

Effect of weather variables and guild interactions in the seasonal patterns of arthropod fauna in *Solanum melongena* agro-ecosystem

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Abstract

Crop health and pest dynamics in horticultural systems are significantly influenced by climate variability. This study examined the seasonal patterns and ecological interactions of 73 arthropod species associated with brinjal cultivation in Central Research Farm, Bidhan Chandra Krishi Viswavidyalaya, Gayeshpur, Nadia, West Bengal, India, across 11 consecutive crop seasons during 2021-2023. The arthropods were categorized into ecological guilds: sucking, chewing, predatory, and ant groups. Key climatic factors, like – temperature, humidity, and rainfall had notable impacts on species abundance and interspecies relationships, with responses being highly species-specific. Mealybugs and epilachna beetles were most affected by rainfall, while lower temperatures and humidity were strongly associated with increased populations of the brinjal shoot and fruit borer, whiteflies, jassids, and aphids. Arthropod interactions shifted with crop cycles and environmental conditions. Predatory species like spiders and ladybird beetles displayed both antagonistic and complementary relationships with pests, depending on the season. Mutualistic interactions, such as those between ants and aphids, also played a critical role in shaping pest dynamics. These findings underscore the complexity of arthropod interactions in brinjal agroecosystems and highlight the importance of incorporating ecological understanding into adaptive, sustainable pest management strategies amid changing climatic conditions.

Introduction

Agriculture is inherently sensitive to climatic variability, with crop productivity heavily dependent on meteorological factors such as temperature and precipitation (Kumar et al. 2025). The escalating prevalence of global warming and climate change presents formidable challenges to agricultural systems worldwide. Rising atmospheric CO₂ concentrations, increasing temperatures, and erratic rainfall patterns exert both direct and indirect effects on agricultural output and the prevalence and severity of insect pests (Skendžić et al. 2021). Climatic variables influence insect mortality, developmental rates, and growth, while simultaneously shaping species abundance, distribution, migration patterns, and the frequency of pest outbreaks (Bale et al. 2002; Chandi et al. 2021).

In the Indian context, agriculture constitutes the backbone of the economy, sustaining over 70% of rural households and contributing approximately 20% to the national GDP, while providing employment to more than 60% of the population (Paul et al. 2022). Within the diverse agricultural sectors, horticulture holds a significant position, encompassing a wide range of crops including fruits, vegetables, flowers, spices, plantation crops such as coconut, and beverage crops like tea and coffee, in addition to numerous medicinal and aromatic plants. According to the National Horticulture Board, India accounts for approximately 17% of global vegetable production and 22% of the world's brinjal production (Horticultural Statistics at a Glance 2021).

Brinjal (*Solanum melongena* L.) is a widely consumed vegetable, with an average daily dietary intake of 7.28 grams per person, and is cultivated year-round across various agro-climatic zones of India (Bushra et al. 2022). The fruit is nutritionally valuable, providing essential vitamins, minerals, and phenolic compounds that are vital for human health (Naeem and Ugur 2019). Despite its importance, the productivity and quality of brinjal are significantly impacted by both abiotic and biotic stresses. Key abiotic factors such as temperature, humidity, and rainfall pose considerable challenges, while the crop is also susceptible to a wide range of insect pests and pathogens, which are major biotic constraints (Javed et al. 2017; Priyadharsan and Muthukumaran 2022). Insect pest infestations throughout various growth stages often hinder yield potential (Dhandapani et al. 2003). Brinjal is known to be affected by 53 species of insect pests, of which eight are considered economically significant across all growing seasons, in addition to a species of mite (Biswas et al. 1992). This issue has been exacerbated in recent years due to increasing climatic unpredictability, which has led to heightened pest pressure and greater yield losses.

Among the pest complex, the brinjal shoot and fruit borer (BSFB) is regarded as the most destructive insect pest in Asia, causing significant damage, particularly during the fruiting phase. Yield losses attributed to BSFB have been reported to range from 25.82–92.50%, with typical reductions of 20–60% under field conditions (Abhirami et al. 2021). In addition, sucking pests such as aphids, jassids, and whiteflies are notably damaging during the winter season, with estimated plant losses ranging from 26–46% (Ingole et al. 2024). Traditional pest control methods often rely on the indiscriminate use of chemical pesticides, which can lead to the development of pest resistance, contamination of ecosystems, and adverse effects on non-target organisms (Popp et al. 2013; Dey Roy and Mukhopadhyay 2025). Sustainable pest management requires maintaining pest populations below the economic threshold level, which can only be achieved through informed, ecologically sound strategies. Accurate estimation of pest populations is crucial for assessing the severity of infestations, understanding the role of natural enemies, evaluating crop losses, and determining the most timely and effective control measures (Kidd and Jervis 2007).

Climatic variability not only directly influences pest development, reproduction, survival, and dispersal, but also indirectly modifies ecological interactions, including those with predators, parasitoids, vectors, and competitors (Bhagarathi and Maharaj 2023). These interactions are integral to the ecological framework of the crop environment. A guild is defined as a group of species that exploit similar resources in comparable ways (Simberloff and Dayan 1991; Williams and Hero 1998). In brinjal agroecosystems, arthropod communities exhibit intricate intra- and inter-guild relationships that shape population dynamics and, ultimately, crop yield. Predator-prey interactions and seasonal fluctuations in arthropod populations serve as indicators of broader ecological processes, including the biological control services provided by natural enemies (Hagler and Blackmer 2013). For the development of effective pest management strategies tailored to a specific agroecosystem, a comprehensive understanding of pest and natural enemy abundance, seasonal occurrence, and their interactions in relation to climatic factors is paramount (Chavan et al. 2013).

Integrated Pest Management (IPM) practices, which combine biological control agents, cultural methods, pheromone-based monitoring tools, and selective chemical applications, provide effective and environmentally sustainable solutions for pest suppression (Dey Roy et al. 2024). A comprehensive understanding of the arthropod complex, including its seasonal variability and trophic interactions, is essential for the development and implementation of such strategies. This study was thus conducted to explore the seasonal dynamics of arthropod populations associated with brinjal cultivation, with a particular focus on identifying dominant pest and beneficial species, monitoring their abundance over time, and elucidating their mutualistic and antagonistic interactions within and between ecological guilds. The findings are anticipated to offer valuable insights into the ecological complexities of the brinjal agroecosystem and contribute to the advancement of sustainable pest management practices.

Materials and methods

Experimental Site

The present investigation was conducted at the Central Research Farm of Bidhan Chandra Krishi Viswavidyalaya, located in Gayeshpur, Nadia district, West Bengal, India (22°57'N latitude and 88°20'E longitude), at an elevation of 9.75 metres above mean sea level. The study, which spanned from 2021 to 2023 (Fig. 1), was carried out under open field conditions. During the experimental period, ambient temperatures ranged from 21.7°C to 32.4°C, with an average rainfall of 25.3 mm and relative humidity fluctuating between 64.2% and 93.8%. The research site is situated within the Gangetic new alluvial plains, a prominent agro-ecological region of West Bengal, India.

Edaphic properties

The soil at the experimental site was classified as sandy loam, characterised by a high sand content and a relatively low proportion of clay. It exhibited an acidic pH, was porous in nature, and had a shallow depth. Notably, the soil tended to form highly erodible crests following rainfall events, a typical characteristic of the region. The results of the chemical analysis indicated that the total nitrogen and available phosphorus levels were very low, while the potassium content was found to be moderate. A detailed account of the soil's chemical properties is presented in Table 1.

Table 1
Chemical properties of the soil of experimental site

Depth of soil (cm)	p ^H	EC (dsm ⁻¹)	Organic C (%)	Available N (Kg ha ⁻¹)	Available P ₂ O ₅ (Kg ha ⁻¹)	Available K ₂ O (Kg ha ⁻¹)	Organic matter (%)
15	6.87	0.21	0.55	180.76	48.39	195.80	0.94

Experimental details

A total of eleven consecutive brinjal crops were cultivated, with seedling transplantations scheduled at two-month intervals. The widely grown local variety, 'Patakata,' was selected for all crop cycles conducted between 2021–22 and 2022–23, starting in May 2021 (Table 2). For operational efficiency, the experimental field was divided into plots measuring 4 m × 3 m. Each crop cycle typically culminated in final harvesting approximately six months after transplantation. Thirty-day-old seedlings were transplanted into the prepared plots, with a spacing of 0.90 m between rows and 0.60 m between plants, accommodating a total of 22 plants per plot. Standard agronomic practices, as recommended by Roy et al. (2023), were adhered to in order to foster healthy crop growth and successful establishment.

Table 2
Duration of brinjal crop seasons

Crop season	Date of transplanting	Date of harvesting
Crop season (2021-22)		
First crop	31st May, 2021	11th November, 2021
Second crop	04th August, 2021	05th January, 2022
Third crop	01st October, 2021	03rd March, 2022
Fourth crop	08th December, 2021	03rd May, 2022
Crop season (2022-23)		
Fifth crop	02nd February, 2022	05th July, 2022
Sixth crop	06th April, 2022	30th August, 2022
Seventh crop	05th June, 2022	11th November, 2022
Eighth crop	06th August, 2022	9th January, 2023
Ninth crop	30th September, 2022	3rd March, 2023
Tenth crop	02nd December, 2022	5th May, 2023
Crop season (2023)		
Eleventh crop	02nd February, 2023	17th May, 2023

Collection and identification of arthropods

The occurrence of arthropods associated with the brinjal ecosystem was monitored weekly, starting from the first week after transplanting in each crop season. Observations were conducted during the early morning hours to ensure consistency. The major insect pests and predatory species present on the crop were collected and preserved in tubes containing 70% ethyl alcohol for subsequent identification. Species-level identification was performed by the Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, India.

Data collection

The populations of mealybugs, aphids, whiteflies, jassids, epilachna beetles, and ladybird beetles were assessed by counting both nymphs or grubs and adult insects on three leaves selected from the top, middle, and bottom portions of five randomly chosen plants in each plot. For aphids and thrips, observations were made within a one square centimetre area on three randomly selected regions of the leaf, with three such leaves examined per plant. The infestation of brinjal fruit and shoot borers was recorded by counting the number of larvae present in infested fruits and shoots on each plant. Additionally, the populations of leaf rollers, tobacco caterpillars, spiders, and ants were recorded as the total number of individuals per plant.

Meteorological data

Meteorological data, including temperature, relative humidity, and rainfall, were obtained from the Department of Agrometeorology and Physics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, India, to facilitate accurate interpretation of the experimental findings. Records of maximum and minimum temperatures (°C), relative humidity (%), and rainfall (mm) were collected and used to calculate weekly averages.

Statistical analysis

Data collected over three consecutive years on weather parameters and arthropod populations were statistically analysed to assess the interactions between biotic and abiotic components within the brinjal ecosystem. The datasets, comprising various meteorological variables and arthropod populations, were subjected to simple correlation analysis to determine the influence of weather factors on arthropod abundance, as well as to explore intra- and inter-guild relationships within the arthropod community. A correlation coefficient (r) matrix was generated, and statistical significance was evaluated using Student's t-test. Data preparation and all statistical analyses were performed using Microsoft Office Excel and R software (version 4.1.2).

Results

Inventory of arthropods in brinjal ecosystem

A total of 73 arthropod species, representing 10 taxonomic orders viz., Orthoptera, Odonata, Hemiptera, Thysanoptera, Neuroptera, Coleoptera, Hymenoptera, Diptera, Lepidoptera, and Araneae were recorded during the study period (Table 3). Among these, the mealybug (*Ferrisia virgata* Cockerell), aphids (*Myzus persicae* Sulzer and *Aphis gossypii* Glover), whitefly (*Bemisia tabaci* Gennadius), jassid (*Amrasca biguttula biguttula* Ishida), and thrips (*Thrips tabaci* Lindeman and *Scirtothrips dorsalis* Hood) were identified as the predominant pests constituting the "sucking guild". The "chewing guild" was represented by the epilachna beetle (*Henosepilachna vigintioctopunctata* Fabricius), flea beetle (*Phyllotreta striolata* Fabricius), brinjal shoot and fruit borer (*Leucinodes orbonalis* Guenée), tobacco caterpillar (*Spodoptera litura* Fabricius), and leaf roller (*Autoba olivacea* Walker). The "predatory guild" included ladybird beetles (*Coccinella transversalis* Fabricius and *Cheilomenes sexmaculata* Fabricius) as well as spiders (*Oxyopes salticus* Hentz, *Tetragnatha bengalensis* Walckenaer, and *Leucauge decorata* Blackwall), while the "ant guild" was represented by ants such as *Camponotus compressus* Fabricius and *Solenopsis geminata* Fabricius.

Table 3
Arthropods recorded and identified in brinjal ecosystem during 2021–2023

Sl. No.	Common Name	Scientific Name	Family	Order	Class	Phylum
1	Tobacco grasshopper	<i>Atractomorpha crenulata</i> (Fabricius)	Pyrgomorphidae	Orthoptera	Hexapoda	Arthropoda
2	Sickle-bearing bush cricket	<i>Holochlora indica</i> Kirby	Tettigonidae	Orthoptera	Hexapoda	Arthropoda
3	Black kneed conehead	<i>Conocephalus melaenus</i> Haan	Tettigonidae	Orthoptera	Hexapoda	Arthropoda
4	Band-winged grasshopper	<i>Oedaleus infernalis</i> Saussure	Acrididae	Orthoptera	Hexapoda	Arthropoda
5	Coromandel marsh dart	<i>Ceragrion coromandelianum</i> (Fabricius)	Coenagrionidae	Odonata	Hexapoda	Arthropoda
6	Orange-tailed midget	<i>Agriocnemis femina</i> Brauer	Coenagrionidae	Odonata	Hexapoda	Arthropoda
7	Pygmy dartlet	<i>Agriocnemis pygmaea</i> Rambur	Coenagrionidae	Odonata	Hexapoda	Arthropoda
8	Wandering percher	<i>Diplacodes bipunctata</i> Brauer	Libellulidae	Odonata	Hexapoda	Arthropoda
9	Long-legged marsh glider	<i>Trithemis pallidinervis</i> Kirby	Libellulidae	Odonata	Hexapoda	Arthropoda
10	Silver leaf whitefly	<i>Bemisia tabaci</i> Genn.	Aleyrodidae	Hemiptera	Hexapoda	Arthropoda
11	Jassid	<i>Amrasca biguttula biguttula</i> Ishida	Cicadellidae	Hemiptera	Hexapoda	Arthropoda
12	Green peach aphid	<i>Myzus persicae</i> Sulzer	Aphididae	Hemiptera	Hexapoda	Arthropoda
13	Cotton aphid	<i>Aphis gossypii</i> Glover	Aphididae	Hemiptera	Hexapoda	Arthropoda
14	Spittle bug	<i>Poophilus costalis</i> Walker	Aphrophoridae	Hemiptera	Hexapoda	Arthropoda
15	Brown marmorated stinkbug	<i>Halyomorpha halys</i> Stål	Pentatomidae	Hemiptera	Hexapoda	Arthropoda
16	Cotton stainer	<i>Dysdercus cingulatus</i> Fabricius	Pyrrhocoridae	Hemiptera	Hexapoda	Arthropoda
17	Yellow and black leafhopper	<i>Ishidaella latomarginata</i> Distant	Cicadellidae	Hemiptera	Hexapoda	Arthropoda
18	Bud and boll shedder	<i>Creontiades pallidus</i> Rambur	Miridae	Hemiptera	Hexapoda	Arthropoda
19	Green jewel bug	<i>Chrysocoris stollii</i> Wolff	Scutelleridae	Hemiptera	Hexapoda	Arthropoda
20	Rice bug	<i>Cletus rusticus</i> Stål	Coreidae	Hemiptera	Hexapoda	Arthropoda
21	Mealybug	<i>Ferrisia virgata</i> Cockerell	Pseudococcidae	Hemiptera	Hexapoda	Arthropoda
22	Southern green stink bug	<i>Nezara viridula</i> Linnaeus	Pentatomidae	Hemiptera	Hexapoda	Arthropoda
23	Potato thrips	<i>Thrips tabaci</i> Lindeman	Thripidae	Thysanoptera	Hexapoda	Arthropoda
24	Chilli thrips	<i>Scirtothrips dorsalis</i> Hood	Thripidae	Thysanoptera	Hexapoda	Arthropoda
25	Green lacewing	<i>Chrysoperla carnea</i> Stephens	Chrysopidae	Neuroptera	Hexapoda	Arthropoda
26	Ladybird beetle	<i>Coccinella transversalis</i> Fabricius	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
27	Ladybird beetle	<i>Micraspis discolor</i> Fabricius	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
28	Ladybird beetle	<i>Cheilomenes sexmaculata</i> Fabricius	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
29	Malaysian Ladybird	<i>Chilocorus nigrinus</i> Fabricius	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
30	Two-spot ladybird	<i>Adalia bipunctata</i> Linnaeus	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
31	Hadda beetle/Epilachna beetle	<i>Henosepilachna vigintioctopunctata</i> Fabricius	Coccinellidae	Coleoptera	Hexapoda	Arthropoda
32	Amaranthus stem weevil	<i>Hypolixus truncatulus</i> Fabricius	Curculionidae	Coleoptera	Hexapoda	Arthropoda
33	Ash weevil	<i>Mylocherus discolor</i> Schoenherr	Curculionidae	Coleoptera	Hexapoda	Arthropoda
34	Common red-soldier beetle	<i>Rhagonycha fulva</i> Scopoli	Cantharidae	Coleoptera	Hexapoda	Arthropoda
35	Soldier beetle	<i>Cantharis livida</i> Linnaeus	Cantharidae	Coleoptera	Hexapoda	Arthropoda
36	Ground beetle	<i>Calleida decora</i> Fabricius	Carabidae	Coleoptera	Hexapoda	Arthropoda
37	Ground beetle	<i>Ophionea indica</i> Thunberg	Carabidae	Coleoptera	Hexapoda	Arthropoda
38	Leaf beetle	<i>Aulacophora lewisii</i> Baly	Chrysomelidae	Coleoptera	Hexapoda	Arthropoda
39	Striped flea beetle	<i>Phyllotreta striolata</i> Fabricius	Chrysomelidae	Coleoptera	Hexapoda	Arthropoda
40	Common green bottle fly	<i>Lucilia sericata</i> Meigen	Calliphoridae	Diptera	Hexapoda	Arthropoda

Sl. No.	Common Name	Scientific Name	Family	Order	Class	Phylum
41	Common flesh fly	<i>Sarcophaga carnaria</i> Linnaeus	Sarcophagidae	Diptera	Hexapoda	Arthropoda
42	Black banded hoverfly	<i>Episyrphus viridaureus</i> Weidemann	Syrphidae	Diptera	Hexapoda	Arthropoda
43	Band-eyed dronefly	<i>Eristalinus taeniops</i> Weidemann	Syrphidae	Diptera	Hexapoda	Arthropoda
44	Black-winged Fruitfly	<i>Platensina tetrica</i> Hering	Tephritidae	Diptera	Hexapoda	Arthropoda
45	Robber fly	<i>Philonicus albiceps</i> Meigen	Asilidae	Diptera	Hexapoda	Arthropoda
46	Sargine soldier fly	<i>Microchrysa flaviventris</i> Weidemann	Stratiomyidae	Diptera	Hexapoda	Arthropoda
47	Shoot and Fruit borer	<i>Leucinodes orbonalis</i> Guenée	Gelechiidae	Lepidoptera	Hexapoda	Arthropoda
48	Flower moth	<i>Eretmocera impactella</i> Walker	Scythrididae	Lepidoptera	Hexapoda	Arthropoda
49	Black looper	<i>Hyposidra talaca</i> Walker	Geometridae	Lepidoptera	Hexapoda	Arthropoda
50	Dark grass blue	<i>Zizeeria karsandra</i> Moore	Lycaenidae	Lepidoptera	Hexapoda	Arthropoda
51	Pointed ciliate blue	<i>Anthene lycaenina</i> Felder	Lycaenidae	Lepidoptera	Hexapoda	Arthropoda
52	Brinjal leaf roller	<i>Autoba olivacea</i> Walker	Erebidae	Lepidoptera	Hexapoda	Arthropoda
53	Bihar hairy caterpillar	<i>Spilosoma obliqua</i> Walker	Erebidae	Lepidoptera	Hexapoda	Arthropoda
54	Tussock moth	<i>Orgyia postica</i> Walker	Erebidae	Lepidoptera	Hexapoda	Arthropoda
55	Tiger moth	<i>Eressa confinis</i> Walker	Erebidae	Lepidoptera	Hexapoda	Arthropoda
56	Beet webworm moth	<i>Spoladea recurvalis</i> Fabricius	Crambidae	Lepidoptera	Hexapoda	Arthropoda
57	Bean pod borer	<i>Maruca vitrata</i> Fabricius	Crambidae	Lepidoptera	Hexapoda	Arthropoda
58	Crambid moth	<i>Sameodes cancellalis</i> Zeller	Crambidae	Lepidoptera	Hexapoda	Arthropoda
59	Tobacco caterpillar	<i>Spodoptera litura</i> Fabricius	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
60	Gram pod borer	<i>Helicoverpa armigera</i> Hübner	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
61	Corn earworm	<i>Helicoverpa zea</i> Boddie	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
62	Bird dropping moth	<i>Acontia crocata</i> Guenée	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
63	African armyworm moth	<i>Spodoptera exempta</i> Walker	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
64	Green garden looper	<i>Chrysodeixis eriosoma</i> Doubleday	Noctuidae	Lepidoptera	Hexapoda	Arthropoda
65	Small banded swift	<i>Pelopidas mathias</i> Fabricius	Hesperiidae	Lepidoptera	Hexapoda	Arthropoda
66	Black ant	<i>Camponotus compressus</i> Fabricius	Formicidae	Hymenoptera	Hexapoda	Arthropoda
67	Red ant	<i>Solenopsis geminata</i> Fabricius	Formicidae	Hymenoptera	Hexapoda	Arthropoda
68	Striped lynx spider	<i>Oxyopes salticus</i> Hentz	Oxyopidae	Araneae	Arachnida	Arthropoda
69	Ant-mimicking spider	<i>Myrmarachne maxillosa</i> Koch	Salticidae	Araneae	Arachnida	Arthropoda
70	Jumping spider	<i>Phidippus</i> sp.	Salticidae	Araneae	Arachnida	Arthropoda
71	Green huntsman spider	<i>Micromata virescens</i> Clerck	Sparassidae	Araneae	Arachnida	Arthropoda
72	Long-jawed spider	<i>Tetragnatha bengalensis</i> Walckenaer	Tetragnathidae	Araneae	Arachnida	Arthropoda
73	Decorative silver orb-weaver spider	<i>Leucauge decorate</i> Blackwall	Tetragnathidae	Araneae	Arachnida	Arthropoda

Cropping season wise general record of occurrence of arthropods in brinjal ecosystem under the influence of salient phenological parameters

The study involved the cultivation of brinjal across 11 consecutive crop seasons to ensure the comprehensive execution of the experiment. The presence of arthropods on the brinjal plants, from transplanting to senescence, was systematically monitored alongside key meteorological variables. The arthropod populations, shaped by the interactions between the plants, arthropods, and corresponding weather conditions, particularly average temperature and humidity, exhibited notable fluctuations in their occurrence (Table 4).

Table 4
Crop wise occurrence of average population of arthropods in brinjal ecosystem during 2021 to 2023

Crop	Temperature		Humidity		Rain fall	Mealybug*	Whitefly*	Jassid*	Aphid**	Thrips**	Epilachna beetle*	Flea beetle*	BSFB ***	Tobacco caterpillar**
	Range	Av.	Range	Av.										
1st	33 – 26	30	94 – 70	82	55	11.54	0.90	0.25	4.56	0.00	0.62	0.14	1.10	0.00
2nd	32 – 22	27	94 – 62	78	22	1.58	3.52	0.78	0.08	0.00	0.99	0.03	0.11	0.09
3rd	29 – 18	23	93 – 56	74	04	0.00	1.16	1.24	18.36	9.44	0.22	0.18	0.52	0.00
4th	31 – 19	25	92 – 51	71	04	0.00	3.64	2.77	5.94	9.15	0.80	0.48	0.92	0.00
5th	34 – 23.6	28.8	92 – 58	75	25	0.03	1.30	2.15	0.18	2.67	2.17	0.35	0.89	0.00
6th	35 – 26	30	93 – 69	81	37	0.24	0.55	0.18	1.10	0.00	2.33	0.05	0.88	0.00
7th	33 – 24	28.5	95 – 76	85	26	0.01	0.82	0.43	13.72	1.43	0.60	0.10	0.89	0.00
8th	31 – 19	25	95 – 69	82	05	0.02	0.83	0.57	8.31	4.81	0.16	0.18	0.89	0.00
9th	29 – 14	21	95 – 55	75	01	0.00	2.83	0.88	4.14	6.47	0.05	0.07	0.50	0.00
10th	30 – 15	22	93 – 50	72	00	0.00	3.01	1.90	6.91	14.75	0.74	0.21	1.26	0.00
11th	35 – 23	29	91 – 53	72	19	0.02	1.55	2.95	0.19	4.18	2.41	0.47	0.99	0.00

BSFB = Brinjal shoot and fruit borer. * Population of arthropods/three leaves. **Population of arthropods/sqcm leaf. *** Population of arthropods/plants. Tmax = Maximum temperature (°C). Tmin = Minimum temperature (°C). RHMax = Maximum relative humidity (%). RHMin = Minimum relative humidity (%). Std. Week = Standard week. Av. = Average.

Humidity was found to be a critical factor influencing the population dynamics of mealybugs, with lower numbers recorded in the third, fourth, ninth, and tenth crop seasons when average humidity levels fell below 76%. Conversely, whiteflies and jassids were more abundant during the third, fourth, ninth, and tenth crops when humidity levels were below 80%. Interestingly, in both cases, the average temperature did not exceed 25°C. Similarly, low temperatures combined with moderate humidity appeared to favour the proliferation of aphids and thrips, as observed in the third, ninth, and tenth crops. In contrast, other arthropods, such as epilachna beetles, brinjal shoot and fruit borers, flea beetles, leaf rollers, ladybird beetles, spiders, and ants, exhibited either consistent or sporadic presence, yet did not display any discernible patterns in relation to the aforementioned weather parameters (Fig. 2–4).

The correlation between the populations of various arthropod guilds and the prevailing weather parameters was analysed to gain a deeper understanding of the relationship between the biotic and abiotic components of the brinjal crop ecosystem (Fig. 5). In the first crop season, both mealybugs and jassids from the sucking guild demonstrated a significant negative correlation with the daily minimum temperature (Tmin), with correlation coefficients of -0.477 and -0.434, respectively. Epilachna beetles from the chewing guild, on the other hand, exhibited a significant positive correlation with daily minimum relative humidity (RHMin), with a coefficient of 0.475. During the second crop season, mealybug populations showed significant negative correlations with maximum temperature (TMax), minimum temperature (Tmin), and maximum relative humidity (RHMax), with correlation values of -0.694, -0.639, and -0.434, respectively. Other meteorological variables had a negligible effect on their populations. For whiteflies, jassids, and epilachna beetles, significant negative correlations were observed with all weather parameters, including TMax, Tmin, RHMax, RHMin, and rainfall. The correlation coefficients for these species were as follows: whitefly (-0.861, -0.882, -0.660, -0.595, and -0.460), jassids (-0.685, -0.697, -0.557, -0.503, and -0.444), and epilachna beetles (-0.434, -0.486, -0.444, -0.529, and -0.541). Among the predators, ladybird beetles exhibited significant negative correlations with both TMax (-0.803) and Tmin (-0.691).

In the third crop season, populations of jassids and thrips exhibited significant negative correlations with Tmin, with correlation coefficients of -0.411 and -0.637, respectively. The brinjal shoot and fruit borer (BSFB) population displayed significant negative correlations with TMax, RHMax, and RHMin, with correlation values of -0.637, -0.416, and -0.541, respectively. During the fourth crop season, both whitefly and aphid populations showed significant negative correlations with Tmin, with values of -0.426 and -0.502, respectively. The population of epilachna beetles demonstrated a significant positive correlation with both TMax (0.507) and Tmin (0.503), as well as a significant negative correlation with RHMax (-0.674). Flea beetles exhibited significant positive correlations with TMax (0.495) and Tmin (0.535), alongside significant negative correlations with RHMax (-0.446) and RHMin (-0.582). BSFB populations revealed a significant positive correlation with rainfall at 0.599, while their relationships with other weather parameters were not statistically significant.

In the fifth crop season, mealybug populations demonstrated significant positive correlations with RHMax, RHMin, and rainfall, with correlation coefficients of 0.489, 0.670, and 0.528, respectively. Jassids exhibited a significant negative correlation with RHMin (-0.466). Epilachna beetle populations showed a

significant positive correlation with the daily minimum temperature (TMin) at 0.505. Flea beetles displayed a significant positive correlation with TMax (0.409), but significant negative correlations with RHMax (-0.575), RHMin (-0.609), and rainfall (-0.412). BSFB populations revealed a significant positive correlation with TMin (0.551), RHMin (0.482), and rainfall (0.561). For the first time, the spider population exhibited significant positive correlations with both TMin (0.484) and rainfall (0.488). In the sixth cropping season, the jassid population exhibited a significant positive correlation with TMax at 0.419 and a significant negative correlation with RHMax at -0.507. The brinjal shoot and fruit borer (BSFB) population showed a significant negative correlation with TMax at -0.596, while the spider population displayed a significant negative correlation with TMin at -0.501. Both RHMax and RHMin had a significant positive effect on the populations of BSFB (0.658 and 0.636, respectively) and spiders (0.503 and 0.459, respectively). In the seventh cropping season, the jassid population demonstrated significant negative correlations with TMin, RHMax, and RHMin, with values of -0.422, -0.546, and -0.642, respectively. The whitefly population showed a significant positive correlation with TMin at 0.407. Within the chewing guild, the epilachna beetle population exhibited significant positive correlations with TMin, RHMin, and rainfall at 0.414, 0.464, and 0.561, respectively. Rainfall had a significant positive effect on flea beetles at 0.504, while the BSFB population displayed a significant negative correlation with rainfall at -0.439.

During the eighth cropping season, the aphid population exhibited a significant positive correlation with TMax at 0.416, while both jassid and flea beetle populations showed significant negative correlations with TMin at -0.431 and -0.419, respectively. The BSFB population displayed significant negative correlations with TMax, TMin, and RHMin at -0.660, -0.767, and -0.701, respectively. Both TMax and TMin had a significant negative impact on the spider population, with correlations of -0.409 and -0.464, respectively, while they exhibited significant positive correlations with the ant guild at 0.507 and 0.470, respectively. In the ninth cropping season, the whitefly population showed significant negative correlations with TMin and rainfall at -0.405 and -0.433, respectively. The BSFB population exhibited significant negative correlations with TMin and RHMin at -0.427 and -0.664, respectively. Both RHMax and RHMin demonstrated significant negative correlations with aphid populations at -0.473 and -0.581, respectively, as well as with ladybird beetle populations at -0.716 and -0.473, respectively. The thrips population showed a significant negative correlation with RHMin at -0.532, while the ant population displayed a significant positive correlation with RHMin at 0.417.

In the tenth cropping season, all arthropod populations exhibited partial significant associations with weather parameters. The whitefly population showed a significant negative correlation with RHMin at -0.438, and a significant positive correlation with rainfall at 0.640. The jassid population demonstrated a significant positive correlation with TMax at 0.437. Both TMax and TMin exerted significant negative effects on the populations of aphids and ants, with correlation values of -0.448 and -0.517 for aphids, and -0.494 and -0.471 for ants, respectively. Both thrips and spider populations exhibited significant negative correlations with RHMax at -0.414 and -0.488, respectively, while rainfall had a significant positive effect on both populations, with correlation values of 0.733 and 0.457, respectively. The ladybird beetle population showed significant negative correlations with RHMax and RHMin at -0.600 and -0.451, respectively. Both TMax and TMin had significant positive correlations with the populations of epilachna beetles at 0.488 and 0.471, flea beetles at 0.567 and 0.660, and the BSFB at 0.671 and 0.663, respectively. In contrast, all three of these insect populations exhibited significant negative correlations with RHMax at -0.447, -0.438, and -0.529, respectively.

In the eleventh cropping season, the mealybug population exhibited a significant positive correlation with rainfall, with a correlation value of 0.510. Both whitefly and jassid populations showed significant negative correlations with RHMin, at -0.442 and -0.490, respectively. The flea beetle population demonstrated significant negative correlations with both RHMax at -0.479 and RHMin at -0.521. The populations of both the epilachna beetle and the BSFB exhibited significant positive correlations with TMin, at 0.593 and 0.577, respectively, as well as with RHMin, at 0.475 and 0.548, respectively, and rainfall, at 0.531 and 0.656, respectively.

The results of this study revealed distinct interactions between various arthropod populations and weather parameters (Fig. 6). Rainfall was identified as the primary weather factor influencing the populations of mealybugs and epilachna beetles, explaining 38.84% and 31.09% of the observed variation, respectively. The populations of whiteflies, tobacco caterpillars, and ladybird beetles were predominantly influenced by TMin, with contributions of 33.23%, 27.97%, and 36.86%, respectively. For jassids, aphids, thrips, leaf rollers, spiders, and ants, RHMin emerged as the key weather factor, accounting for 44.78%, 23.62%, 35.37%, 33.42%, 23.74%, and 38.78% of the variation in their populations, respectively. The BSFB populations were influenced almost equally by TMin and RHMin, with contributions of 22.79% and 22.74%, respectively. The flea beetle population, on the other hand, was most strongly affected by TMax, explaining 37.45% of the variation.

Study on intra-guild and inter-guild correlation of arthropods

The study investigated the intra- and inter-guild interactions among arthropod species in the brinjal ecosystem using statistical correlation tools. These relationships, shaped by weather conditions as well as the physico-morphological and biochemical factors present in the ecosystem, were examined across 11 cropping seasons (Fig. 7).

Within the sucking guild, interspecies interactions were observed throughout the cropping seasons. The mealybug demonstrated significant positive correlations with whiteflies during the second and seventh crops, with jassids during the first and second crops, with aphids during the first and fifth crops, and with thrips during the eighth crop. Whiteflies, in turn, exhibited significant positive interactions with jassids in the second, third, fourth, fifth, tenth, and eleventh crops, with aphids in the fourth and eighth crops, and with thrips in the fourth, fifth, eighth, tenth, and eleventh crops. Additionally, jassids showed significant positive interactions with thrips in the fourth, fifth, eighth, ninth, tenth, and eleventh crops, and with aphids in the ninth crop. However, in the sixth crop, jassids displayed a significant negative interaction with aphids.

Within the chewing guild, the BSFB exhibited statistically significant co-occurrence with epilachna beetles in the fifth and eleventh crops, but a significantly negative relationship in the ninth crop. Additionally, BSFB showed a significant positive association with flea beetles. Overall, members of the sucking guild displayed significant positive interactions within their own guild across most cropping seasons, and intra-guild relationships within the chewing guild were also predominantly positive.

In the analysis of inter-guild relationships between the sucking and chewing guilds across the eleven cropping seasons, several significant interactions were observed. Mealybugs and epilachna beetles demonstrated a significant positive relationship in the second and eleventh crops. Furthermore, a significant positive relationship between mealybugs and BSFB was noted in the fifth and eleventh crops. In the second, third, and eighth crops, whiteflies and epilachna beetles exhibited a significant positive interaction, although this relationship turned significantly negative in the fourth crop. Whiteflies also showed a significant positive relationship with BSFB in the tenth crop. Overall, the inter-guild interactions between members of the sucking and chewing guilds were predominantly positive across most of the cropping seasons.

The study also explored the inter-guild relationships between predators and members of the sucking and chewing guilds, revealing that variations in crop duration and species had a notable influence on these interactions. The population of ladybird beetles exhibited significant positive correlations with several arthropod species across different cropping seasons. For instance, ladybird beetles demonstrated a significant positive relationship with mealybugs in the second crop, whiteflies in the second, fifth, ninth, and eleventh crops, jassids in the second and ninth crops, aphids in the ninth crop, and thrips in the seventh, ninth, and tenth crops. Furthermore, ladybird beetles showed significant positive interactions with epilachna beetles in the second and eighth crops, as well as with the BSFB in the tenth crop. Spiders, too, exhibited significant positive interactions with various arthropods. These included whiteflies in the third, fourth, and ninth crops, and thrips in the fourth and eighth crops. Additionally, spiders showed significant positive associations with epilachna beetles in the second and fifth crops, and with BSFB in the second, fifth, sixth, and eighth crops.

The analysis of the relationships between ants and other arthropods revealed several significant interactions. Ants exhibited notable positive correlations with jassids in the first crop, aphids in the sixth, eighth, and tenth crops, and whiteflies in the eighth crop. Additionally, ants displayed a significant positive relationship with thrips in the fifth crop, but a significant negative relationship with thrips in the ninth crop. Overall, the interactions between the predatory guild and the members of the sucking and chewing guilds, as well as those between the ant guild and these two guilds, were predominantly positive across most cropping seasons. However, ants showed significant negative interactions with thrips, BSFB, and ladybird beetles in the ninth, ninth, and tenth crops, respectively, as well as with ladybird beetles in the fourth crop.

Statistical analysis of the data highlighted the significant influence of co-occurring arthropods on the population dynamics of each species, with a particular emphasis on both intra- and inter-guild interactions (Fig. 8). The population of mealybugs was most notably influenced by the presence of leaf rollers, accounting for 23.14% of the variation. Ladybird beetles played a dominant role in the population dynamics of whiteflies, contributing 30.68%. The jassid population was strongly affected by flea beetles, which accounted for 42.79%, indicating substantial inter-guild interactions. Both aphid and BSFB populations were primarily influenced by thrips, contributing 23.11% and 19.19%, respectively. The populations of thrips and flea beetles were most influenced by the presence of jassids, with contributions of 31.31% and 40.01%, respectively. Epilachna beetles exhibited a strong intra-guild relationship with BSFB, with a contribution of 24.84%. Spiders had the most significant influence on the tobacco caterpillar population, accounting for 49.66%, while leaf roller populations were highly influenced by mealybugs, contributing 48.12%. Ladybird beetles demonstrated a strong inter-guild relationship with whiteflies, with a contribution of 53.56%, and spider populations were most influenced by epilachna beetles, contributing 13.64%. Finally, the ant guild exhibited a significant interaction with aphid populations, accounting for 27.61%.

Discussions

A central challenge in understanding population dynamics lies in exploring the mechanistic links between population changes and climate variability (Stenseth et al. 2002; Boggs and Inouye 2012; Solbreck et al. 2022). The primary aim of this study was to examine the relationships between key weather variables and the population dynamics of arthropods in the brinjal ecosystem, as well as to investigate the interactions both within arthropod guilds and between different guilds. The brinjal crop ecosystem is characterised by a high diversity of insect pests and natural enemies (Vevai 1970). In this context, Das (2006) recorded 27 insect species and one mite, alongside 23 natural enemies, within the brinjal crop ecosystem. These findings align with those of Dar et al. (2015), who also documented a wide array of arthropod pests and predatory insects in the brinjal ecosystem, contributing to the maintenance of environmental balance. Earlier, Latif et al. (2009) identified 20 species of harmful arthropods, including brinjal shoot and fruit borers (BSFB), aphids, jassids, whiteflies, and epilachna beetles, as major pests. Yasodha and Natarajan (2009) recorded twelve parasitoid species from field-collected BSFB larvae, and Sankari (2010) observed eight different spider species and their predatory role against insects in brinjal crops. Kumar et al. (2022) reported 29 species of arthropods in the brinjal ecosystem over two cropping seasons, including 14 pest species, 12 predators, and 3 parasitoids. Kumari et al. (2023) documented 16 species of pests and natural enemies in the brinjal ecosystem during a single crop season. Collectively, these studies highlight the ecological richness and complexity of the brinjal crop ecosystem, where a diverse community of pests and natural enemies coexists, interacts, and contributes to the dynamic stability of arthropod populations across seasons.

Insect population dynamics are influenced by a complex interplay between intrinsic factors, such as density dependence and trophic web interactions, and external forces, including weather conditions (Solbreck et al. 2022). The present study revealed that different arthropod species responded variably to the prevailing weather parameters. These findings are consistent with those of Ghuge et al. (2020) on okra, who observed significant positive correlations between aphid, jassid, and ladybird beetle populations and evening relative humidity, while whitefly populations exhibited a significant positive correlation with daily temperature. Chatterjee et al. (2018) similarly found that mealybug populations in the brinjal ecosystem were significantly positively correlated with both maximum and minimum relative humidity and rainfall, a result that aligns with our findings. In a study of sucking pests in groundnut, Dey Roy and Mukhopadhyay (2024) reported significant negative correlations between whitefly and thrips populations and daily temperature and relative humidity, respectively. Dhole et al. (2023) underscored the dominant role of environmental factors in regulating whitefly populations, noting a negative correlation with rainfall and relative humidity, while temperature showed a positive correlation with their population. Nabil and Hegab (2019) found a significant positive correlation between maximum temperature and mealybug populations in okra, with a significant negative correlation with mean relative humidity. However, the present study contrasts with the findings of Patel and Radadia (2018), who reported a significant positive correlation between jassid populations and temperature, humidity, and rainfall.

Salve et al. (2021) reported a significant negative correlation between the population of the BSFB and all the weather parameters, which is consistent with the findings of the present study. Kumar et al. (2022) partially corroborated our results, observing a significant negative correlation between the larval population of BSFB and maximum temperature, although they also identified a significant positive correlation with other weather parameters. Swetha et al. (2023) found a significant positive correlation between the population of epilachna beetles and both maximum and minimum temperatures, while a significant negative correlation was noted with both maximum and minimum relative humidity, which aligns with the observations in this study. Singh et al. (2024) reported a significant positive correlation between the BSFB population and both maximum and minimum temperatures, along with a significant negative correlation with relative humidity. Haq and Rizvi (2023) suggested that BSFB populations decline with increasing temperature, humidity, and rainfall, a finding that supports the present study. Similarly, Vijayalakshmi et al. (2021) observed significant negative correlations between BSFB populations and both maximum and minimum temperatures.

The findings regarding spider population dynamics are consistent with those of Mouly et al. (2018) and Raghul and Kumar (2022), who reported that spider populations increased with rising temperatures, while exhibiting a negative correlation with relative humidity and rainfall. Kataria and Kumar (2017) observed that ant populations showed a significant negative correlation with minimum temperature, although their interactions with other weather factors were not significant. Samantaray and Singh (2024) noted that ladybird beetle populations had a negative correlation with minimum temperature, relative humidity, and rainfall, while displaying a positive correlation with maximum temperature. Overall, these findings stress that weather factors affect arthropod populations in strongly species-specific and sometimes opposing manners. Whereas a few pests and beneficial insects thrive under increasing temperatures or humidity, others react negatively. This type of diversity conveys the complexity of insect-weather interactions and underscores the value of location- and crop-specific pest forecast models. Inclusion of these ecological subtleties in integrated pest management models would greatly enhance their accuracy and efficacy.

Variations in crop duration and species had a marked impact on the interactions between predators, ants, and members of both the sucking and chewing guilds, as evidenced by intra- and inter-guild dynamics. Patel and Radadia (2018) found a significant positive correlation between spider populations and jassid populations, while ladybird beetles exhibited a non-significant positive correlation. Jain (2008) documented a significant positive correlation between ladybird beetles and the populations of jassids, aphids, and whiteflies. Bindu and Pramanik (2017) also reported a significant positive relationship between ladybird beetles and epilachna beetles. Rathod et al. (2017) demonstrated that aphid populations were positively correlated with the population of predatory coccinellids. During the kharif season, leafhopper populations were negatively correlated with predatory coccinellids, but this relationship became significantly positive in the rabi season.

A moderate positive linear correlation between total pest abundance and total predator abundance was observed by Lee et al. (2022) in soybean. Nikolova (2024) found that the population density of ladybird beetles was negatively correlated with aphid populations, suggesting that as the ladybird beetle population increased, aphid populations declined. Suroshe and Chander (2022) reported potential intra-guild competition among different species of ladybird beetles. Chen et al. (2023) observed a significant negative correlation between predatory spiders and jassid populations. Glacet et al. (2024) highlighted that the presence of honeydew influenced inter-guild relationships between aphids and their predators. Samuel and Rastogi (2022) demonstrated that ants increased aphid abundance but reduced the abundance of multiple insect herbivores and arthropod predators on plants. Pequeno et al. (2023) suggested that the positive relationship between spider abundance and insect prey abundance diminished as ant populations increased. Das and Degee (2023) noted that aphid pests reduced intraguild predation in ladybird beetles, a finding also supported by Tiwari et al. (2010), who reported that increasing aphid populations led to a rise in ladybird beetle populations.

The findings compiled by Prashanth et al. (2023) indicated that ladybird beetle populations increased in response to rising populations of the BSFB. Similarly, Katkar et al. (2023), in their regression model study on brinjal pests, observed that consistent abiotic conditions resulted in increased populations of jassids, aphids, and BSFB. This suggests that an upsurge in populations within the sucking guild may also contribute to an increase in populations within the chewing guild under similar environmental conditions. These results together indicate that arthropod associations within and between trophic guilds are extremely dynamic and context-dependent, determined by crop phenology, seasonal fluctuation, and the influence of mutualistic species like ants. The co-occurrence of both positive and negative correlations among predators and pests indicates the intricacy of trophic networks, in which intra-guild competition, predator facilitation, and resource-mediated associations are essential.

Conclusion

Brinjal (eggplant) farming in India is strongly limited by a complex of arthropod pests, and it usually results in indiscriminate and excessive pesticide application. Not only does it encourage pesticide resistance and pest revival, but also residual toxicity and environmental pollution. The current study stresses the crucial necessity of an ecological approach towards pest management. Through the explanation of the interaction among climate variability, crop phenology, and trophic interactions, this study offers useful information on the population dynamics of pests and their natural enemies in the brinjal agroecosystem. The results emphasize species-specific weather parameter responses, indicating that climatic variables differentially affect pest and natural enemy populations. In addition, the research unveils that intra- and inter-guild interactions, regulated by crop growth phases and the presence of mutualistic species like ants, demonstrate context-dependent dynamics regulated by competition, facilitation, and intraguild predation. The result of co-occurrence and intricate associations in arthropod communities highlights the urgency of formulating location-specific pest forecasting models and adopting ecologically based integrated pest management (IPM) tactics. Integrating this ecological knowledge into pest management systems will increase the accuracy, sustainability, and resilience of pest control in brinjal farming, thus aiding environmentally friendly agriculture.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

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This article does not contain any studies with human participants or animals performed by any of the authors.

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Figures

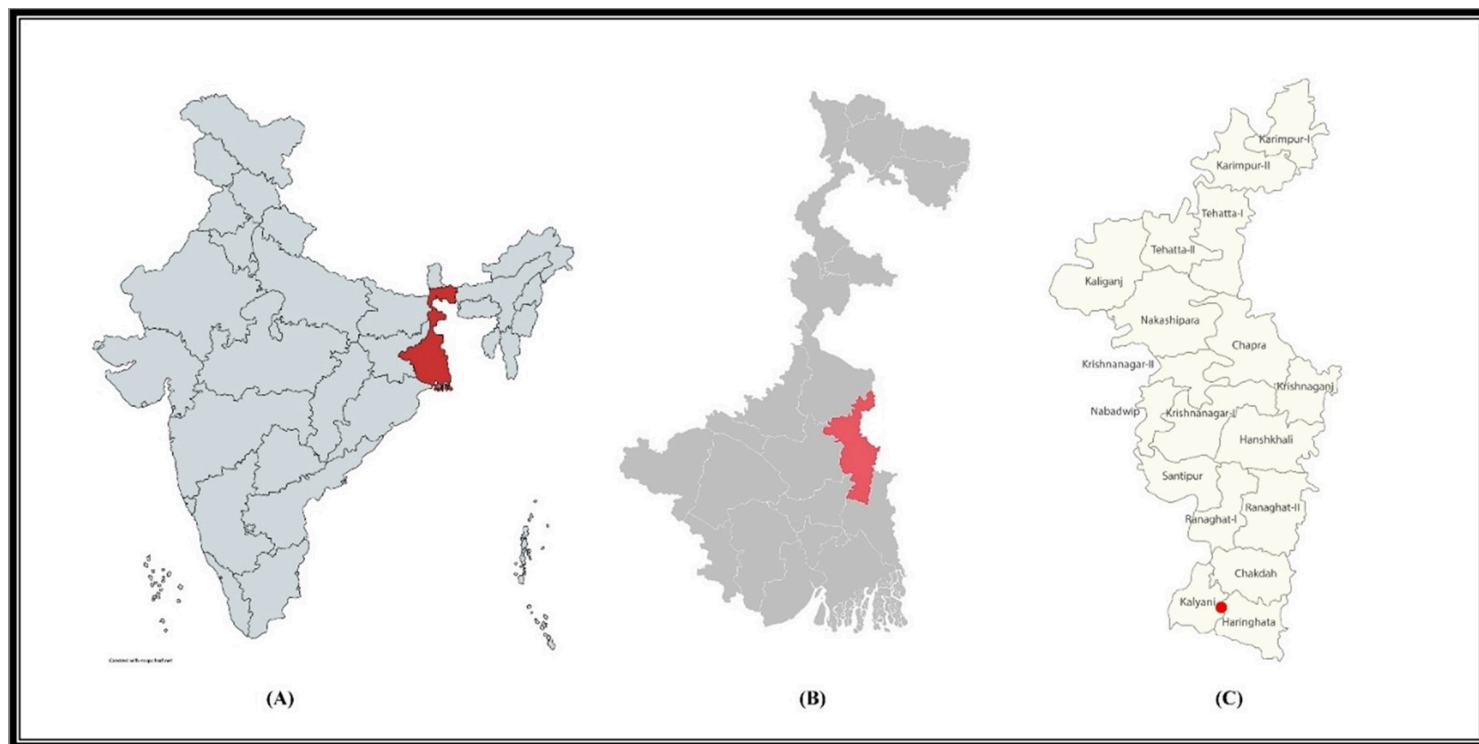


Figure 1
Location of experimental site: (A) map of India with the state West Bengal marked in red colour; (B) map of West Bengal with the district Nadia marked in red colour; and (C) map of Nadia with the study location marked in red colour

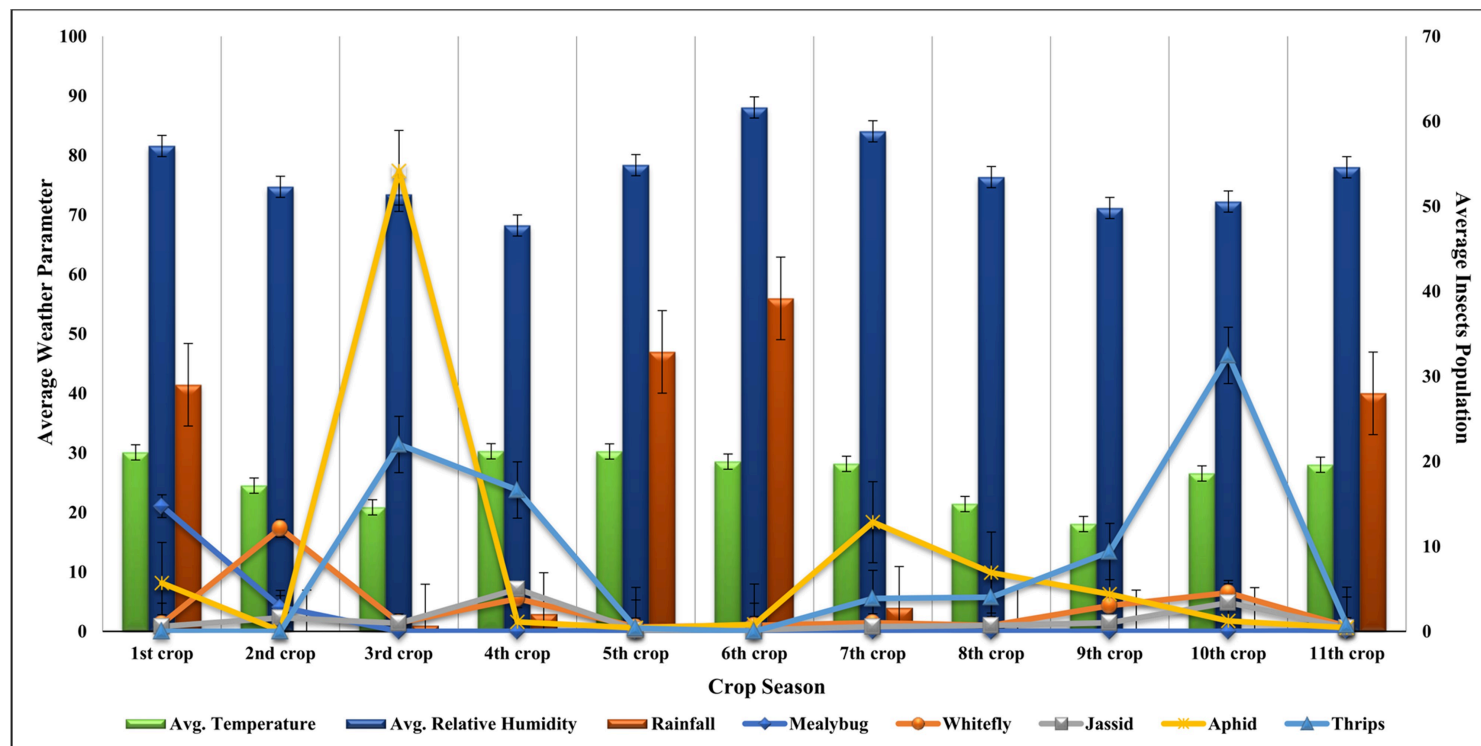


Figure 2
Crop season wise natural occurrence of average population of members of sucking guild in brinjal ecosystem during 2021 to 2023.

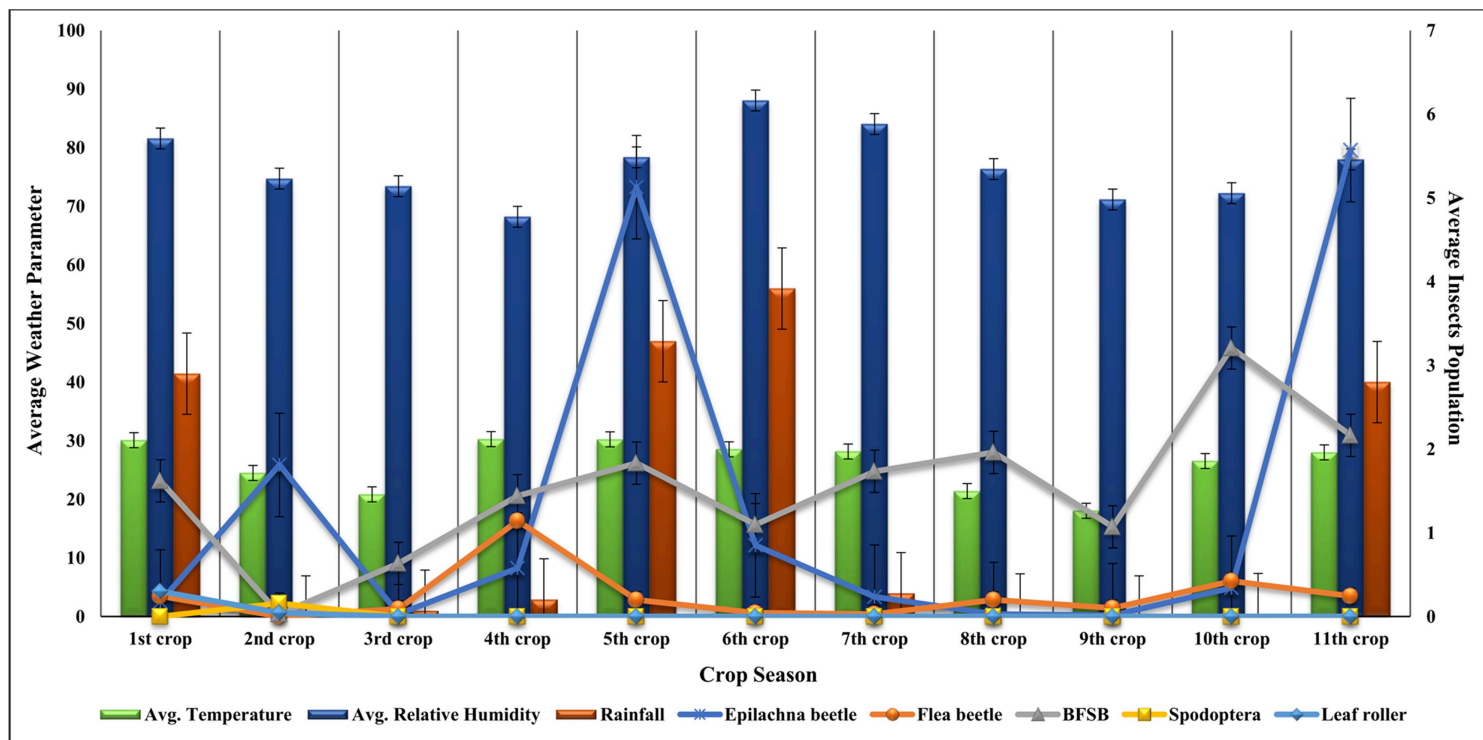


Figure 3

Crop season wise natural occurrence of average population of members of chewing guild in brinjal ecosystem during 2021 to 2023.

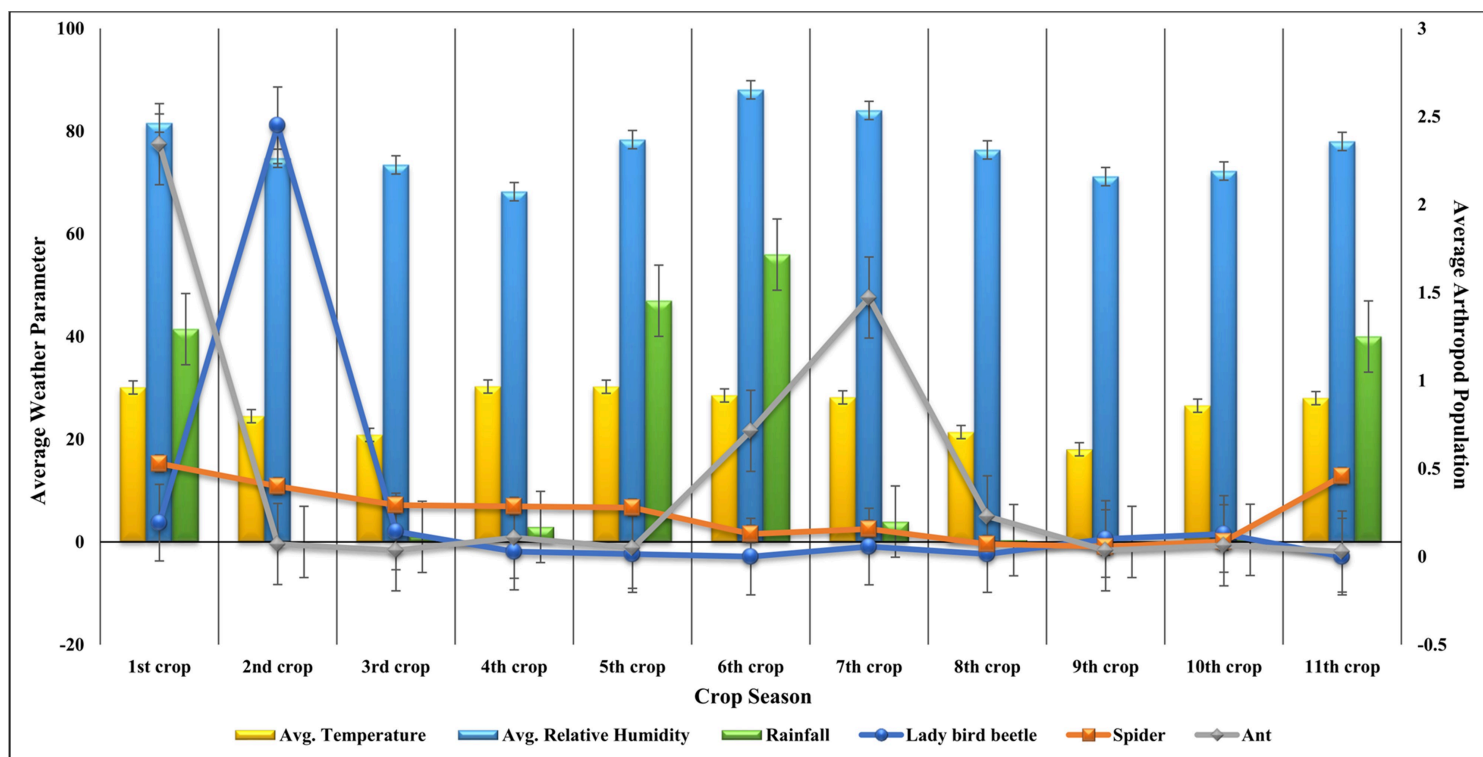


Figure 4

Crop season wise natural occurrence of average population of members of predatory and ant guild in brinjal ecosystem during 2021 to 2023.

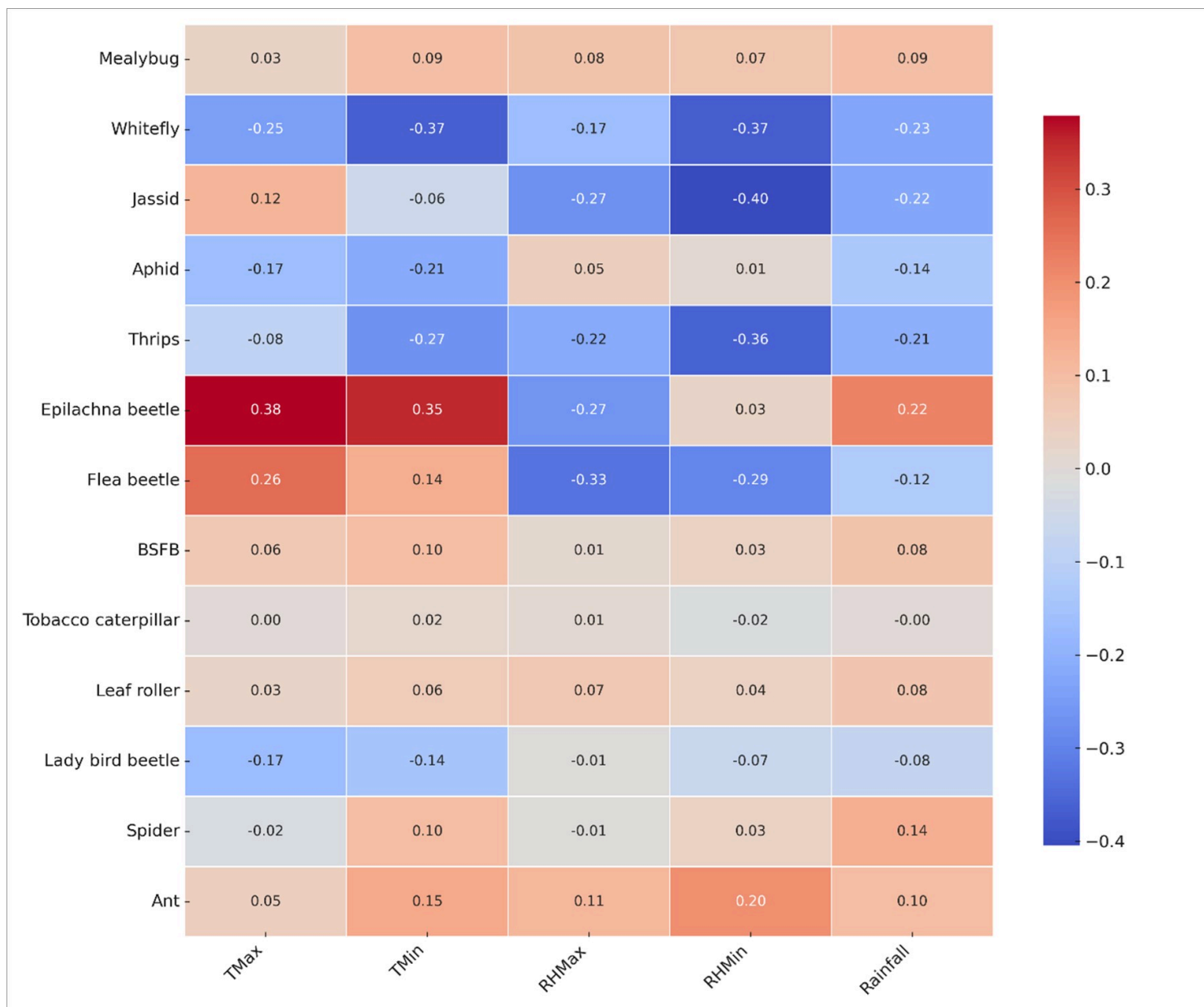


Figure 5

Correlation among the arthropod members and abiotic factors in brinjal ecosystem during 2021 to 2023. The light and dark coloured areas refer to higher and lower level of correlation, respectively.

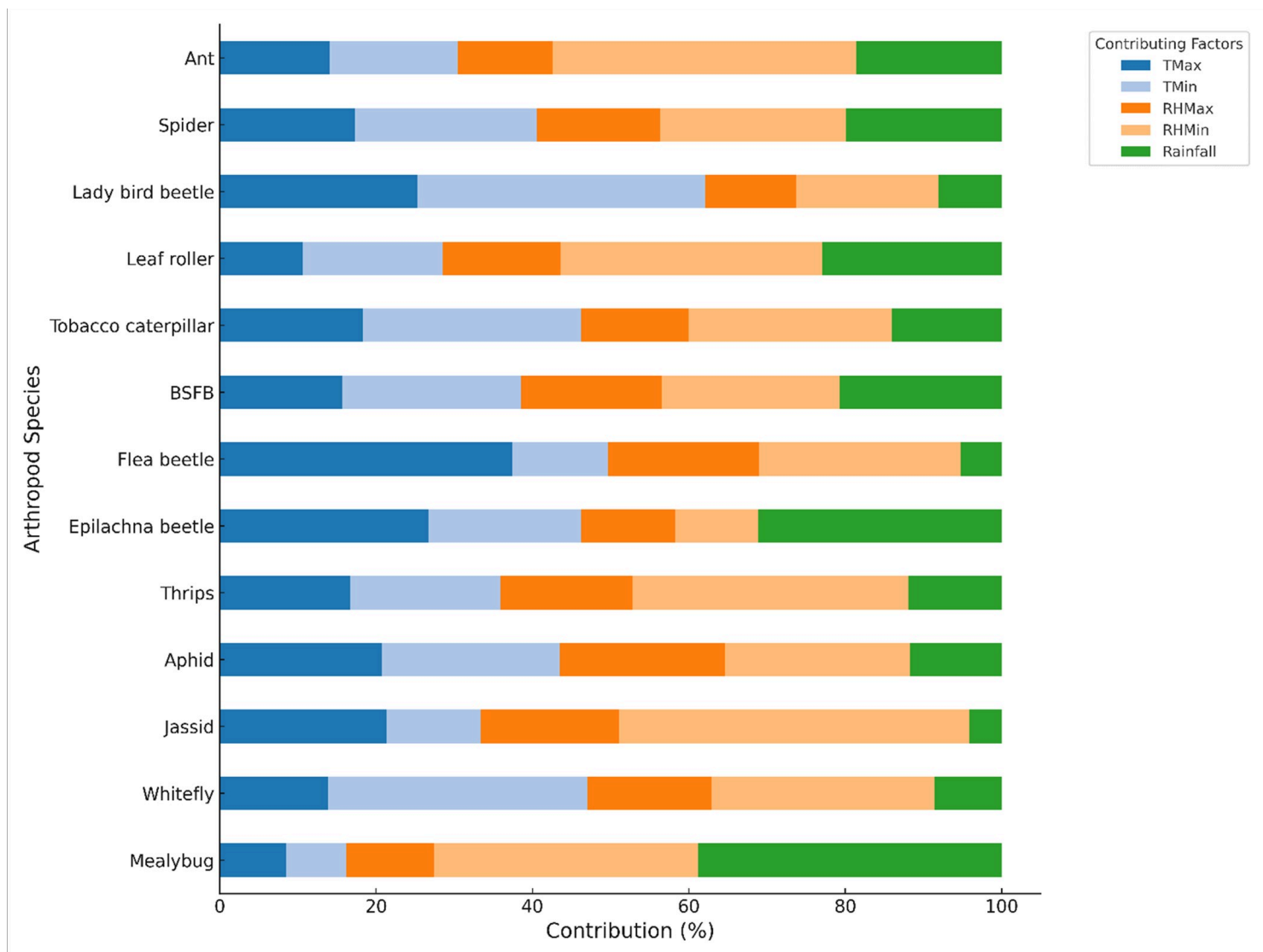


Figure 6

Relative contribution of weather parameters to the population dynamics of arthropod species. Each horizontal bar represents an arthropod species, with colored segments indicating the percentage contribution of individual weather variables to population variability.

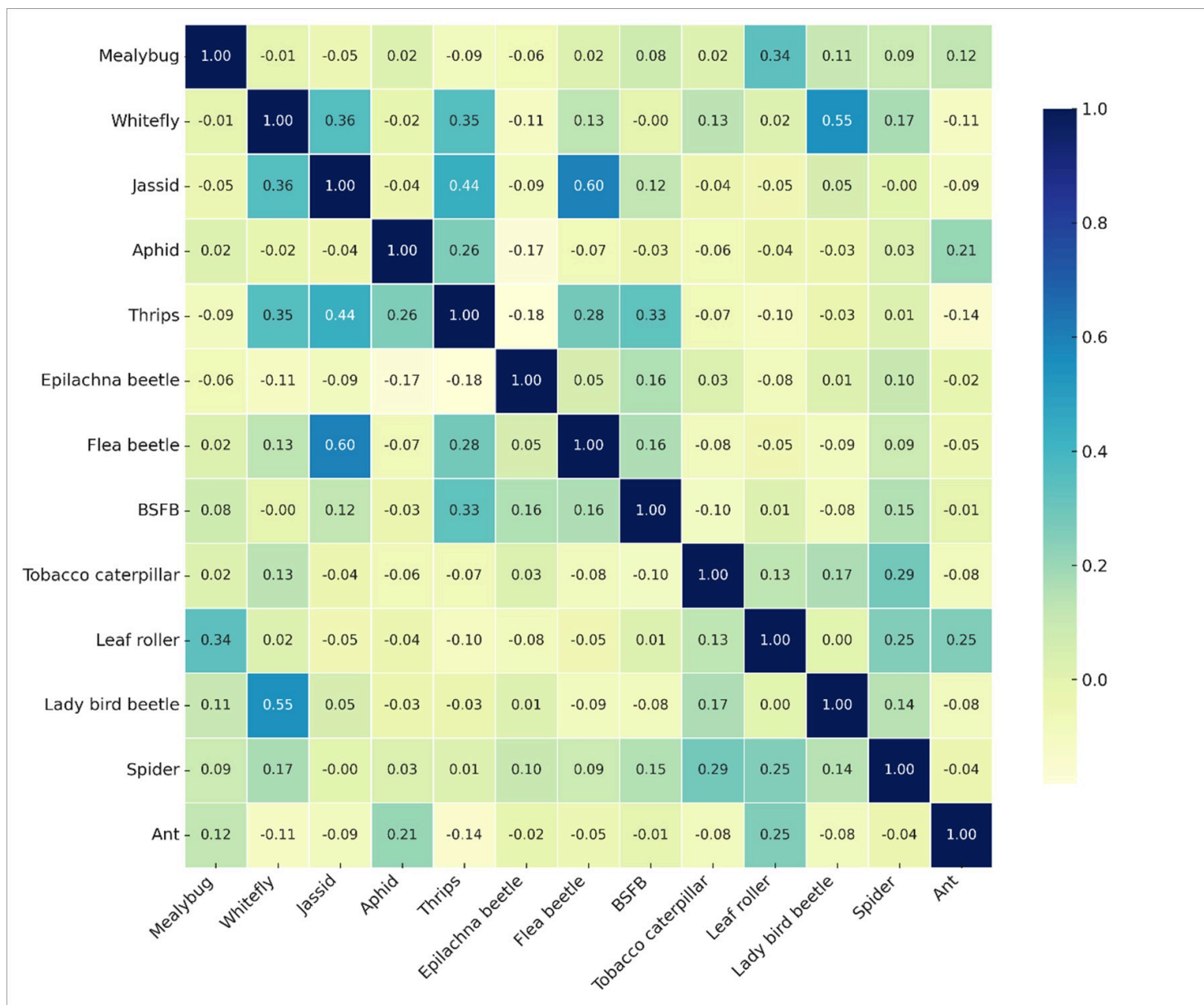


Figure 7
Inter- and intra-guild relationship among the arthropod members in brinjal ecosystem during 2021 to 2023. The light and dark coloured areas refer to higher and lower level of correlation, respectively.

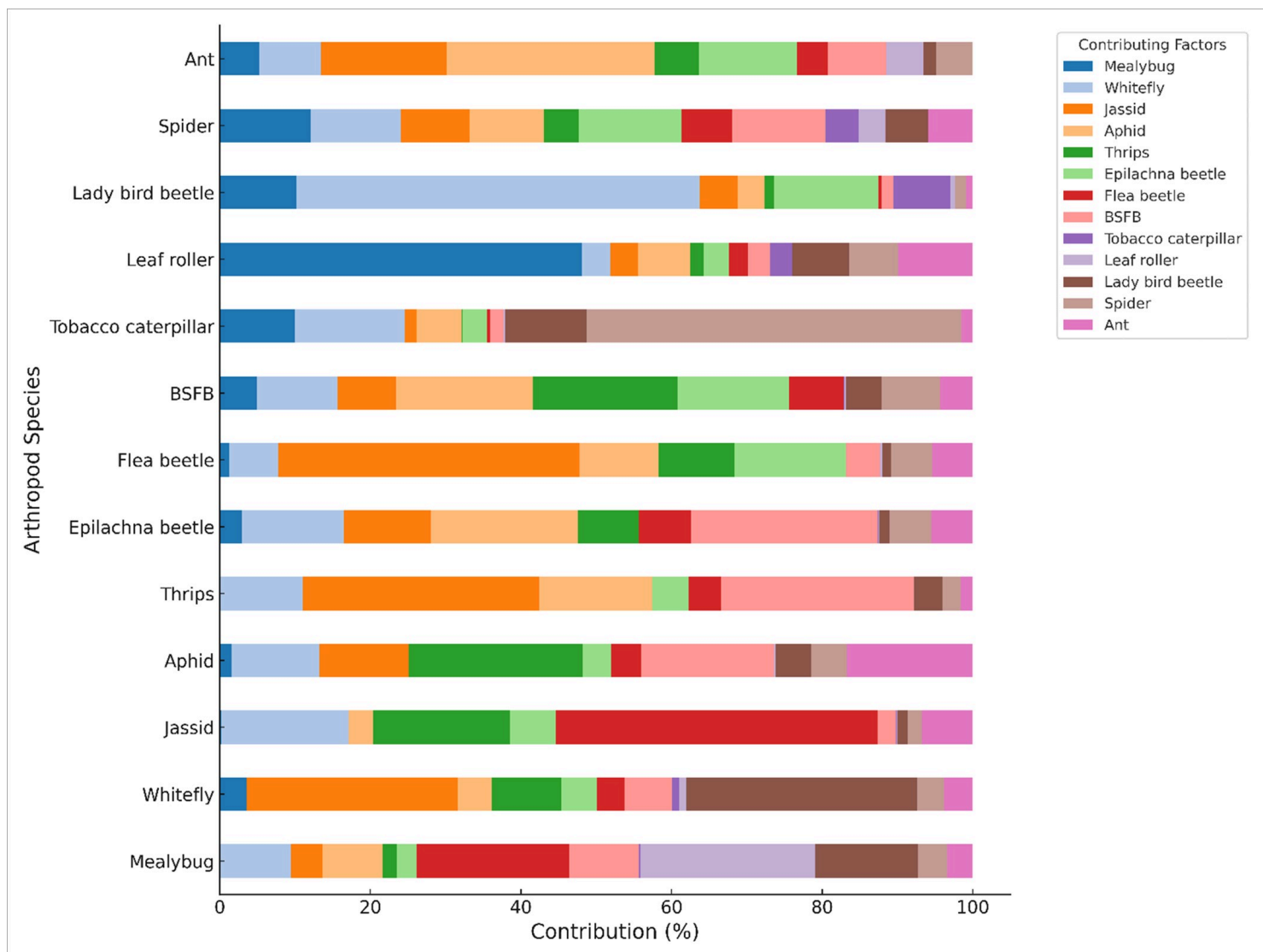


Figure 8

Relative influence of co-occurring arthropods on the population dynamics of target species. Bars represent target arthropod species, with each colored segment denoting the proportional contribution of other arthropods to their population fluctuations.

Supplementary Files

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- [floatimage1.jpeg](#)