses a rich variety of landscapes with plains, deserts, mountains and forests having 30.3753° N Latitude and longitude 69.3451° E. A preliminary survey was done from the four different districts of the Punjab viz. Faisalabad, Layyah, Vehari and Sahiwal (Figure 1). This region has distinct ecological habitats and shows seasonal variations during the entire year. In this survey, the citrus orchards were selected for the sampling/ collection purpose of the arthropod's fauna. The description of each district is given below.

Experimental Layout

Sampling of arthropods' fauna: For the sampling purpose, a field of 5 hectare was selected from each of four selected sites (Faisalabad, Layyah, Vehari and Sahiwal) of citrus orchards. There was one orchard selected from each district. The arthropods fauna was collected from all the sites fortnightly for the consecutive two years (January 2020 to December 2021) and collected 48 samples from each site. Three subunits (each 4 acres) were also made from each site as replicates. Sweep nets, pitfall traps, forceps (lightweight spring-steel and sharp-pointed depending upon the specimen structure) and direct hand-picking methods were used for collection purposes. The fauna was collected from 08:00 to 10:00 am each day of sampling for two hours using the sweep nets. The pitfall traps that were used contained 12 cm diameter plastic jars containing 10% formalin and a few drops of detergents for surface tension. The traps were dug using the gardener's trowels into the soil where their upper surface reached the upper layer. Each trap was placed at the 10 meters distance. These pitfall traps were placed for 24 hours, then specimens were collected and shifted in the glass jars.

The collected specimens from the sweep nets, forceps and handpicking were kept in killing glass jars. Some specimens such as butterflies, moths, dragonflies and damselflies were placed in the wide-mouthed jars containing the potassium cyanide as a killing agent (which was handled very carefully) (Gibb and Oseto, 2019). Specimens with fragile wings were handled separately to prevent damage. The jars were labeled with the sampling day's date, time, temperature and humidity. All specimens collected were considered one sample.

Identification: After complete sampling, these specimens were shifted to the Biodiversity Laboratory for further shifting in the glass vials. Before shifting the specimens from killing jars to the vials (having leak-proof caps), specimens were washed with distilled water using petri dishes and removed all the vegetation and soil material attached with specimens.

The glass vials were prepared with Ethanol and distilled water (70:30) for preservation and identification. The specimens having the same morphological structure were shifted in the same glass vials with sampling date and number.

The glass vials containing the specimens were used for identification purposes. For the identification, a Petri plate, glass slide, glass lens, light microscope and stereomicroscope were used. The identification was made up to the lower possible taxonomic level using different taxonomic keys, fauna of British India, books, literature, (Holloway *et al.*, 1992; Rafi *et al.*, 2005; Triplehorn *et al.*, 2005; Beutel and Leschen, 2016; Bharti *et al.*, 2016; Rasheed *et al.*, 2019; Kalkman *et al.*, 2020) internet resources and websites (https://bugguide.net, https://www.antwiki.org, https://www.antweb.org, https:// indiabiodiversity.org, https://www.insectidentification.org, https://content.ces.ncsu.edu/catal og/series/166/entomology-insect-notes). After the identification, the vials were labeled with the species name, family and order.

All the protocols were used under the ethical and safety concern provided institutional Biosafety and Bioethics committee (IBC) of university.

Statistical Analyses: After the identification and tabulation of all arthropod species in accordance with their taxonomic level i.e. Class, Order, Family, Species. The interaction of abiotic factors was computed according to the variables of the selected sites (Steel et al., 1997). Arthropods are an integral part of agroecosystems, as they balance the ecosystem functioning and play an important role in the sustainability of global biodiversity. Hence, the species dynamics of arthropods were elucidated by the Diversity Index. The diversity indices were used to find the Shannon diversity index, richness, evenness, dominance, Simpson index (Shannon, 1948; Simpson, 1949; Ludwig and Reynolds, 1988; Magurran, 1988a; b) and community structure. The detail is given below:

Diversity Indices for measurement of species diversity and richness

Shannon's Diversity Index (H'): Data were analyzed to determine the species diversity with the

$$\text{Shannon diversity index } (H') = -\Sigma\ (pi \ln pi)$$

Dominance Index

$$D = \Sigma(pi^2)$$

Evenness Index

$$\text{Evenness } (E) = H' / \ln S$$

Simpson Index

$$\text{Simpson Index } (1 - D) = 1 - \Sigma\ (pi^2)$$

Individual based Rarefaction and Species Accumulation Curve: Individual based Rarefaction curve was plotted using the number of species against the number of samples data. This curve was made by random pool of N samples and then plotting average number of species found on each sample. This aimed to test if a particular sample has enough sequence information to accurately reflect its identity (Colwell *et al.*, 2012; Colwell and Elsensohn, 2014). A species accumulation curve was drawn to determine the observed species' expected number (Colwell *et al.*, 2004).

A Generalized Linear Model was used to assess the effects of environmental variables (temperatures and relative humidity) on the abundance and richness of arthropods. Orders richness and abundance were considered as response variables while districts and climatic factors were predictor variables. As all abundances were count data, GLMs were fitted using a Poisson distribution error and log link function. Jaccard Distance measure a similarity dendrogram was created (Kosub, 2019), which enabled the assessment of insect community patterns in the different months.

Non-metric Multidimensional Scaling (NMDS): Non-metric Multidimensional Scaling (NMDS), a rank-based multivariate analysis, was applied to correlate the dissimilarities of species abundance and elucidate the relationships among arthropod species and their sample-wise occurrence in all habitats. The R functions metaMDS and envfit were used to run NMDS. The stress value was observed 0.079.

Redundancy Analysis (RDA): Redundancy Analysis RDA was used to examine the relationship between arthropods assemblages and the explanatory variables (Legendre and Legendre, 1998). We developed an ordination (Redundancy Analysis–RDA) approach to test for the association of arthropod composition with environmental variables while controlling for geographic separation between sampling areas. Species were selected for inclusion through the 'ordistep' function in 'vegan'. Redundancy analysis ('rda'in 'vegan') was then performed on the composition of insect species with geographical distance as a conditioning variable.

Principal Coordinate Analysis (PCoA): Principal Coordinates Analysis (PCoA) was used to explore and visualize similarities or dissimilarities of data (Zuur *et al.*, 2007).

The data were analyzed using the software i.e., Microsoft Excel, Graph pad prism, PAST4.03 (Hammer *et al*., 2001), R Studio and base. The R version v.4.3.0 and the package' vegan' was used for analyses (R Development Core Team 2023) (Oksanen *et al*., 2019). All the statistical analyses were performed at the significance level of α = 0.05.

RESULTS

Population abundance of Arthropods: A total of 16794 specimens were collected from all the sites. The highest abundance was recorded from Faisalabad 32.99%, followed by Sahiwal 26.01%, Vehari 23.73% and least was recorded from Layyah 17.25% (Figure 2).

Taxa Composition: The arthropod taxa compsotion recorded from Faisalabad was 11 orders, 61 families, 141 species; from layyah 9 orders, 39 families and 75 species. Vehari had 10 orders, 48 families and 101 species, while Sahiwal pertained 11 orders, 53 families and 113 species (Table 1).

Relative abundance up to order level: Arthropods were recorded during the current research work from Faisalabad having lowest abundance (0.22%) from Dermaptera and highest (32.22%) form Diptera (Table 2). (Figure 3A). From Layyah, the highest relative abundance was found for order Diptera. The order Blattodea and Dermaptera were not found from Layyah (Table 2) (Figure 3B).

From Vehari, the highest relative abundance was found for order Diptera (n=1522) and the lowest for order Neuroptera (n=5). The only order Dermaptera was not found (Table 2). The maximum percentage was 38.18% for order Diptera (Figure 3C). From Sahiwal, the highest relative abundance was found for the Diptera (n=1704) (Table 2). The highest percentage was (39%) for order Diptera (Figure 3D).

Relative abundance up to species level

Faisalabad: The highest relative abundance was recorded from Faisalabad orchards for *Diaphorina citri* (Liviidae: Hemiptera) (n=326), followed by *Coccinella septempunctata* (Coccinillidae: Coleoptera) (n=195), *Tanytarsus* sp. (Chironomidae: Diptera) (n=179) and *Musca domestica* (Muscidae: Diptera) (n=125). While least species recorded from Faisalabad were *Agonischius* sp. (Elateridae: Coleoptera) (n=2) and *Aphodius* sp. (Scarabaeidae: Coleoptera) (n=3) (Table S1).

Layyah: The highest relative abundance was recorded from Layyah orchards for *C. septempunctata* (n=115), followed by *Tanytarsus* sp. (n=109), *Bactrocera zonata* (Tephritidae: Diptera) (n=102) and *Bemisia tabaci* (Aleyrodidae: Hemiptera) (n=92). While least species recorded from Layyah were *Crocothemis* sp. (Libellulidae: Odonata) (n=6) and *Macrosteles* sp. (Cicadellidae: Hemiptera) (n=7) (Table S1).

Vehari: From Vehari, highest abundance was found for *Culex quinquefasciatus* (Culicidae: Diptera) (n=164), followed by *Tanytarsus* sp. (n=144), *C. septempunctata* (n=124) and *D. citri* (n=124). Whereas least recorded species were *Ceriagrion* sp. (n=2) (Coenagrionidae: Odonata) and *Asteiidae* sp. (Asteiidae: Diptera) (n=4) (Table S1).

Sahiwal: The highest relative abundance was recorded from Sahiwal orchards for *B. dorsalis* (n=194), followed by *Tanytarsus* sp. (n=185) *Drosophila suzukii* (Drosophilidae: Diptera) (n=153) and *C. septempunctata* (n=128). While least species recorded from Layyah were *Catopsilia* sp. (Nymphalidae: Lepidoptera) (n=2) and *Lestes* sp. (Lestidae: Odonata) (n=2) (Table S1).

Diversity Indices: The maximum Diversity H was recorded from Faisalabad 4.52, followed by Sahiwal 4.25, Vehari 4.19 and least from Layyah 4.11. The Evenness was maximum in Layyah 0.813 followed by Vehari 0.699, Sahiwal 0.664 and minimum for Faisalabad 0.653. Dominance was higher in Layyah 0.019 and less in Faisalabad 0.015. Simpson was maximum in Faisalabad 0.984 followed by Sahiwal 0.983, Vehari 0.982 and Layyah 0.980. Margalef richness was recorded highest from Faisalabad 15.24 and lowest from Layyah 9.28. Other diversity factors are also presented in the Table 3.

Individual-Based Rarefaction Curve: The species richness rarefaction curve explained that most rare species were present in Faisalabad, while Sahiwal and Vehari showed likely similar plateau of the curve. The Layyah showed less species richness when compared to all other regions (Figure 4 and 5). Figure 6 detailed that the Shannon diversity was higher in the Faisalabad region and lower in the Layyah, while both (Vehari and Sahiwal had the average diversity). The similarity was calculated using the Jaccard index and found less than 20% similarity when considering the presence and absence of arthropod species. The cophenetic correlation was 0.899 and ≥ 0.8 indicates dendrogram reasonably fits dissimilarities (Figure 7).

The species richness and abundance were correlated with the temperature and relative humidity. It was found that the overall temperature influenced the species abundance more than the humidity. In the order Araneae, temperature was significantly correlated with abundance for all territories except Vehari while, non-significant with relative humidity. Species richness was also significantly correlated with temperature while relative humidity showed a non-significant correlation in Layyah and Vehari. The order Coleoptera species richness and abundance were significantly correlated with the temperature and humidity in Faisalabad, Vehari and Sahiwal, while species richness was non-significantly correlated with the temperature and humidity only in Layyah.

The species abundance and richness of order Diptera was significantly correlated with the humidity and temperature except in Layyah where arthropods fauna non-significantly correlated with humidity. In the order Hemiptera, species richness was significantly correlated with temperature while, humidity showed non-significant results in all regions except Faisalabad. The abundance was significant with temperature and was non-significant with humidity in Vehari and Sahiwal. The species abundance and richness of order Hymenoptera were significantly correlated with the temperature and humidity in all sites except in Layyah where fauna non-significantly correlated with humidity.

In the order Lepidoptera, the richness and abundance were not found significant from all the sites except the abundance in Faisalabad and Sahiwal. There was no significant interaction in Faisalabad and Layyah for order Odonata while, richness and abundance in Vehari and Sahiwal showed significant correlation with temperature and humidity. Order Orthoptera showed the significant interaction with humidity and temperature with respect to species abundance and richness, while the species richness was not significant with relative humidity in the Layyah region (Table 4).

Non-Metric Multidimensional Scaling (NMDS): The arthropods community composition varied among four areas viz. Faisalabad, Layyah, Vehari and Sahiwal. A PERMANOVA test demonstrated that taxonomic compositions of arthropods communities were significantly varied among different habitats (p = 0.001). Meanwhile, the NMDS plot results demonstrated that the arthropod species from different regional habitats varied with occurrence. There was a clear cluster difference and smooth gradient in one direction across the samples from the four different regions (Figure 8).

The arthropod species communities were clustered into an ordination plot using the PCoA based on the bray-Curtis distance matrix. The PCoA analysis of the first and second axes explained together percent (%) of the total variance. The variance was largely explained by the order Diptera, Dermaptera, Neuroptera, Blattodea, Araneae and Odonata (Figure 9).

Redundancy Analysis (RDA): It was observed that the temperature and humidity factor influenced the species occurrence. Both axes of RDA retained for interpretation were significant (F= 4.5175; p < 0.001) and constrained inertia 16.7% (Table 5). In the Faisalabad site the species Di. ci., Phy. Ci., P. wa. and P. car. were positively correlated with temperature and B. zo., Spo. sp. showed negative correlation. The B. zo, A. go showed somewhat positive correlation and Sc. Gr, Dy, ci, cl. Sp., C. sep., E. co were negatively correlated with humidity (Figure 10a). In Layyah site, species He. Ar., D. su., P. wa., C. sep., Di. ci. were positively correlated with temperature and B. zo. negatively correlated. The Spo. sp showed a positive correlation and weak positive Ste. sp. while C. sep., P.wa., Phy. Ci., Ve.s. sp., D. su were negatively correlated with humidity (Figure 10b). Both axes of RDA retained for interpretation were significant (F= 2.9928; p < 0.001) and constrained inertia 11.5% (Table 5).

In Figure 10c, the species B. br., V.e.sp. were increased positively with increasing humidity level while negatively correlated species were He. Ar., B. coc., I. Sp. The temperature showed a positive correlation with B. do., Rho. Sp., He. Ar., P. wa. and B. br. Spo. sp. was in negative relationship. The axes of RDA retained for interpretation were significant (F= 2.9687; p < 0.001) and constrained inertia 11.7% (Table 5).

The axes of RDA retained for interpretation were significant (F= 3.4201; p < 0.001) and constrained inertia 13.2% (Table 5). In Sahiwal site, the species Sce. sp were positively correlated with humidity and B. zo., Ep. vi., Dy. ko. negatively correlated. The Di.ci., He. ar. showed positive correlation while Mon. sp. showed weak negative correlation with temperature (Figure 10d).

Table 1: Taxa compositon of arthropods recorded from all the terrioties

Taxa Composition	Faisalabad	Layyah	Vehari	Sahiwal
Order	11	9	10	11
Family	61	39	48	53
Species	141	75	101	113

Table 2: Relative abundance of arthropods' different orders recorded from all the territories.

Order	Faisalabad	Layyah	Vehari	Sahiwal	Total
Arachnida					
Araneae	2.74(152)	1.97(57)	1.23(49)	1.08(47)	1.82(305)
Sub-total (a)	2.74**(152)**	1.97**(57)**	1.23**(49)**	1.08**(47)**	1.82**(305)**
Insecta					
Blattodea	1.50(83)	0.00(0)	0.43(17)	1.53(67)	0.99(167)
Coleoptera	14.71(816)	13.98(405	8.53(340)	10.12(442)	11.92(2003)
Diptera	32.22(1787)	27.48(796)	38.18(1522)	39.00(1704)	34.58(5809)
Dermaptera	0.22(12)	0.00(0)	0.00(0)	0.78(34)	0.27(46)
Hemiptera	16.86(935)	15.48(459)	15.18(605)	14.01(612)	15.57(2611)
Hymenoptera	15.27(847)	17.54(508)	17.31(690)	13.07(571)	15.57(2611)
Lepidoptera	7.32(406)	11.29(327)	6.97(278)	9.29(406)	8.44(1417)
Neuroptera	0.56(31)	0.31(9)	0.13(5)	0.18(8)	0.32(53)
Odonata	1.60(89)	3.07(89)	3.06(122)	3.71(162)	2.75(462)
Orthoptera	6.92(384)	8.53(247)	8.98(358)	7.23(316)	7.77(1305)
Sub-total (b)	97.26**(5390)**	98.03**(2840)**	98.77**(3937)**	98.92**(4322)**	98.18**(16489)**
Total (a+b)	**5542**	**2897**	**3986**	**4369**	**16799**

Table 3: Diversity indices recorded from all the territories

Diversity factors	Faisalabad	Layyah	Vehari	Sahiwal
Diversity H	4.52	4.11	4.19	4.25
Evenness e^H/S	0.653	0.813	0.699	0.664
Dominance D	0.015	0.019	0.017	0.018
Simpson 1-D	0.984	0.980	0.982	0.983
Brillouin	4.46	4.04	4.19	4.25
Menhinick	1.89	1.39	1.6	1.71
Margalef	15.24	9.28	12.06	13.36
Equitability J	0.914	0.952	0.922	0.913
Fisher alpha	26.34	14.06	18.85	21.19
Berger-Parker	0.058	0.039	0.041	0.044
Chao-1	141	75	101	113

Table 4: Relationship of environmental variables with richness and abundance of arthropods (* = *p* < 0.05, ** = *p* < 0.005, * = *p* < 0.0001; non-significant = *p* > 0.05)**

Order	Metric	Variable	Faisalabad	Layyah	Vehari	Sahiwal
			p-value	***p-value***	***p-value***	***p-value***
Araneae	Abundance	Temperature	*	*	**> 0.05**	*
		Relative humidity	**> 0.05**	**> 0.05**	**> 0.05**	**> 0.05**
	Richness	Temperature	**	**	*	*
		Relative humidity	**	**> 0.05**	**> 0.05**	*
Blattodea	Abundance	Temperature	*	**NIL**	*	*
		Relative humidity	**> 0.05**		**> 0.05**	**> 0.05**
	Richness	Temperature	*		*	**> 0.05**
		Relative humidity	**> 0.05**		**> 0.05**	**> 0.05**
Coleoptera	Abundance	Temperature	***	*	**	**
		Relative humidity	**	*	*	**
	Richness	Temperature	***	**> 0.05**	*	*
		Relative humidity	*	**> 0.05**	**	**
Diptera	Abundance	Temperature	***	*	**	**
		Relative humidity	**	*	*	**

	Richness	Temperature	***	*	*	**
		Relative humidity	**	**> 0.05**	*	*
Dermaptera	Abundance	Temperature	*	**NIL**	**NIL**	*
		Relative humidity	**> 0.05**			*
	Richness	Temperature	**> 0.05**			**> 0.05**
		Relative humidity	**> 0.05**			**> 0.05**
Hemiptera	Abundance	Temperature	**	*	*	*
		Relative humidity	*	*	**> 0.05**	**> 0.05**
	Richness	Temperature	**	*	**	*
		Relative humidity	*	**> 0.05**	**> 0.05**	**> 0.05**
Hymenoptera	Abundance	Temperature	**	*	**	*
		Relative humidity	**	*	*	*
	Richness	Temperature	**	*	**	*
		Relative humidity	*	**> 0.05**	*	*
Lepidoptera	Abundance	Temperature	*	**> 0.05**	**> 0.05**	*
		Relative humidity	*	**> 0.05**	**> 0.05**	*
	Richness	Temperature	*	**> 0.05**	**> 0.05**	**> 0.05**
		Relative humidity	**> 0.05**	**> 0.05**	**> 0.05**	**> 0.05**
Neuroptera	Abundance	Temperature	*	**> 0.05**	**> 0.05**	**> 0.05**
		Relative humidity	*	**> 0.05**	**> 0.05**	**> 0.05**
	Richness	Temperature	**> 0.05**	**> 0.05**	**> 0.05**	**> 0.05**
		Relative humidity	**> 0.05**	**> 0.05**	**> 0.05**	**> 0.05**
Odonata	Abundance	Temperature	**> 0.05**	**> 0.05**	*	*
		Relative humidity	**> 0.05**	**> 0.05**	*	*
	Richness	Temperature	**> 0.05**	**> 0.05**	*	*
		Relative humidity	**> 0.05**	**> 0.05**	*	**> 0.05**
Orthoptera	Abundance	Temperature	**	*	**	**
		Relative humidity	**	*	*	**
	Richness	Temperature	**	*	*	*
		Relative humidity	*	**> 0.05**	*	*

Table 5: The statistical values of Redundancy Analysis (RDA) analysis for each site

Site Tested	**df**	**F**	**P**	**Constrained Inertia**	**adj. R^2**
Faisalabad	2,45	4.5175	0.001	16.7%	0.13
Layyah	2,45	2.9228	0.001	11.5%	0.0756
Vehari	2,45	2.9687	0.001	11.7%	0.0773
Sahiwal	2,45	3.4201	0.001	13.2%	0.0934

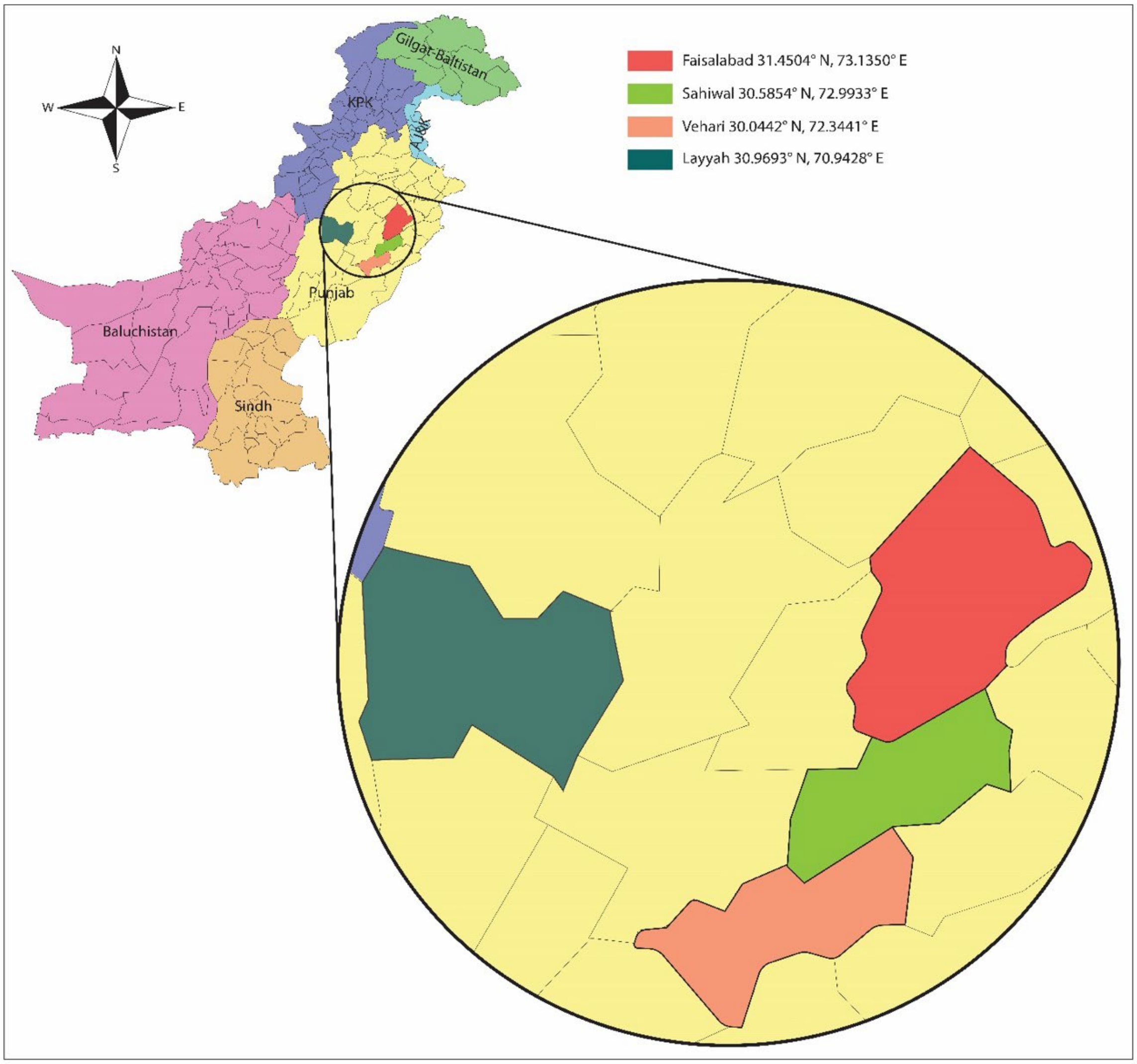

Figure 1: Map showing the districts and sites for sampling with coordinates

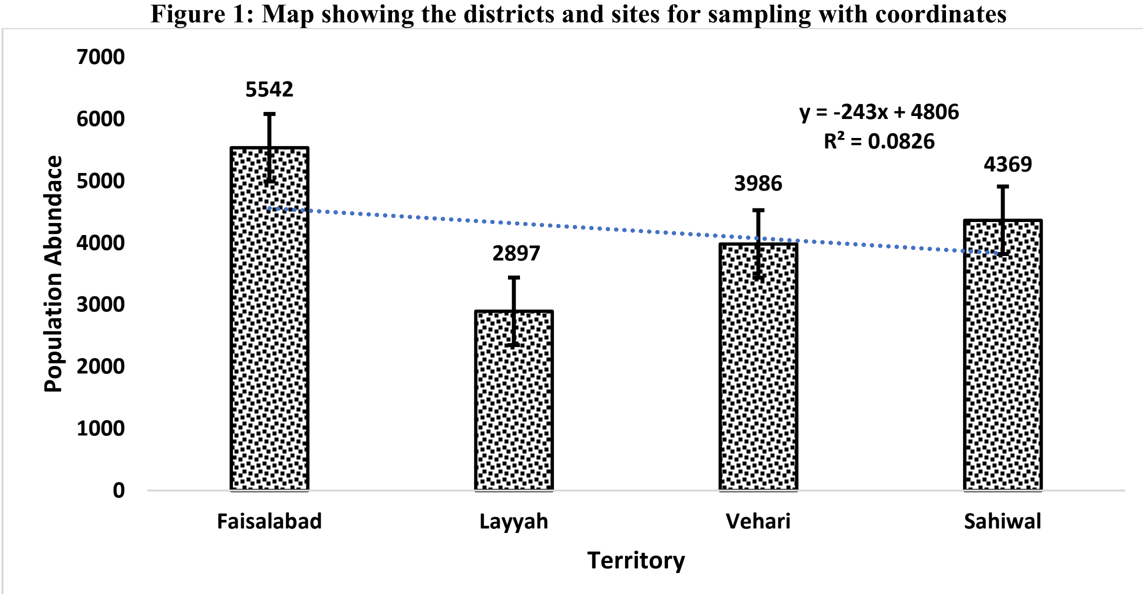

Figure 2: Relative abundance of arthropods among all studied sites

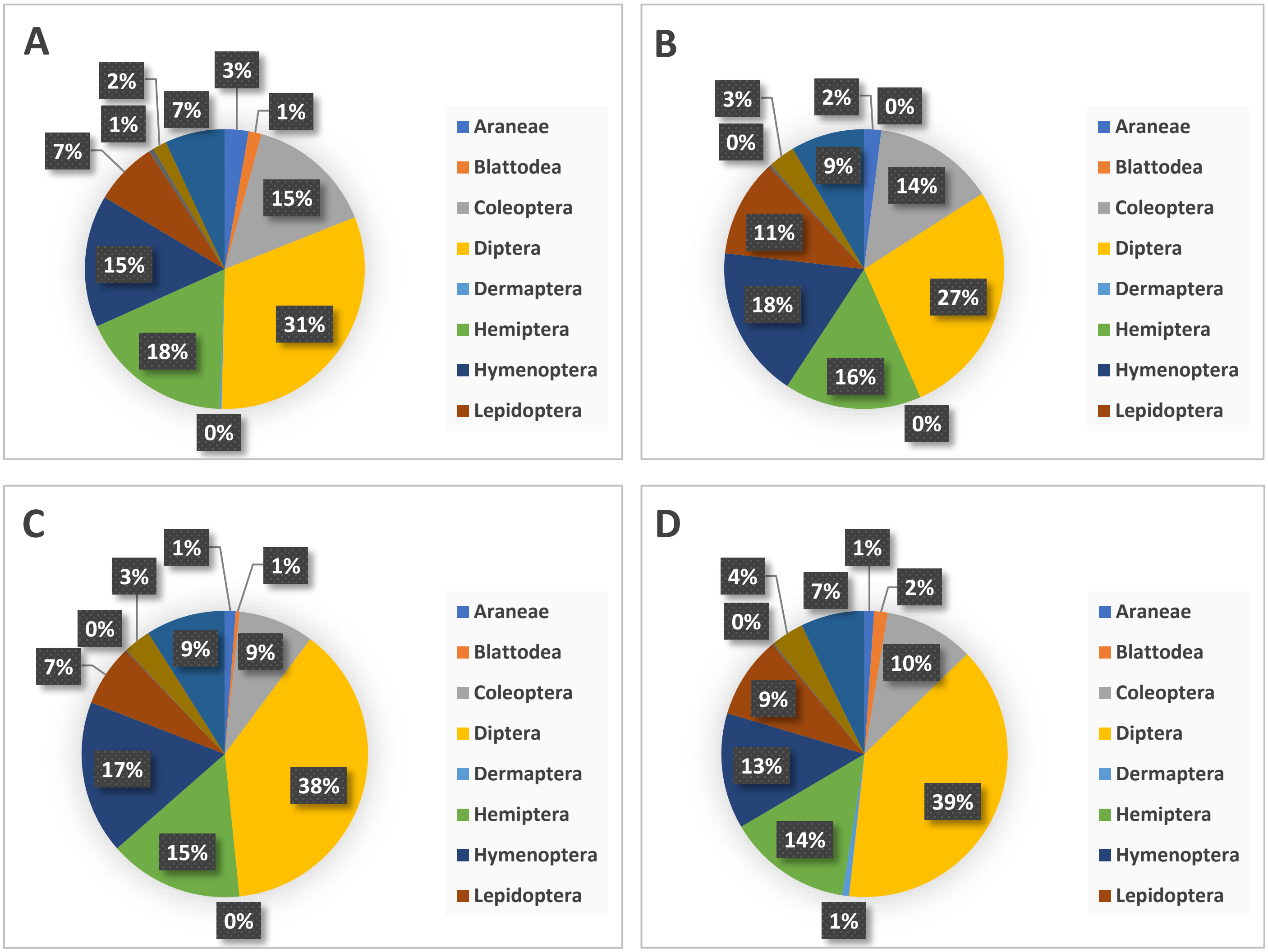

Figure 3: Comparison of arthropods orders from selected districts citrus orchards A) Faisalabad **B)** Layyah **C)** Vehari **D)** Sahiwal

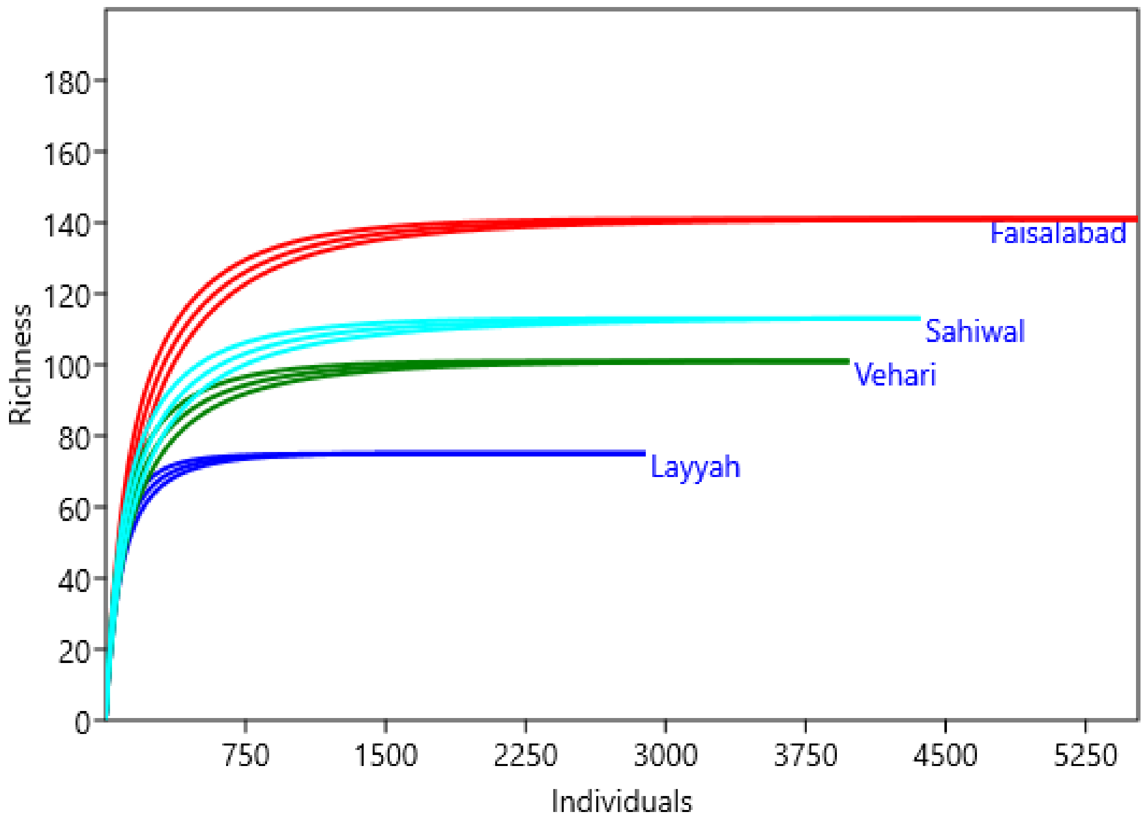

Figure 4: Individual-based rarefaction curve for species richness

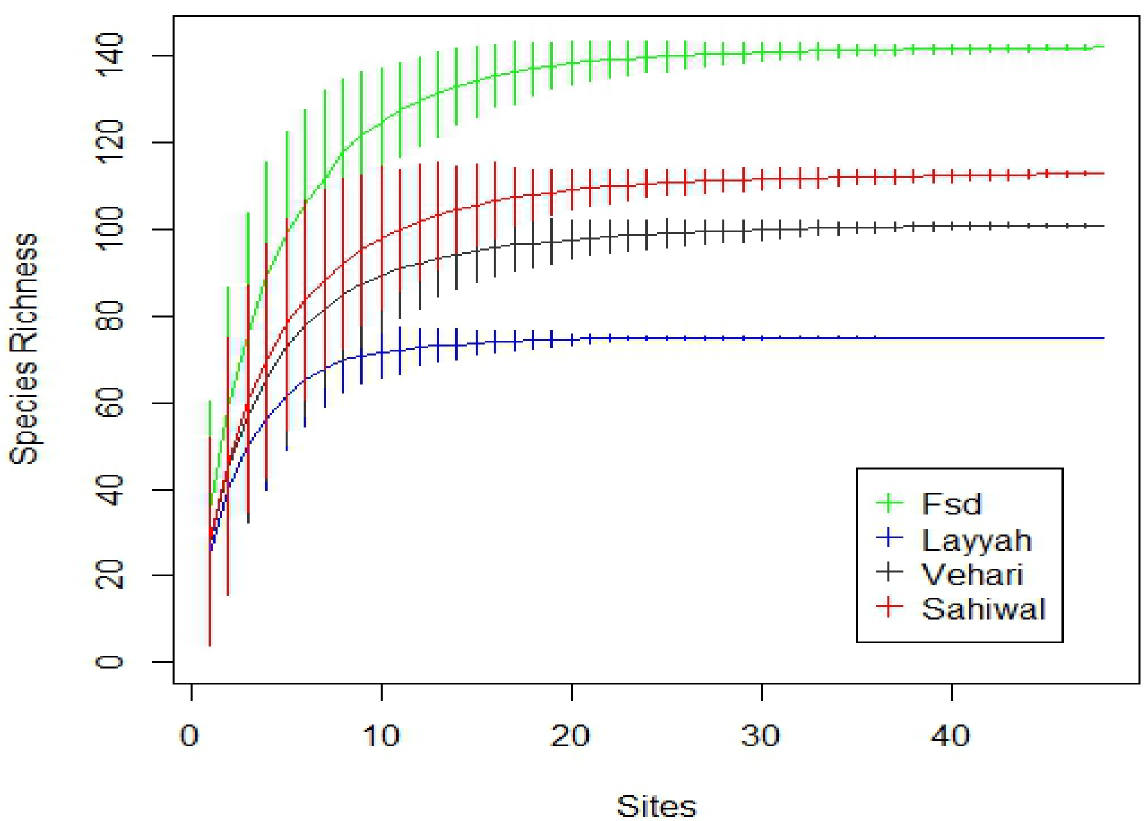

Figure 5: Species accumulation curve of arthropods collected from all the sites

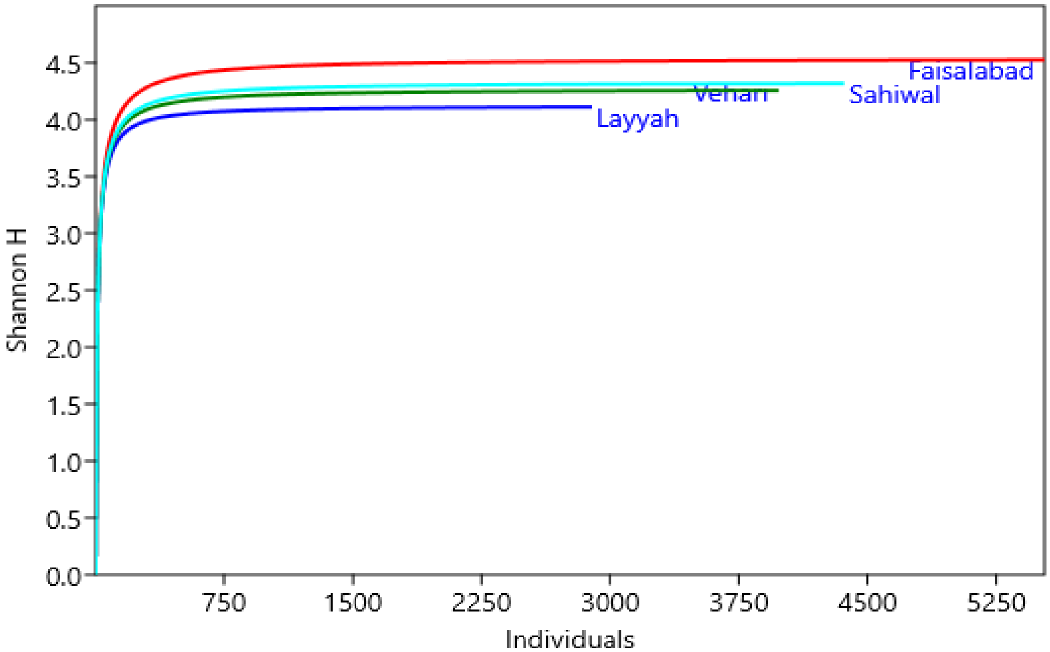

Figure 6: Individual-based rarefaction curve for Shannon Diversity

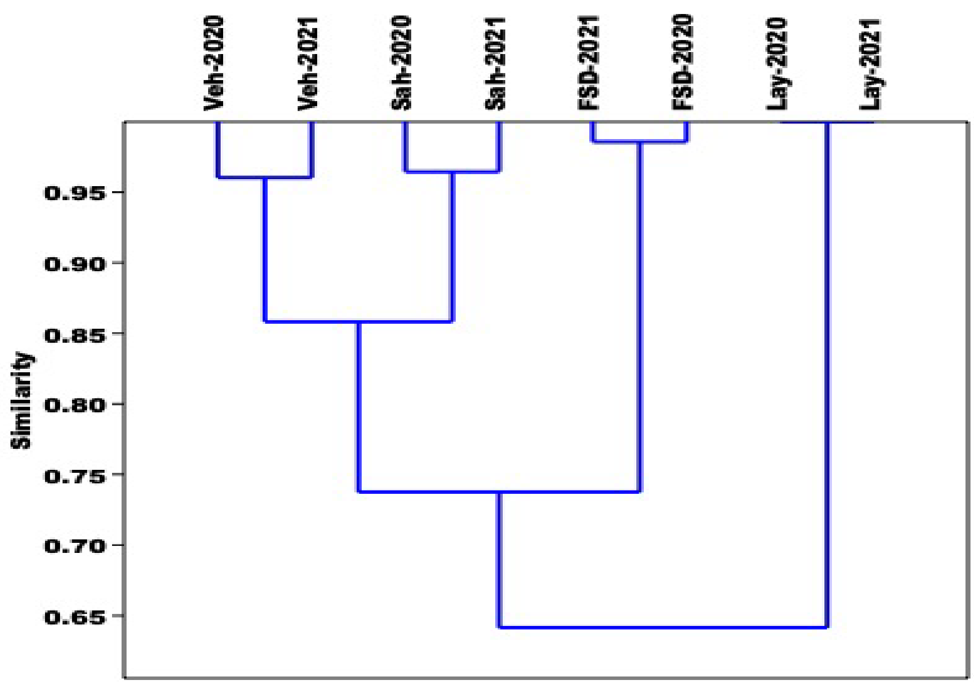

Figure 7: Jaccard similarity dendrogram showing the similarity of arthropods among different territories. Cophenetic Correlation = 0.889

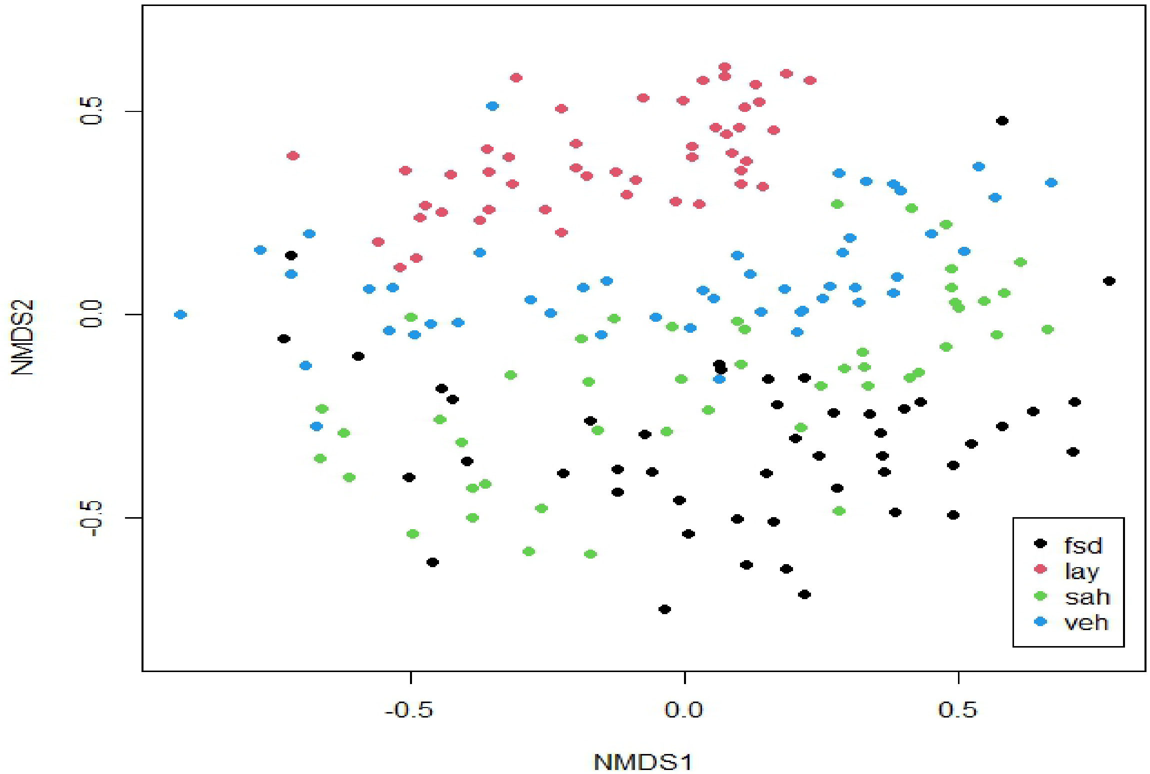

Figure 8: Non-Metric Multidimensional Scaling calculated on Bray-curtis dissimilarity using data collected from all four areas. Species were added as the weight of their abundance. fsd = Faisalabad; lay = Layyah; sah = Sahiwal; veh = Vehari

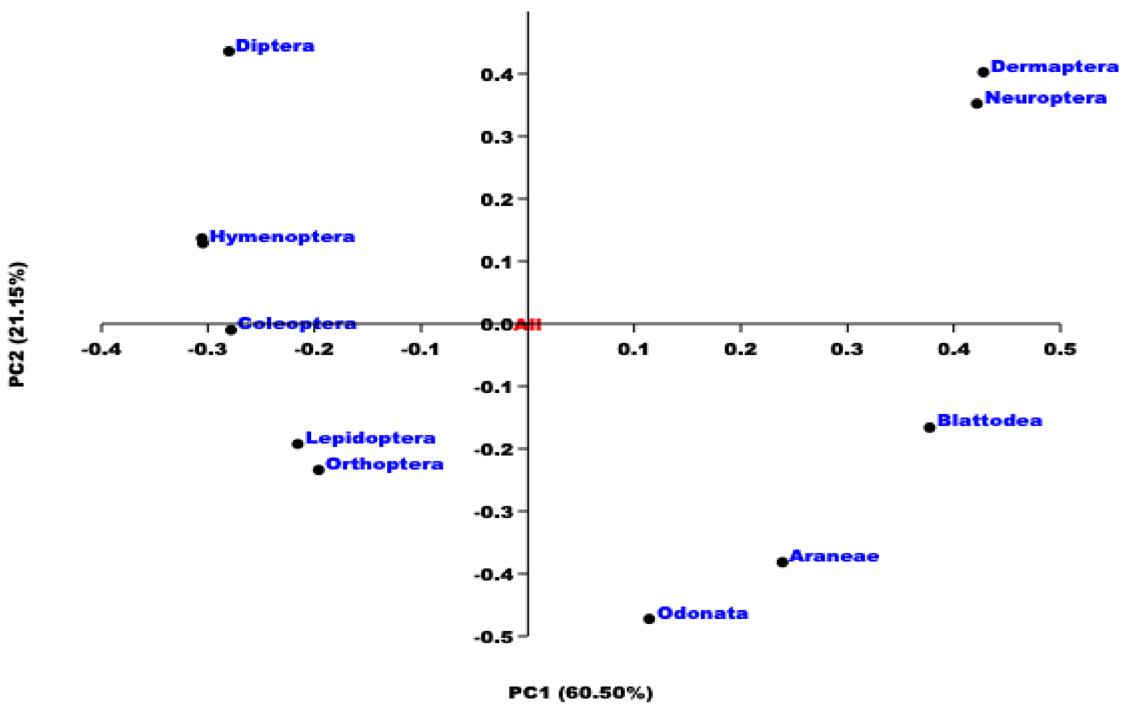

Figure 9: Principal Coordinate Analysis (PCoA) ordination based on the Bray-curtis distance matrix among the orders of arthropods

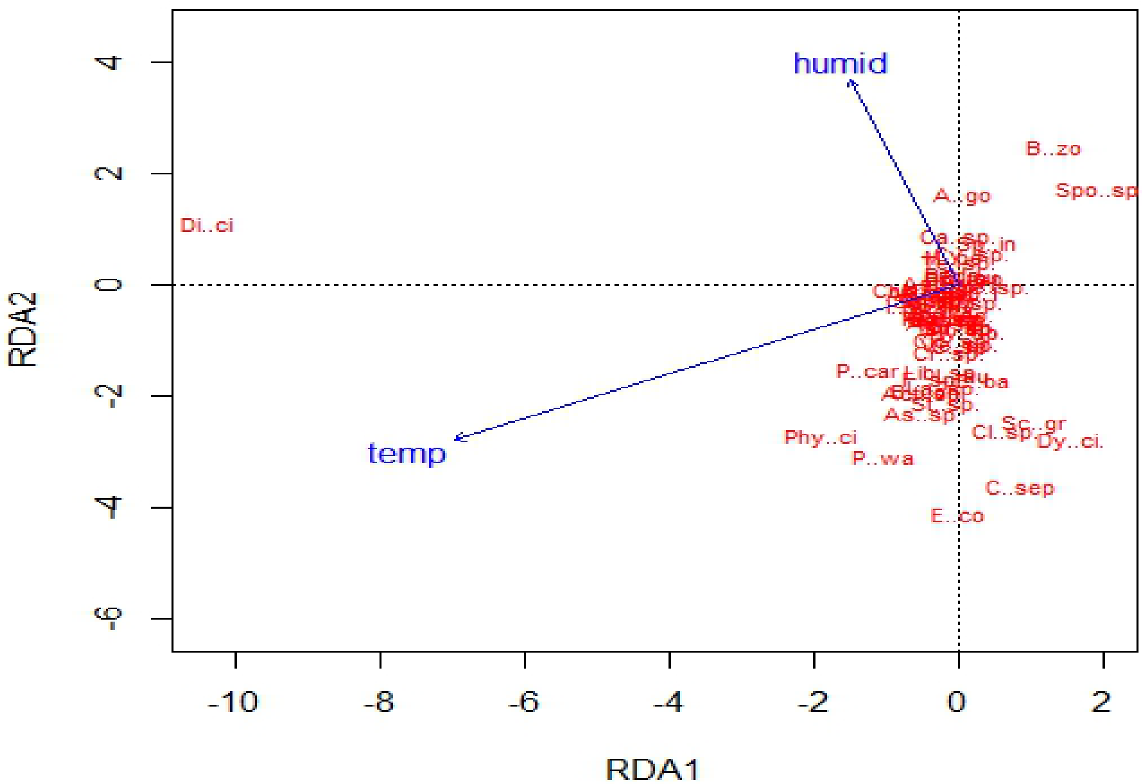

Figure 10a: Biplot RDA showing the impact of environmental variables on the species of Faisalabad site (see the Table S2 for species names abbreviations)

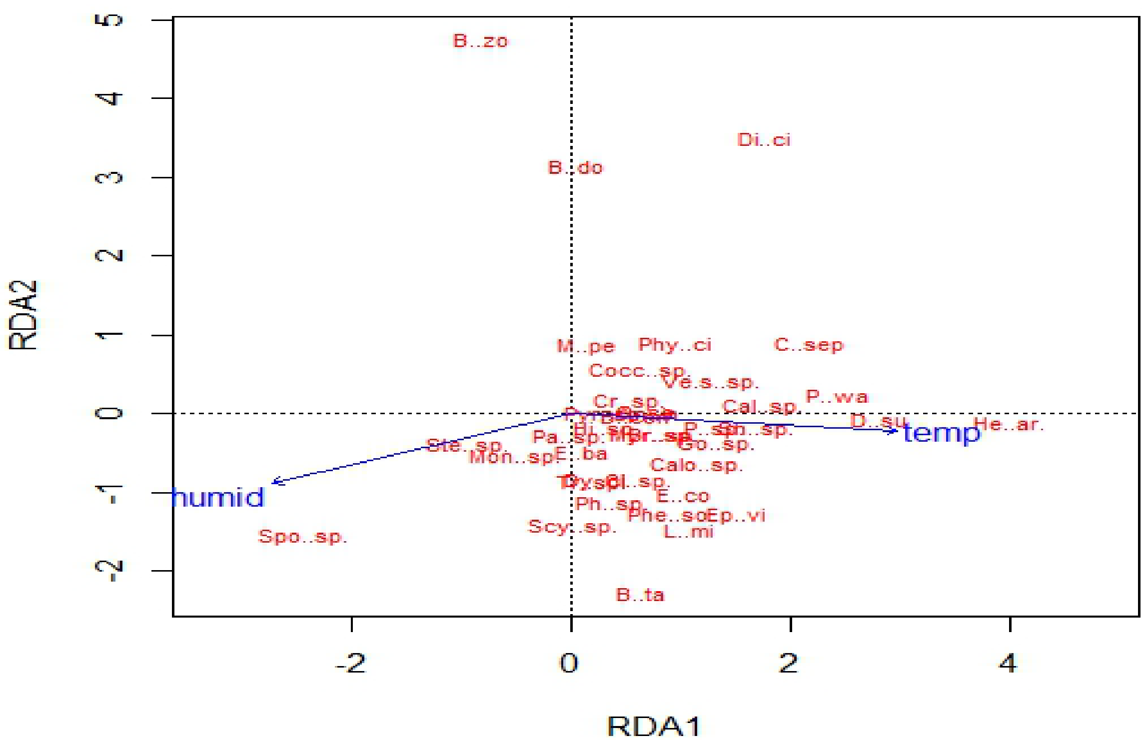

Figure 10b: Biplot RDA showing the impact of environmental variables on the species of Layyah site (see the Table S2 for species names abbreviations)

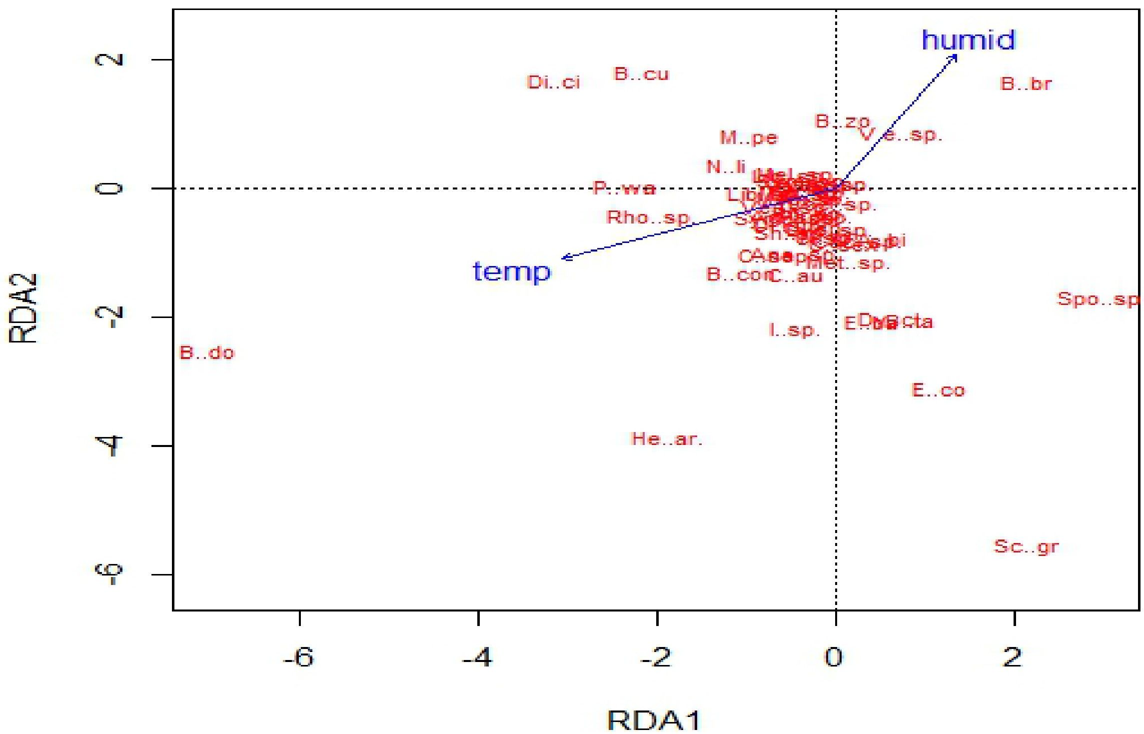

Figure 10c: Biplot RDA showing the impact of environmental variables on the species of Vehari site (see the Table S2 for species names abbreviations)

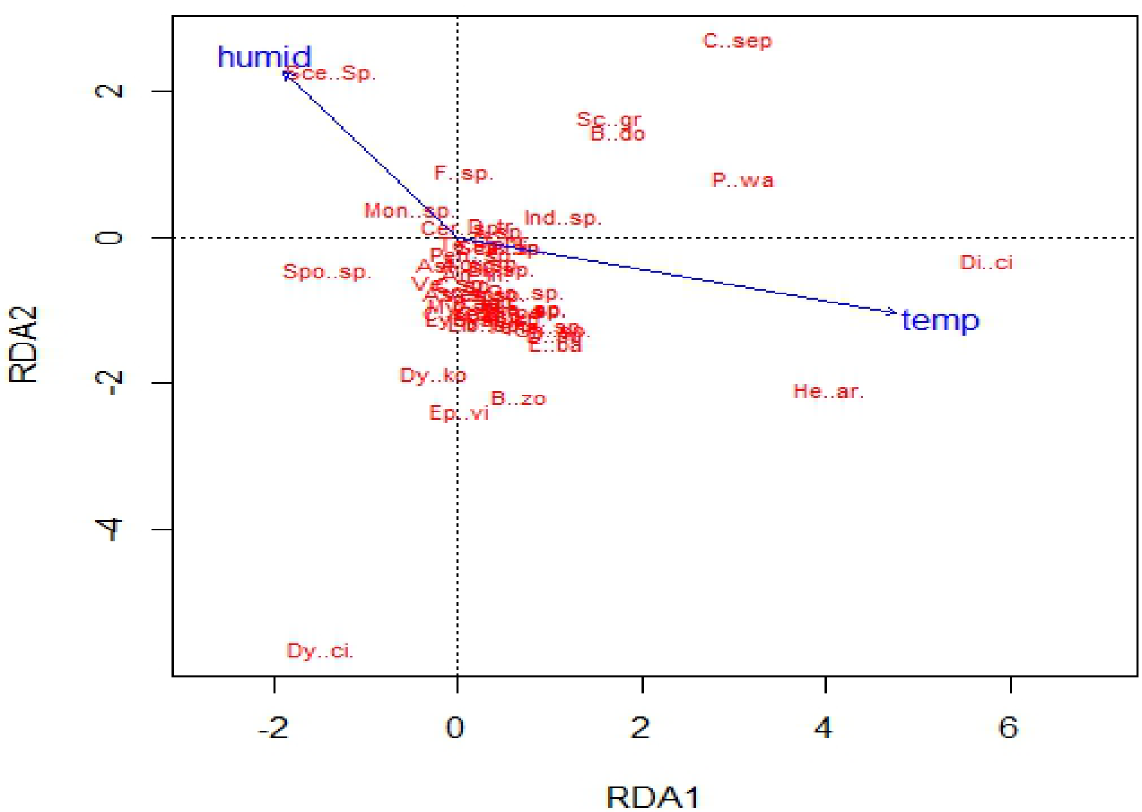

Figure 10d: Biplot RDA showing the impact of environmental variables on the species of Sahiwal site (see the Table S2 for species names abbreviations)

DISCUSSION

The functional group richness of the arthropod communities increased with better proportion of environmental variables (Sattler *et al.*, 2010; González-Césped *et al.*, 2021). These findings are expanded in this research to demonstrate that functional group richness and the variety of functions performed is similarly impacted. The directly influenced species from habitat alterations have been the focus of most research.

In the present study, the highest abundance was found from Faisalabad, followed by Sahiwal, Vehari and Layyah. This may be due to the more favorable environmental conditions in Faisalabad and less favorable in Layyah. The Arthropods' diversity is primarily based on the meteorological and land use parameters which increase or decrease with their change (Majeed *et al.*, 2020; Horák *et al.*, 2021). Our results showed that diversity indices were lower in the Layyah region than in other regions. Either citrus orchard has some common weeds but some vegetation changes with respect to the areas. This difference may be responsible for the change in insect species diversity and abundance (Khadijah *et al.*, 2013). This is also reported in the former study of Fauziah & Ibnu (2009) that vegetation strongly influences the occurrence of the species. In the present study, Layyah had less species richness when compared to all other regions due to minimum vegetative area.

In the current study, it was observed that space and time affected the pattern of arthropods diversity. Host specificity, geographical specialization, and temporal fluctuations in faunal abundance are the patterns of insect communities that are most often reported (Wardhaugh, 2014). Gao et al. (2021) evaluated the arthropod species distribution under the influence of latitudinal gradients and observed that the fauna occurrence is highest when climate warms moderately. Other studies showed that spatiotemporal factors change the arthropod diversity in agroecosystems (Nickell *et al.*, 2018; Nargis *et al.*, 2021). Notably, spatial gradients have been useful for assessing the effect of climatic factors on community composition changes and pest interaction with predators (Defossez *et al.*, 2018).

It is well established that environmental variables and the influence of biogeographic factors account for most fluctuations in species abundance. Climatic conditions impact the biodiversity of species (Garcia et al. 2014; Williams and Newbold 2020). In our study, environmental variables' effects were recorded, which showed strong control over arthropods fauna's diversity and abundance. The results of this investigation demonstrated that variations in temperature, precipitation, and humidity impacted insect diversity. Previous research has also shown that higher temperatures and decreased humidity influence diversity patterns of insect populations (Majeed *et al.*, 2020). Spatio-temporal patterns of biodiversity in ecological community reserves may be under risk because of local activities and changes in land use (Frondoni *et al.*, 2011; Hassan and Syakir, 2023). Prather et al. (2020) suggested that humidity regulates arthropod abundance and diversity while temperature regulates arthropod diversity (Xu *et al.*, 2013). Low humidity increases surface temperatures, and higher surface temperatures reduce arthropod diversity while increased humidity promotes higher arthropod abundance and diversity (Torode *et al.*, 2016).

Moreover, our results showed that predator and pests' species were most common in all orders. Keeping in view the importance of pest and predator relationship in niche, their survival is critical. The applications of pesticides don't only affect pests; they also kill natural predator when they come into touch with them directly (Jacobsen *et al.*, 2019; Sattler *et al.*, 2020). Over the last several decades, there has been a worldwide surge in the usage of pesticides in agriculture. Consequently, we may assume that the study's agricultural area had observed change in the ratio of pests to predators (Popp *et al.*, 2013). Ecosystem healthier production depends on a balanced pest-to-predator ratio (Ghosh and Kar, 2014; Mushtaq *et al.*, 2023). In any agricultural landscape, environmental management is necessary to maintain the diversity and effectiveness of insect communities, which can help to balance insect pests and predators in an agroecosystem (Arshad et al., 2018). Tena et al., (2017) evaluated that parasitoids fail to control mealy bugs population in citrus which caused deformations in shape, particularly around the apex and fruit size. Hence, there is a need to know the exact number and feeding habits of all inhabiting arthropods to control pest damage via environment-friendly approaches (Tena *et al.*, 2015). Therefore, it is vital to research the arthropods' distribution pattern and their feeding habits in fruit orchards (Hasinu *et al.*, 2021).

Predictions involving how changes in landscape arrangement may impact species distributions seem to be much improved by considering the functional features of pollinators, natural enemies, and pests' species (Wood *et al.*, 2015). Many fruit crops depend on insect pollination increasing the nutritional content of fruits. Meanwhile, fruit crops benefit more from insect pollination than other crops (Balfour and Ratnieks, 2017). Conversely, if pollinator diversity is declined, fruit output would likewise fall below levels consumed globally (Samnegård *et al.*, 2019; Nunes-Silva *et al.*, 2020). The existence of spatio-temporal associations between pests and predators is useful in implementing biological control of pests and can increase the efficiency of predators (Karimzadeh and Sciarretta, 2022; Lewin *et al.*, 2022).

Conclusion: Ecological distribution of species varies according to the abiotic factors and spatiotemporal gradients in any region, as they significantly impact the abundance and richness of arthropod fauna in terrestrial ecosystems. The fauna from Faisalabad was recorded more than Sahiwal, Vehari and Layyah because of the better environmental conditions and agroecological zones. The moderate temperature and humidity support the higher diversity of soil fauna compared to the intense weather conditions in summer and winter. For future sustainability, strategies to manage and sustain arthropod fauna, capitalization of biotic components, and more tree plantation are necessary as they provide the food source and favorable habitat to live the arthropods in terrestrial ecosystems. Arthropod biodiversity programs should be established at a large scale to understand the significance of fauna at a single patch. It represents new thinking by ecologists about the importance of faunal diversity because there is still extensive unexplored arthropod faunal diversity in many world regions. This study provides the baseline data for the arthropod's species, which can be helpful in the management of the pests. By getting the predators information from the study, biological control tools can be applied for ecofriendly management of species. This study can be helpful in the planning of conservation programs as well as provide information to farmers and researchers to initiate integrated pest management strategies in particular areas.

Conflict of interest: We declare no conflict of interest between our work.

Author Contribution: WM, NR and NE designed the study. WM, NR, NE wrote the manuscript. WM analyzed the data. NR supervised the experiment. NR and NE critically reviewed the final manuscript.

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