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Article

Diversity and interaction network of mites on agri-horticulture crops of selected areas of West Bengal in India

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ABSTRACT
The South 24 Parganas district of West Bengal, India is very rich in the cultivation of agri-horticultural crops, but nowadays the crop production yield is declining due to the attack of phytophagous mites. A survey was undertaken in selected localities of the South 24 Parganas to understand the diversity of mite fauna associated with agri-horticultural crops. A network approach was applied to determine some of the mite-plant network parameters such as specialization and nestedness. The present paper deals with a total of 39 species of plant mites (18 phytophagous, 19 predatory, and two fungal feeding groups) belonging to 19 genera and 10 families. The majority of the plants on which these mites were recorded formed new host/habitat records. *Brevipalpus rica*, *Tetranychus ludeni*, and *T. macfarlanei* were found important injurious mites, while *Amblyseius largoensis* and *Paraphytoseius bhadrakaliensis* were found abundantly as predators and had biocontrol importance. The study also showed that the phytophagous mites had greater sample diversity compared to predatory mites. The network analysis of mite-plant association revealed that mites form a highly specialized and less nested network with host plants. It was also observed that in this network, *Phaseolus vulgaris* has a mite hub-like role having high centrality values. This study may form a baseline of acarological studies in South Bengal area, which might be helpful in designing pest management strategies.

KEYWORDS: Bipartite network, mite diversity, phytophagous mites, predatory mites, robustness, South 24 Parganas.

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INTRODUCTION

The cultivation of various agricultural crops comprised about 4.3% of global GDP (Gross Domestic Product) during 2021(The Economic Times 2023), but the pest infestation in major crops caused a loss of about US $ 21.5 billion during 2007–2008 (Dhaliwal *et al.* 2010). Among arthropod pests, the mites associated with agri-horticultural crops are of special mention. Though many of the plant-associated mites are innocuous in nature, some of them threaten the crop cultivation, causing severe economic loss. For example, *Tetranychus urticae* Koch and *Schizotetranychus smirnovi* Wainstein seriously threaten the crop production and reduce the quantity and quality of nuts (Saeidi 2013; Saeidi

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and Nemati 2020). The broad mite, *Polyphagotarsonemous latus* (Banks), which is extremely polyphagous, is considered a pest of substantial economic importance (Peña and Campbell 2005). They have threatened the cultivation of agri-horticultural crops causing economic loss as they are responsible for 80–100% foliage loss and 12–60% loss in yield [NPCS Board of Consultants & Engineers (2007)]. On the other hand, another group of mites belonging to the Phytoseiidae family are highly predaceous and feed on phytophagous arthropods including different species of Tetranychidae, Tenuipalpidae, and Eriophyoidea (Beard *et al.* 2014). Predatory mites belonging to families Phytoseiidae, Ascidae, under the order Mesostigmata and Cunaxidae, Bdellidae, Stigmaeidae, Cheyletidae, and Iolinidae under the order Trombidiformes are important and have the potential to suppress the pest mite population (James *et al.* 2023; Xiang *et al.* 2024). Most of the predatory mites are considered food generalists because of their feeding abilities on a number of prey species along with pollen, plant exudates and fungi according to Tixier (2018). The diversity study of plant-associated mites is very important to design an effective pest management program. Studies on diversity, relative abundance, and distribution of plant associated mites have been conducted by many researchers such as Patient *et al.* (2019) on cowpea, okra, and maize; Bala and Karmakar (2022b) on agri- horticultural crops; and also, by Chi *et al.* (2024) on *Megalurothrips usitatus* (Bagnall). Such studies have been proven to be important in the detailed understanding of community attributes through the Shannon-Weiner Diversity Index (1948) and Simpson's Index (1949). Many ecological studies often also consider networks as an important tool for understanding community structure.

The district of South 24 Parganas (Pgs.) in West Bengal is very rich due to the presence of a wide range of cultivation of vegetables, fruit trees, medicinal plants, etc. In view of that, several workers attempted to explore the mites occurring on these plants in this district. A perusal of literature survey indicates that some of such works are done by Gupta *et al*. (2003), Roy *et al*. (2011), Mondal and Gupta (2016), Mitra *et al.* (2017), Samaddar *et al*. (2017), Gupta and Mondal (2018), Karmakar *et al.* (2018), Samaddar *et al.* (2021) and Bala and Karmakar (2022a) which included many mite species belonging to phytophagous and predatory groups from these regions. Those works dealt with mites of various plants of agri-horticultural ecosystem including vegetables, fruits, ornamentals, medicinal etc. Through these publications, a good number of mites have been reported and some new species were described from these areas. Since South 24 Parganas district covers a huge area with multifarious crops (Gupta 2012), many regions thereof remain unexplored, from an acarological point of view. To explore the diversity of mite fauna associated with agri-horticultural crops, the present investigation was undertaken. The analysis of the plant-mite network has been made to understand the degree of ecological association between the partners. The robustness of the plant-mite network was also addressed in this study as it can influence the structure of interactions within a community.

MATERIAL AND METHODS

Study area

The survey was conducted around the selected places (Fig. 1) of South 24 Parganas district, West Bengal, India in the following localities: Gosaba (22° 16' 44.29" N, 88° 48' 33.63" E), Rupayan (22° 9' 50.94" N, 88° 48' 32.69" E), Bagbagan (22° 10' 39.61" N, 88° 50' 50.80" E), and Narendrapur (22° 26' 11.01" N, 88° 24' 0.62" E) from October 2022 to July 2023 to identify the diversity of mite fauna associated with the agri-horticultural crops. The study site falls on the fringes of the Sundarban Biosphere Reserve. The climate is tropical, with an average temperature ranging between 13.3–36.3 °C (Goswami and Mondal 2015) while the average annual rainfall is 150–200 mm (Sahana *et al*. 2020). The land of the district is very fertile mainly because of the alluvial and partly saline soil carried by the rivers and sea waves (Mondal 2021).

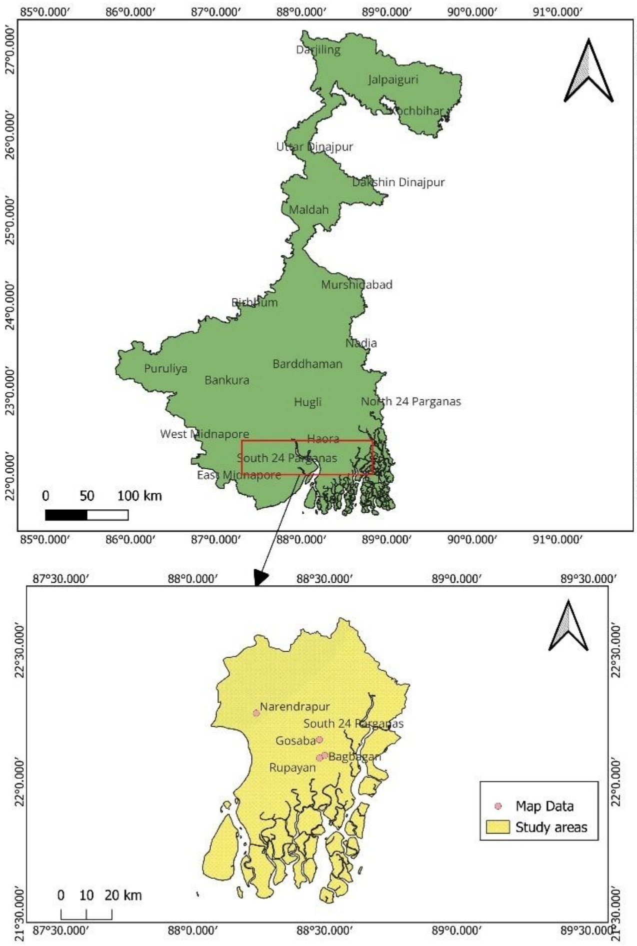

Figure 1. Map showing the study areas (Gosaba, Rupayan, Bagbagan and Narendrapur) of West Bengal, India.

Collection and preservation

At each study area, a 100 m × 100 m quadrate was laid. Each quadrate was divided into a grid of 10 m × 10 m plots. From these, 10 plots were randomly chosen for mite sampling. The minimum distance between the plots was kept at 10 m to minimize the movement of the said pests from the neighboring plots. From each said plot, five plants were randomly selected and from them 15–20 infested leaves were plucked from the basal, middle, and apex portions (Gupta *et al.* 1975; Helle and Overmeer 1985). A total of 32 species of plants were examined. Then these leaves were examined under a 10× lens in the field and the mites were directly collected from the leaves with the help of a fine sable hairbrush (size 00) and preserved in small glass vials containing 70% ethyl alcohol. The vials were labeled, mentioning the name of the host and location. Infested leaf samples were also taken in separate polyethylene zipper bags and leaves were brought to the laboratory for proper identification of mites using Stereo Zoom Microscope (Magnus MSZ-TR). The identification up to the lowest possible taxa was done by consulting the keys of Gupta (2003), Moraes *et al.* (2004), and Chant and McMurtry (2007).

Statistical analysis

To understand the community and diversity structure, the relative abundance, distribution, and number of each species of phytophagous and predatory mites in the mentioned locations were calculated based on the formulae provided by the Shannon-Weiner Diversity Index (1948), also known as Shannon's Diversity Index; Simpson's Index (1949) and Pearson's Chi-square (χ^2) test (1900) using MS Excel.

$$Simpson's\ Index\ (D) = \sum_{i=1}^{s}(ni/N)^2 \text{ or } D = \sum ni(ni-1)/N(N-1)$$

where, N = total number of species observed, ni = number of individuals in species i and

$$ni/N = Pi$$

The value of Simpson's index (D) ranges between 0 and 1 and greater the value of D, the lower diversity.

$$Shannon\text{-}Weiner\ Diversity\ Index\ (H) = -\sum_{i=1}^{s} Pi * lnPi$$

where, Pi = relative abundance of each species, ln = natural logarithm and s = species richness.

It is used to measure the species diversity (especially relative abundance and also the number of species present in the area) when the sampling is random.

$$Pearson's\ Chi\text{-}square\ (\chi^2)\ test = \sum \frac{(O-E)^2}{E}$$

where, O = number of individuals observed, E = number of individuals expected.

The analysis of the association of mites and plants as a plant-mite network was performed. A Network is a graphical representation with species as nodes and ecological interactions as links (Poisot *et al.* 2016). The interacting partners in a network may share mutualistic (plant-pollinator or plant-seed disperser) or parasitic (plant-herbivore) relations. In such networks, the interaction intimacy and degree of ecological association between partners can influence the specialization and structure of interactions within a community. Not only that, the importance of key species in sustaining the network and the robustness of the network can also be deduced from such analysis (Chakraborty *et al.* 2021). This network analysis approach is very useful for understanding the structure and dynamics of food webs involving various groups of organisms. A mite-plant bipartite network (Fig. 2) was constructed in which the higher nodes represented mites and the lower nodes represented the plant species. Closeness centrality (CC) (which measures how much a focal species is close to all other species of the network) (Gonzalez *et al.* 2010) and betweenness centrality (BC) (measures the fraction of the shortest paths among all the pairs of species in the network, which passed through a particular species) (Gonzalez *et al.* 2010) of each member of the network were also calculated. The centrality indices helped to find out the more crucial interactions i.e. connected links indicating the 'keystoneness' of the species (Gonzalez *et al.* 2010). The degree of specialization (H_2') and nestedness of the entire network were also determined. H_2' gives details about the degree of "complementarity specialization" of the entire network (Bluthgen *et al.* 2006) and with the help of 'H_2fun' command in the 'bipartite' package in R statistical software. It also describes the extent of deviation of the observed interactions, from those that would be expected given the species marginal totals. If the species in the network are more selective, the H_2' value for the web would be larger (Bluthgen *et al.* 2006). The value ranges from 0 (no specialization) to 1 (highly specialized) (Dormann *et al.* 2020). Nestedness of the network was calculated using the algorithm metric, based on the overlap and on decreasing fill (NODF metric) (Almeida-Neto *et al.* 2008). NODF was performed with the weighted matrix where mite infestation was used for the analysis with the help of 'nestednodf' command built in the 'vegan' package (Oksanen *et al*. 2013) and "sna" (Butts and Butts 2016) package in R statistical software (version 3.4.3). Values of 'NODF' ranges between '0' (no nestedness) to '100' (complete nestedness). In a highly nested matrix, the more specialist species interact only with the proper subsets of those species interacting with the more generalists (Bascompte *et al*. 2003).

RESULTS

A total of 323 identified mites belonging to 39 species of 19 genera, 10 families from the above-mentioned localities of South 24 Parganas district of West Bengal, India are given in Tables 1 and 2.

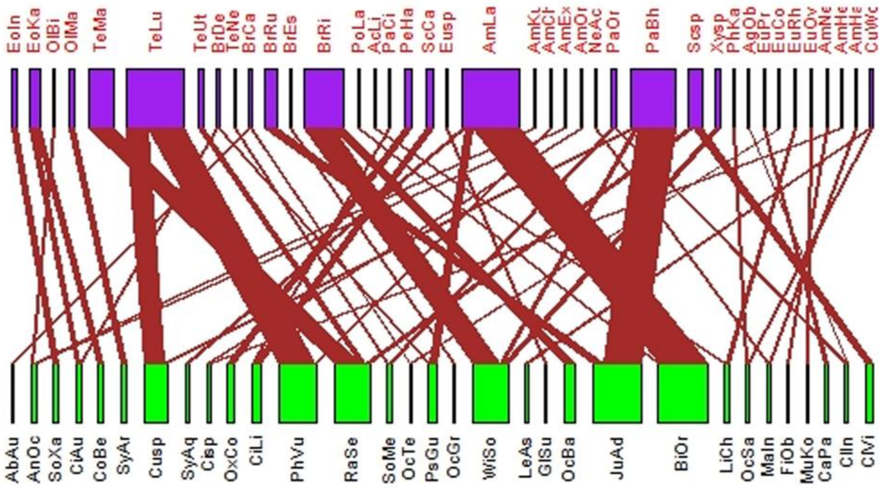

Figure 2. Mite-plant network - where the lower nodes (AbAu = *Abroma augusta*; AnOc = *Anacardium occidentale*; SoXa = *Solanum xanthocarpum*; CiAu = *Citrus aurantifolia*; CoBe = *Commelina benghalensis*; SyAr = *Syzygium aromaticum*; Cusp = *Cucurbita* spp.; SyAq = *Syzygium aqueum*; Cisp = *Citrus* spp.; OxCo = *Oxalis corniculata*; CiLi = *Citrus limon*; PhVu = *Phaseolus vulgaris*; RaSe = *Rauwolfia serpentina*; SoMe = *Solanum melongena*; OcTe = *Ocimum tenuiflorum*; PsGu = *Psidium guajava*; OcGr = *Ocimum gratisimum*; WiSo = *Withania somnifera*; LeAs = *Leucas aspera*; GlSu = *Gloriosa superba*; OcBa = *Ocimum basilicium*; JuAd = *Justicia adhotoda*; BiOr = *Bixa Orellana*; LiCh = *Litchi chinensis*; OcSa = *Ocimum sanctum*; MaIn = *Mangifera indica*; FiOb = *Ficus obscura*; MuKo = *Murraya koenigii*; CaPa = *Carica papaya*; ClIn = *Clerodendrum infortunatum*; ClVi = *Clerodendrum viscosum*) represent the plants while the higher nodes and EoIn = *Eotetranychus indicus*; EoKa = *Eotetranychus kankitus*; OlBi = *Oligonychus biharensis*; OlMa = *Oligonychus mangiferus*; TeMa = *Tetranychus macfarlanei*; Te Lu = *Tetranychus ludeni*; TeUt = *Tetranychus urticae*; BrDe = *Brevipalpus deleoni*; TeNe = *Tetranychus neochaledonicus*; BrCa = *Brevipalpus californicus*; BrRu = *Brevipalpus rugulosus*; BrEs = *Brevipalpus essigi*; BrRi = *Brevipalpus rica;* PoLa = *Polyphagotarsonemus latus*; AcLi = *Aceria litchi*; PaCi = *Panonychus citri*; PeHa = *Petrobia harti*; ScCa = *Schizotetranychus cajani*; Eusp = *Eupodes* sp ; AmLa = *Amblyseius largoensis*; AmKu = *Amblyseius kulini* ; AmCh = *Amblyseius channabasavannai*; AmEx = *Amblyseius excelsus*; AmOr = *Amblyseius orientalis*; NeAc = *Neoseiulus aceriae*; PaOr = *Paraphytoseius orientalis*; PaBh = *Paraphytoseius bhadrakaliensis*; Scsp = *Scheloribates* sp; Xysp = *Xylobates* sp; PhKa = *Phytoseius kapuri*; AgOb = *Agistemus obscura*; EuPr = *Euseius prasadi*; EuCo = *Euseius coccineae*; EuRh = *Euseius rhododendronis*; EuOv = *Euseius ovalis*; AmNe = *Amblyseius neorykei*; AmHe = *Amblyseius herbicolus*; AmHa = *Amblyseius hapoliensis*; CuWo = *Cunaxa womersleyi* represent the mites. The width of maroon color indicates interaction strengths between these two nodes.

The mite-plant network (Fig. 2) revealed that 51% plants have BC > 0 and 9 out of 37 plant species (24.32%) have BC above 10 and 3 of them have BC > 300. Similarly, only 3 plants (8.1%) have CC > 0.0055. *Anacardium occidentale* and *Phaseolus vulgaris* exhibited the highest BC and CC values, respectively. The network is much less nested (NODF = 1.699) and highly specialized ($H_2´$= 0.9274).

The distribution pattern of these plant-associated mites can be understood by applying the Chi-square (χ^2) test (Table 3) at 5% significance level. The total number of phytophagous and predatory mites are 202 and 102 respectively and after calculating the Chi-square (χ^2) test, the value of chi-square in the case of phytophagous and predatory mites are 388.82 and 434.84 respectively. The results of the chi square test at 5% significance level shows that the observations are might not be evenly/equally distributed for both phytophagous mites and predatory mites' species.

Table 1. Phytophagous, and predatory mites' fauna of suborder Prostigmata associated with different agri-horticulture crops in West Bengal.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
TETRANYCHIDAE	*Eotetranychus indicus* Gupta & Gupta	*Solanum xanthocarpum* Schard. & Wendl.	Narendrapur, South 24 Parganas District, West Bengal, India	5	The species was found on the leaves during October–December 2022.
	Eotetranychus kankitus Ehara	*Citrus aurantifolia* (Christmann) and *Commelina benghalensis* L.	Bagbagan, South 24 Parganas District, West Bengal, India	11	The species formed web on the undersurface of leaves during October 2022 and June 2023.
	Oligonychus mangiferus Pritchard & Baker	*Syzygium aromaticum* (L.)	Bagbagan	6	Found on the undersurface of leaves during April & May 2023.
	Oligonychus biharensis Hirst	*Anacardium occidentale* L.	Rupayan, South 24 Parganas District, West Bengal, India	2	Found on the under surface of the leaves during April 2023.
	Panonychus citri Mc Gregor	*Citrus limon* (L.)	Narendrapur	2	The species was found on the lower surface of the leaves during the month of August 2023.
	Petrobia harti Pritchard & Baker	*Oxalis corniculata* L.	Narendrapur	8	The leaves were infested by this mite during March and April 2023.
	Schizotetranychus cajani Gupta	*Citrus limon* (L.)	Bagbagan	8	It produced yellowish spots on infested leaves during April 2023.
	Tetranychus ludeni Zacher	*Phaseolus vulgaris* L. & *Cucurbita* spp.	Bagbagan, & Gosaba, South 24 Parganas District, West Bengal, India	60	Occurrence of this mite was noticed on the leaves of pumpkin and flat beans at Gosaba during March-May 2023. The colony was covered with thin webs where all stages of mites were observed. Feeding caused chlorosis. One phytoseiid predator *Paraphytoseius bhadrakaliensis* was also recovered from the colony.

Table 1. Continued.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
TETRANYCHIDAE	*Tetranychus macfarlanei* Baker & Pritchard	*Rauwolfia serpentina* (L.)	Narendrapur	27	Infestation of this mite was noticed on *Rauwolfia serpentina* in huge number causing chlorosis of leaves during May 2023.
	Tetranychus neocaledonicus Andre	*Solanum melongena* L.	Narendrapur	2	Found associated with the *Paraphytoseius orientalis* on the *Solanum melongena*. The feeding produced yellowish spots on leaves and such leaves gradually dried up. Infestation occurred during December 2022.
	Tetranychus urticae Koch	*Rauwolfia serpentina* (L.)	Narendrapur	6	Infestation of these mites was noticed on *Rauwolfia serpentina* heavily causing full covering of leaves with waves. Later such leaves turned brown and defoliate. *Amblyseius largoensis* was found associated. During December 2022 & March 2023.
	Brevipalpus californicus (Banks)	*Ocimum tenuiflorum* L. and *Ambroma augusta* (L.)	Narendrapur and Rupayan	3	The species found on the *Ocimum tenuiflorum* and *Ambroma augusta* leaves during January and February 2023. Characteristic chlorosis symptoms were found due to its feeding on *Ambroma augusta*.
	Brevipalpus deleoni Pritchard & Baker	*Citrus aurantiflora* (Christmann) and *Psidium guajava* L.	Narendrapur	3	The species found on the under surface of leaves during May & June 2023.
TENUIPALPIDAE	*Brevipalpus essigi* Baker	*Ocimum grattisimum* L.	Narendrapur	1	The species found on the under surface of the leaf during October 2023.

Table 1. Continued.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
TENUIPALPIDAE	*Brevipalpus rica* Chaudhri	*Withania somnifera* (L.) and *Ocimum basilicium* L.	Narendrapur	42	Leaves of *Withania somnifera* and *Ocimum basilicium* were highly infested with this mite during October –November 2022 and May-July 2023.
	Brevipalpus rugulosus Chaudhri *et al.*	*Justicia adhotoda* L.	Narendrapur	12	The species was found on the under surface of leaves during January-March 2023. Feeding cause yellowing of leaves initially and later became brown.
TARSONEMIDAE	*Polyphagotarsonemus latus* Banks	*Bixa orellana* L.	Narendrapur	2	The species was found during February 2023. The young leaves were more affected and those turned wrinkled.
ERIOPHYOIDEA	*Aceria litchi* Keifer	*Litchi chinensis* Sonn.	Narendrapur	2	The species was found associated with the *Euseius rhododendronis* on the under surface of *Litchi chinensis* leaves during November 2022.
CUNAXIDAE	*Cunaxa womersleyi* Baker & Hoffmann	*Leucas aspera* (Willd.)	Narendrapur	2	The species was found crawling on the under surface of the *Leucas aspera* leaves during November 2022.
EUPODIDAE	*Eupodes* sp.	*Gloriosa superba* L.	Rupayan	2	Casual occurrence *during* April 2023.
STIGMAEIDEA	*Agistemus obscura* Gupta	*Clerodendrum infortunatum* L.	Narendrapur	1	The species was found on *Clerodendrum infortunatum* leaf during January 2023.

To understand the community and diversity structure of phytophagous and predatory mites in the mentioned locations, different diversity indices are calculated. Shannon-Weiner Diversity Index (H) is commonly used to characterize the species diversity in a community; in this study, the value of the Shannon's Diversity Index of phytophagous mite fauna and predatory mite fauna were 2.218 and 1.948 respectively, which depicts that the phytophagous group may be slightly more diverse than the predatory group. The Bar diagram of the relative abundance of phytophagous mites (Fig. 4) shows the relative abundance of each species of phytophagous group and *Tetranychus ludeni* Zacher and

Brevipalpus rica Chaudhri of Tetranychidae and Tenuipalpide family respectively have comparatively high value of relative abundance. Whereas, in the Bar diagram of the relative abundance of predatory mites (Fig. 5), the relative abundance values of *Paraphytoseius bhadrakaliensis* and *Amblyseius largoensis* of Phytoseiidae family are comparatively high. The mean and mean ± S.E of relative abundance (Pi) of phytophagous mites and predatory mites are also given in Figure 3. The value of Simpson's Index of diversity (1−D) of phytophagous mite fauna (0.842) is also greater than the index value of predatory mite fauna (0.73), so overall, the data collected from the survey may have a greater sample diversity of phytophagous mites as compared to predatory mites.

Table 2. Predatory and oribatid mites' fauna of suborder Mesostigmata associated with different agri-horticulture crops in West Bengal.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
PHYTOSEIIDAE	*Amblyseius channabasavannai* Gupta & Daniel	*Phaseolus vulgaris* L.	Rupayan	2	The species was found on the under surface of the *Phaseolus vulgaris* leaves. The colony of *Tetranychus ludeni* was observed during May 2023.
	Amblyseius excelsus Chaudhri	*Anacardium occidentale* L.	Gosaba	2	The species was found on the leaves May 2023.
	Amblyseius hapoliensis Gupta	*Mangifera indica* Linn.	Narendrapur	1	The species was found on the leaves during July 2023.
	Amblyseius herbicolus (Chant)	*Citrus* spp	Narendrapur	1	The species was found on *Citrus* spp. during June 2023.
	Amblyseius kulini Gupta	*Anacardium occidentale* L.	Gosaba	2	The species was found on the leaves during April 2023.
	Amblyseius largoensis (Muma)	*Bixa Orellana* L., *Psidium guajava* L. and *Syzygium aqueum* (Burm. F.)	Narendrapur and Gosaba	17	*Amblyseius largoensis* is one of the most abundant phytoseiid mites available in any agricultural field and their occurrence has been noticed on a large number of plants belonging to vegetables, fruit trees and ornamental plants. The species was found during February-July 2023 on the leaves of *Bixa orellana*, *Psidium guajava* and on *Syzygium aqueum*.
	Amblyseius neorykei Gupta	*Ficus obscura* Blume.	Gosaba	2	The species was found on leaves during October 2022.

Table 2. Continued.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
PHYTOSEIIDAE	*Amblyseius orientalis* Ehara	*Citrus* spp.	Gosaba	2	The species was found on leaves during November 2022.
	Neoseiulus aceriae Gupta	*Mangifera indica* Linn.	Narendrapur	2	The species was found crawling on the leaves during December 2022.
	Paraphytoseius orientalis (Narayan et al.)	*Solanum melongena* L. and *Clenodrendrum infortunatum* L.	Gosaba and Narendrapur	6	The species was found on the lower surface of *Solanum melongena* leaves crawling on the upper surface of the *Clenodrendrum infortunatum* leaves during November 2022 & January-February 2023.
	Paraphytoseius bhadrakaliensis (Gupta)	*Justicia adhotoda* L., *Withania somnifera* (L.) and *Cucurbita* spp.	Narendrapur, Gosaba and Rupayan	50	*Paraphytoseius bhadrakaliensis* was found associated with *Adhotoda vasica* in association with *Brevipalpus rugulosus*, on *Cucurbita* spp. in association with *Tetranychus ludeni* and on *Withania somifera* in association with *Brevipalpus rica*.
	Phytoseius kapuri Gupta	*Ocimum sanctum* L.	Narendrapur	2	The species was collected during January 2023.
	Euseius coccineae (Gupta)	*Ocimum tenuiflorum* L.	Narendrapur	1	It was collected during January 2023.
	Euseius ovalis (Evans)	*Murraya koenigii* (L.)	Narendrapur	2	It was collected during November 2023.
	Euseius prasadi Chant & Baker	*Carica papaya* L.	Narendrapur	2	This species is very common and found on the leaves during May 2023
	Euseius rhododendronis (Gupta)	*Litchi chinensis* Sonn.	Narendrapur	3	It was collected during October 2022.
SCHELORIBATIDAE	*Scheloribates* sp.	*Clerodendrum viscosum* Vent. and *Rauwolfia serpentina* (L.)	Bagbagan and Narendrapur	14	It is a fungivorous mite. It was collected during October and December 2022, May and July 2023.

Table 2. Continued.

Family	Name of the genus/species	Host/Habitat	Location	No. of mites	Remarks
XYLOBATIDAE	*Xylobates* sp.	*Withania somnifera* (L.)	Narendrapur	5	It was collected during March 2023.

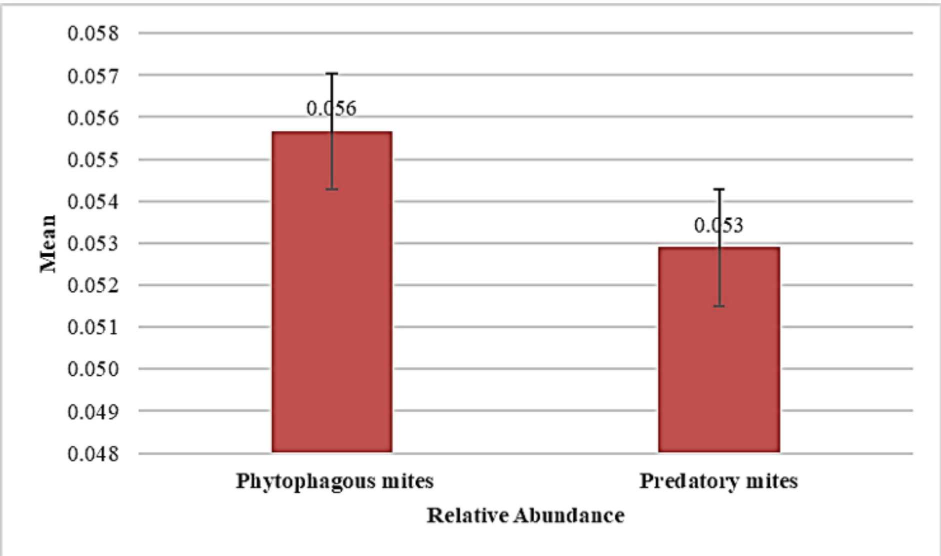

Figure 3. Bar-Diagram showing mean and mean ± S.E of relative abundance (Pi) of phytophagous mites and predatory mites.

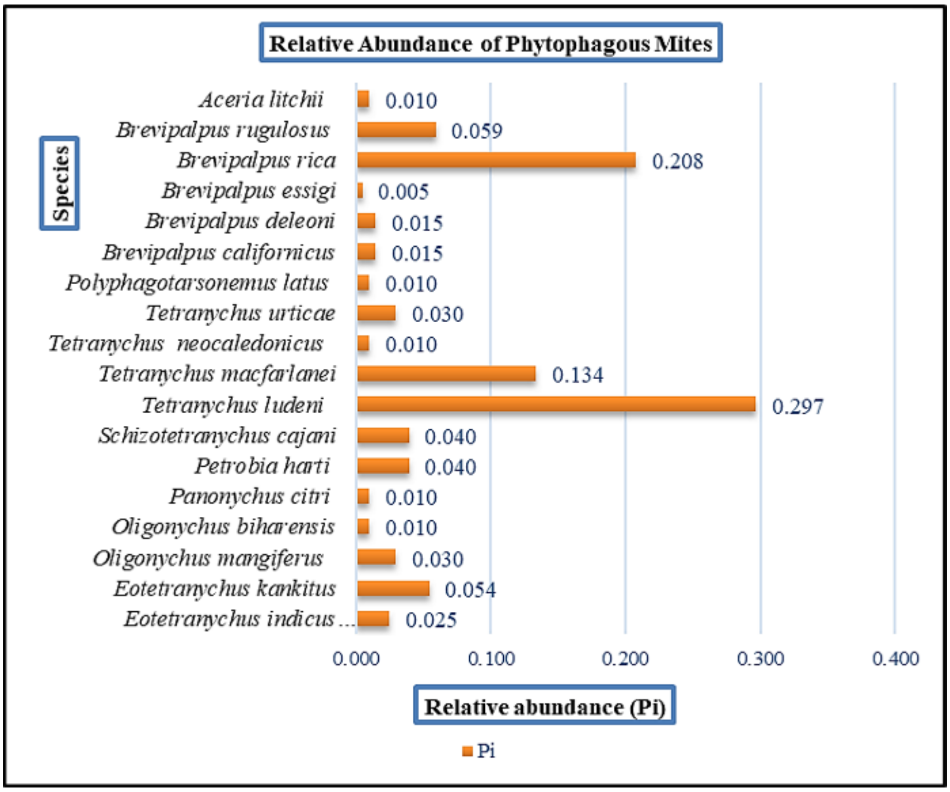

Figure 4. Bar-Diagram showing the Relative Abundance of each species under phytophagous mites.

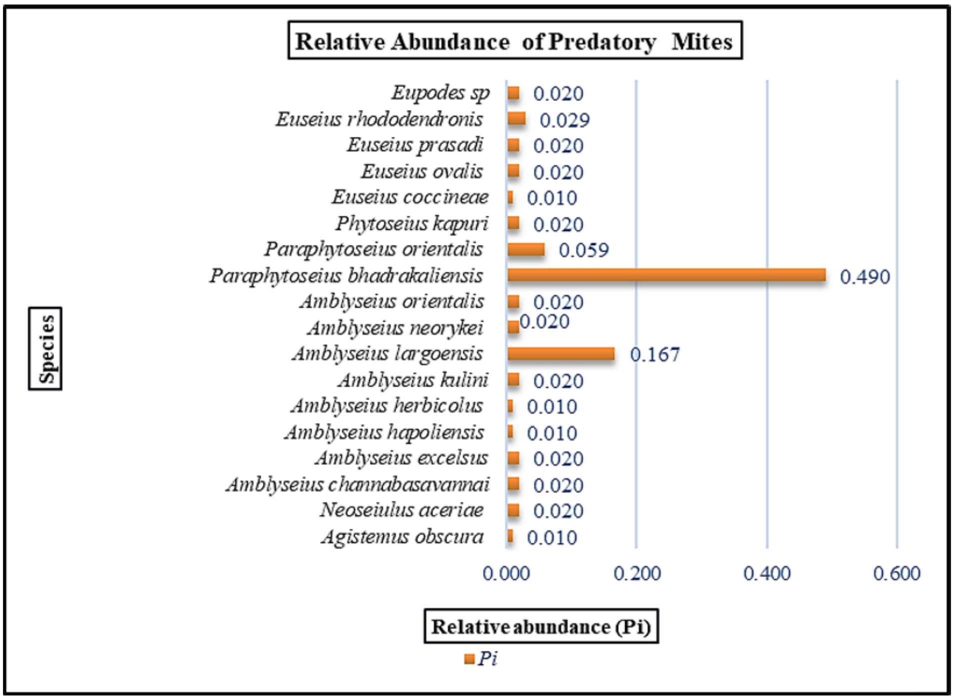

Figure 5. Bar-Diagram showing the Relative Abundance of each species under predatory mites.

Table 3. Chi-square (χ^2) values at 5% significance level for number of observation of species of phytophagous and predatory mites.

Chi-square (χ^2) values		Significance	
Phytophagous mites	Predatory mites	Phytophagous mites	Predatory mites
388.82 (N = 202)	434.84 (N = 102)	Significant at 5% level of significance [degrees of freedom (v) = 17]	Significant at 5% level of significance [degrees of freedom (v) = 18]

DISCUSSION

The present study aimed to focus on diversity of plant-associated mites in different agri-horticultural crops in selected areas of South 24 Parganas, West Bengal, India. Among the mite species encountered, there are as many as two species that were common with Rahaman and Gupta (2022), one species common with Bala and Karmakar (2022c), four species common with Roy *et al*. (2011), seven species each common with Gupta *et al*. (2003), and Samaddar *et al*. (2017, 2021). Compared to the previous researchers related with the reporting of species belonging to Bdellidae (Samaddar *et al*. 2021), Tydeidae, Acaridae, Saproglyphidae, Ascidae (Mondal and Gupta 2016), Erythraeidae (Roy *et al*. 2011), Raphignathidae (Samaddar *et al*. 2021) were not incorporated in the present study. Furthermore, the representatives of Eriophyidae, Cunaxidae, and Phytoseiidae were very few compared to those reported by earlier researchers. Among the phytophagous mites *Oligonychus mangiferus* Rahman & Sapra on *Syzygium aromaticum* L. (Myrtaceae), *Panonychus citri* Mc Gregor on *Citrus limon* (L.) Burm. (Rutaceae), *Petrobia harti* (Ewing) on *Oxalis corniculata* L. (Oxalidaceae), *Tetranychus ludeni* on *Phaseolus vulgaris* L. (Fabaceae), and *Aceria litchii* Keifer on *Litchi chinensis* Sonn. (Sapindaceae) were comparatively most damage causing. Among the predatory species, *Amblyseius largoensis* Muma, *Paraphytoseius bhadrakaliensis* Gupta and *Euseius coccineae* Gupta, were found relatively abundant. However, the abundance of other predatory species was limited. The value of diversity indices also predicts that the phytophagous mites may have greater sample diversity than the predatory mites.

In this study, a bipartite network approach was used to illustrate the mite-plant interaction patterns. The approach elucidates the asymmetry and robustness of such interactions (Bascompte and Jordano 2007). Mutualistic networks (as in the case of plant-pollinator networks) are highly nested, i.e. organized asymmetrically, in which the generalist partners make the core of the network to which other species are attached (Gonzalez *et al*. 2010). Usually, such networks are more nested and less specialized (Bascompte *et al.* 2003; Bluthgen *et al.* 2007). However, specialist plant-pollinator networks such as those comprising of moths and plants are more specialized (Lenka *et al.* 2023) due to functional complementarity (Bluthgen and Klein 2011). The network studies have been reported by Araújo and Daud (2018); Araújo and Kollár (2019); Araújo *et al.* (2019); Melo *et al.* (2024). The study by Araújo and Kollár (2019) is worth special mention as they conducted a meta-analysis of previous plant-mite studies available in the literature worldwide. In West Bengal, India, plant-mite networks have been vividly studied by Mondal *et. al.* (2023) in which such networks in many geographical regions in the state have been covered. However, as they considered a specific group of mites, a more general consideration of plant-mite interactions from a network point of view is still lacking for this region.

On the contrary to plant-pollinator networks, plant-mite relationships are more parasitic than mutualistic in nature. In this study, the network is less nested and more generalist as indicated by the lower NODF and $H_2´$ values respectively. Studies done by Araújo and Daud (2018), Araújo and Kollár (2019), and Oliveira *et al.* (2019) follow a similar trend. Their studies also revealed that phytophagous mites form more specialized networks with plants than predatory mites. The reason could be multidimensional involving the chemical and structural limitations of both partners (Krantz and Lindquist 1979). The more specialist network describes lower nestedness as in a perfectly nested network all species tend to interact among them through generalist connectors (Bascompte and Jordano 2007). Such inverse relation of nestedness and specialization is also reflected in the present study. Opposing to the above studies, Mondal *et al.* (2023) encountered a more generalist plant-mite network dominated by generalist Tarsonemidae mites.

The centrality measurement of the network reveals that only a few plants (51%) have higher BC values (BC > 0) i.e. act as connector species and harbor many mite species. Higher BC values (> 300) of *Anacardium occidentale*, *Phaseolus vulgaris*, and *Ocimum gratisimum* suggest that these plants are important to the network to maintain cohesiveness. Likewise, higher CC values (CC > 0) of *Phaseolus vulgaris*, *Justicia adhotoda*, and *Litchi chinensis* suggest that these plants have the potential to affect many other species in the network.

Interestingly, *Phaseolus vulgaris* proves to be an eligible candidate to be a more keystone species as it has high BC (323) and CC (0.0066) values. Subsequent virtual removal of the plant species from the network, having BC > 300 and CC > 0.0055 from the network causes a gradual decrease in specialization (as reflected by lower $H_2´$ values) and a gradual increase in nestedness (indicated by higher NODF values) of the plant-mite network. Similar studies have been reported by Chakraborty *et al.* (2021) in plant-pollinator mutualistic networks. However, in their case, the virtual exclusion of plants having higher CC and BC values jeopardized the robustness of the network but in the current study, the reverse seems to happen.

In conclusion, it can be stated that more exhaustive survey work in South 24 Parganas will reveal many interesting species which may also include new taxa. It is hoped that the outcome of the present study will help to develop mite-pest management strategies through the identification of phytophagous mites along with the conservation of predatory mites. The present study will highlight the future work regarding tritrophic association between phytophagous mites, predatory mites and their host plant association.

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چکیده

ناحیهٔ ۲۴ جنوبی پارگاناس در بنگال غربی هند از نظر کشت محصولات کشاورزی و باغبانی بسیار غنی است، اما امروزه عملکرد تولید محصول به دلیل حملهٔ هرناهای گیاهخوار در حال کاهش است. برای درک تنوع زیاگان هرناهای مرتبط با محصولات کشاورزی-باغی، یک بررسی در محلات منتخب ۲۴ جنوبی پارگاناس انجام شد. یک رویکرد شبکه‌ای نیز برای تعیین برخی از فراسنجه‌های شبکهٔ هرنا-گیاه مانند تخصصی بودن و تداخل استفاده شد. مقاله حاضر در مجموع به ۳۹ گونه هرنای گیاهی (۱۸ گونه گیاهخوار، ۱۹ گونه شکارگر و دو گروه قارچخوار) متعلق به ۱۹ جنس و ۱۰ خانواده می‌پردازد. بیشتر گیاهانی که این هرناها روی آنها ثبت شده‌اند، گزارش‌های جدیدی از میزبان/زیستگاه را تشکیل می‌دهند. گونه‌های *Brevipalpus rica*، *Tetranychus ludeni* و *T. macfarlanei* هرناهای مهم آسیب‌رسان یافت شدند، در حالی که شکارگرهای *Amblyseius largoensis* و *Paraphytoseius bhadrakaliensis* فراوان بودند و اهمیت مهار زیستی داشتند. همچنین این بررسی نشان داد که هرناهای گیاهخوار در مقایسه با هرناهای شکارگر تنوع نمونه بیشتری داشتند. تجزیه و تحلیل شبکه ارتباط هرنا-گیاه نشان داد که هرناها یک شبکه بسیار تخصصی و کمتر متداخل با گیاهان میزبان تشکیل می‌دهند. همچنین مشاهده شد که در این شبکه، *Phaseolus vulgaris* دارای نقش هاب‌مانند هرنایی با ارزش مرکزیت زیاد است. این مطالعه ممکن است پایه‌ای برای بررسی‌های کنه‌شناسی در منطقه بنگال جنوبی را تشکیل دهد که بتواند در طراحی راهبردهای مدیریت آفات مفید باشد.

واژگان کلیدی: شبکهٔ دوبخشی، تنوع هرناها، هرناهای گیاهخوار، هرناهای شکارگر، استحکام، ۲۴ جنوبی پارگاناس.

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