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Diversity of Predators Associated with the Mealybug Complex in Cassava Growing Districts of Tamil Nadu, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An extensive survey was carried to study the diversity of predators associated with the mealybug complex in the cassava growing districts *viz.,* Salem, Namakkal, Erode, Tiruppur and Coimbatore of Tamil Nadu, India from January to September, 2021. The survey revealed the dominance of *Phenacoccus manihoti* Matile-Ferrero 1977 (Hemiptera: Pseudococcidae) than other mealybug species in all the surveyed districts. The incidence of *P. manihoti* ranged from 12 to 90 per cent while *Paracoccus marginatus* Williams and Granara de Willink 1992 (Hemiptera: Pseudococcidae) incidence was found to be between 8 and 54 per cent. The incidence of *Ferrisia virgata* Cockerell 1893 (Hemiptera: Pseudococcidae) was found to be very low (8-16%) compared to other mealybug species. Association of total predators with *P. manihoti* were found to be maximum (30.87%) followed by the total predators with *P. marginatus* (6.49%) whereas 0.53 per cent of total predators associated with *F. virgata*. The fourteen different predators *viz., Cryptolaemus montrouzieri* Mulsant 1853 (Coleoptera: Coccinellidae), *Menocheilus sexmaculatus* Fabricius 1781 (Coleoptera: Coccinellidae), *Anegleis cardoni* Weise 1892 (Coleoptera: Coccinellidae), *Hyperaspis maindroni* Sicard 1929 (Coleoptera: Coccinellidae), *Brumoides suturalis* Fabricius 1798 (Coleoptera: Coccinellidae), *Scymnus* spp. (Coleoptera: Coccinellidae), *Chrysoperla* spp. (Neuroptera: Chrysopidae), *Mallada* spp. (Neuroptera: Chrysopidae), *Spalgis epeus* Westwood 1851

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(Lepidoptera: Lycaenidae), *Geocoris* spp. (Hemiptera: Geocoridae), *Cardiastethus* spp. (Hemiptera: Anthocoridae), *Diadiplosis* spp. (Diptera: Cecidomyiidae), *Oxyopes* spp. (Araneae: Oxyopidae) and *Argiope* spp. (Araneae: Araneidae) were found to associated with the mealybug species *viz., P. manihoti, P. marginatus* and *F. virgata*. Among the predators of the mealybug complex, the most relative abundant species were *H. maindroni* (11.74%) associated with *P. manihoti* and *C. montrouzieri* (6.49%) associated with *P. marginatus* followed by *S. epeus* (0.67%) associated with *F. virgata*. The diversity of predators assessed through Simpson's Index of Diversity, Shannon-Wiener, Pielou's Evenness and Margalef indices revealed highest species diversity, species richness and species evenness in Namakkal district.

Keywords: Survey; predators; mealybug complex; diversity indices.

1. INTRODUCTION

Cassava, *Manihot esculenta* Crantz (Malpighiales: Euphorbiaceae) is an important industrial crop cultivated predominantly in the southern states of India. Cassava was relatively free from major pests though several mealybug species have been reported. The introduction of invasive papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink 1992 (Hemiptera: Pseudococcidae) in 2008 caused great havoc on cassava. However, the papaya mealybug was successfully managed by introducing the biological control agent, an encyrtid parasitoid, *Acerophagus papayae* 2003 Noyes &Schauff (Hymenoptera, Encyrtidae) during 2010. Likewise, the recent most serious biological invasion is the cassava mealybug (CMB), *Phenacoccus manihoti* 1977 Matile-Ferrero (Hemiptera: Pseudococcidae) on cassava which threatens the cassava cultivation.

It was reported for the first time in India on cassava at Thrissur district of Kerala during April, 2020 [1]. The CMB infestation causes curling of the leaves at the plant's growing tip, leading to the formation of bunchy tops and adventitious buds on almost all the internodes. Heavy infestation results in drying of leaves and complete defoliation. The CMB infestation ranged from 7.0% to 86.7% (per cent) in Salem and Namakkal districts of Tamil Nadu [2]. Besides, *P. marginatus* and *P. manihoti,* occurrence of striped mealybug, *Ferrisia virgata* Cockerell 1893 (Hemiptera: Pseudococcidae), Jack Beardsley mealybug, *Pseudococcus jackbeardsleyi* Gimpel and Miller 1996 (Hemiptera: Pseudococcidae), and Madeira mealybug, *Phenacoccus madeirensis* Green 1923 (Hemiptera: Pseudococcidae), Spherical mealybug, *Nipaecoccus viridis* Newstead 1894 (Hemiptera: Pseudococcidae) were also reported on cassava. Chemical-based pesticides are ineffective against cassava mealybug, which warrants eco-friendly methods involving biological control agents like *A. papayae* against papaya mealybug. In the above context, it is crucial to document the natural enemies associated with the mealybug complex on cassava to design biological control based management strategies. In view of the above facts, the present study was carried out to inventory the predator fauna associated with the mealybug complex on cassava and their diversity status was also documented.

2. MATERIALS AND METHODS

2.1 Survey on the Incidence of Mealybug Complex and Relative Abundance of their Associated Predators on Cassava

An extensive survey was carried out at cassava growing areas of Salem, Namakkal, Erode, Tiruppur and Coimbatore districts of Tamil Nadu to explore the incidence of different mealybug species and their associated predators on cassava. A total of twenty five cassava plants were selected at random per field and observed for the incidence of mealybug species and their associated predators.

2.1.1 Incidence of mealybug complex on cassava

The incidence of individual species among the mealybug complex on cassava was worked out by using the following formula,

Incidence of individual mealybug species (%) = (Number of plants affected with individual species/ Number of plants observed) x 100

2.1.2 Relative abundance of predators associated with the mealybug complex on cassava

The relative abundance of total predators and individual predators in each location of a district was worked out by the following formulae:

Relative abundance (%) = (Number of predators collected in each location of a district / Number of predators collected in all locations of a district) x 100

2.2 Diagnostic Characteristics of Predators Associated with the Mealybug Complex on Cassava

Adults and immature stages of the predators found during the survey were brought to the laboratory; the immature stages of predators were reared till their adult stage and preserved in 70 per cent ethanol for further identification.

The adult predators were examined under Stemi (Zeiss) 200 C microscope and photographed under a stereo zoom microscope (Leica M 205 A). The specimens were identified based on its diagnostic characteristics with the help of available literature [3-7].

2.3 Assessment of Diversity Indices

The diversity of the predators were assessed through different indices viz., Simpson's Index of Diversity (SID), Shannon-Wiener Index (H'), Pielou's Evenness Index (E1) and Margalef index (α).

2.3.1 Simpson's index of diversity (SID)

Simpson's Index of Diversity is the measure of diversity of the species. The following formula is used to work out the Index of diversity [8].

$$D = 1 - \frac{\sum n\,(n-1)}{N\,(n-1)}$$

where, n= total number of individuals in a species, N = total number of individuals in all species

2.3.2 Shannon-wiener Index (H')

It is an another index for measuring the diversity of the species and the Index is calculated by the following formula [9]

$$H' = -\sum Pi \log_e (Pi)$$

where, Pi = proportion of i^{th} species, $\log_e$ (Pi) = Natural logarithm of Pi

2.3.3 Pielou's evenness index (E1)

Pielou's evenness index (E1) to calculate the species evenness and the formula is as follows [10];

$$E1 = H'/ \log_e(S)$$

where, H' = Shannon-Wiener diversity index, S = total number of species collected

2.3.4 Margalef index (α)

It is an index is used to study the species richness and it was calculated for all the study area using the formula as follows [11]:

$$\alpha = \frac{(S-1)}{\log_e (N)}$$

where, S = total number of species collected, N = total number of individuals in all species

The data were subjected for analysis using 'Biodiversity Calculator' (Al Young Studios) to understand the diversity of predators.

3. RESULTS AND DISCUSSION

3.1 Survey on the Incidence of Mealybug Complex and Relative Abundance of their Associated Predators on Cassava

3.1.1 Incidence of mealybug complex on cassava

The survey conducted in Salem, Namakkal, Erode, Tiruppur and Coimbatore districts during January to September, 2021 revealed the occurrence of three different mealybug species *viz., Phenacoccus manihoti* Matile-Ferrero 1977 (Hemiptera: Pseudococcidae), *Paracoccus marginatus* Williams and Granara de Willink 1992 (Hemiptera: Pseudococcidae), *Ferrisia virgata* Cockerell 1893 (Hemiptera: Pseudococcidae) (Tables 1-5).

The mealybug species, *P. manihoti* was found in all the districts surveyed. The incidence of *P. manihoti* ranged from 16 to 86 per cent in Salem district, 12 to 90 per cent in Namakkal district 32 to 74 per cent in Erode district, 16 to 48 per cent in Tiruppur and, 32 to 76 per cent in Coimbatore district. Therefore, the incidence of *P. manihoti* was found to be maximum and it was ranged from 12 to 90 per cent among all the districts surveyed. The results corroborate with the results of Sampath Kumar [2] who reported 7.00 to 86.75 per cent infestation of *P. manihoti* in Salem and Namakkal districts during 2020.

The incidence of *P. marginatus* ranged from 18 to 42 per cent in Salem district, 24 to 34 per cent in Namakkal district and 32 to 54 per cent in Coimbatore district and revealed that the incidence of *P. marginatus* 8 to 54 per cent in Salem, Namakkal and Coimbatore districts. Likewise, [12] stated about 2 to 100 per cent incidence of *P. marginatus* were found in different blocks of Coimbatore, Erode, Perambalur, Salem and Tiruppur districts of Tamil Nadu during the period 2011- 2012. It was found that the incidence of *P. marginatus* was decreased from the period 2011 to 2021 and it might be due to the introduction of the biological control agent, an encyrtid parasitoid, *A. papaya*e and abundance of different predators.

The incidence of *F. virgata* was found to be lower (8-16%) than other mealybug species and was recorded only in Anaikattipalayam village of Namakkal district (16%) and Akkichettipalayam village of Salem district (8%). This species was found to be very low in occurrence among the mealybug complex on cassava.

3.1.2 Relative abundance of predators associated with the mealybug complex on cassava

The fourteen different predators such as *Cryptolaemus montrouzieri* Mulsant 1853 (Coleoptera: Coccinellidae), *Menocheilus sexmaculatus* Fabricius 1781(Coleoptera: Coccinellidae), *Anegleis cardoni* Weise 1892 (Coleoptera: Coccinellidae), *Hyperaspis maindroni* Sicard 1929 (Coleoptera: Coccinellidae), *Brumoides suturalis* Fabricius 1798 (Coleoptera: Coccinellidae), *Scymnus* spp. (Coleoptera: Coccinellidae), *Chrysoperla* spp. (Neuroptera: Chrysopidae), *Mallada* spp., (Neuroptera: Chrysopidae), *Spalgis epeus* Westwood 1851 (Lepidoptera: Lycaenidae), *Geocoris* spp. (Hemiptera: Geocoridae), *Cardiastethus* spp. (Hemiptera: Anthocoridae), *Diadiplosis* spp. (Diptera: Cecidomyiidae), *Oxyopes* spp. (Araneae: Oxyopidae), *Argiope* spp. (Araneae: Araneidae) were found to associated with the mealybug species (*P. manihoti, P. marginatus and F. virgata*) (Tables 1-5).

A total of thirteen predators *viz., H. maindroni*, *M. sexmaculatus*, *B. sutralis*, *Scymnus* spp., *S. epeus*, *C. montrouzieri*, *Chrysoperla* spp., *Mallada* spp., *Geocoris* spp., *Cardiastethus* spp., *Diadiplosis* spp., *Oxyopes* spp., *Argiope* spp. were recorded on *P. manihoti*. The relative abundance of total predators associated with *P. manihoti* ranged from 3.72 to 27.66 per cent in Salem district, 0.34 to 30.92 per cent in Namakkal district, 4.30 to 30.47 per cent in Erode district, 21.63 to 27.99 per cent in Tiruppur and 8.48 to 26.28 per cent in Coimbatore district. Among the districts surveyed, the relative abundance of total predators was found to be higher in Alampatti village of Namakkal district (30.87%) which also recorded highest (90%) incidence of *P. manihoti.*

Among the predators of *P. manihoti*, the relative abundance of individual predator, *H. maindroni* was found to be higher in Alampatti village of Namakkal district (11.74%) followed by *Diadiplosis* spp. in Andigoundanur village of Tiruppur district (7.94%), *Mallada* spp. (6.46%) and *M. sexmaculatus* (5.06%) in Naapalaiyam village of Salem district, *S. epeus* in Kattukottai village of Salem district (3.72%), *C. montrouzieri* in TNAU Orchard of Coimbatore district (3.39%),*Chrysoperla* spp. in Devarayapuram village of Coimbatore district (3.39 %), and *Scymnus* spp. in Komarayanur village of Erode district (3.25%), *Geocoris* spp. in Kannapalli village of Erode district (2.73%), *B. sutralis* in Nappalaiyam village of Salem district (2.66%), *Cardiastethus* spp. in Merkuputhur village of Erode district (1.56%), *Oxyopes* spp., (0.67%) in Alampatti village of Namakkal district, *Argiope* spp., (0.53%) in Kattukottai village of Salem district (Tables 1-5).

Therefore, the results showed that *H. maindroni* was found to be common and relatively abundant species predating *P. manihoti* among all the districts surveyed which was in accordance with [13]. Similarly, Neuenschwander and Hammond (1988) [14] reported coccinellid species under the genus *Hyperaspis viz., Hyperaspis aestimabilis* Mader 1955 (Coleoptera: Coccinellidae) and *Hyperaspis delicatula* Mulsant 1850 (Coleoptera: Coccinellidae), *Exochomus* spp. (Coleoptera: Coccinellidae) on *P. manihoti* in Africa.
A cecidomyiid predator, *Diadiplosis* spp. was found to be next abundant predator after *H. maindroni* during the present survey. Likewise, [15] stated that *Dicrodiplosis manihoti* Harris 1981 (Diptera: Cecidomyiidae) was the second most common predator of *P. manihoti* next to coccinellids in Nigeria.

Neuenschwander and Hammond [14] and Lohr *et al.,* [16] reported *Chrysoperla externa* Hagen 1861 (Neuroptera: Chrysopidae),

Kalodiplosis spp. (Diptera: Cecidomyiidae), *Ceraeochrysa* spp. (Neuroptera: Chrysopidae), *Spalgis lemolea* Druce 1890 (Lepidoptera: Lycaenidae) and *Sympherobius maculipennis* Kimmins 1929 (Neuroptera: Hemirobiidae) as predators of *P. manihoti* in Africa

In India, Joshi *et al.,* [1] reported *H. maindroni*, *Cardiastethus* spp., *S. epeus* and Scymnus *coccivora* Ramakrishna Ayyar, 1925 (Coleoptera: Coccinellidae) as predators of *P. manihoti.*

About eight different predators, *C. montrouzieri*, *B. sutralis, M. sexmaculatus*, *A. cardoni*, *S. epeus, Chrysoperla* spp., *Mallada* spp., *Oxyopes* spp. were recorded on *P. marginatus*. The relative abundance of total predators associated with *P. marginatus* ranged from 5.45 to 18.42 per cent in Salem district, 7.96 to 10.01 per cent in Namakkal district and 9.32 to 20.34 per cent in Coimbatore district. Among the districts surveyed, the total predators associated with *P. marginatus* were found to be higher in Kumarapalayam village of Coimbatore district (20.34%) which also recorded 54 per cent incidence of *P. marginatus* (Tables 1, 2 & 5).

Among the predators of *P. marginatus*, the relative abundance of *C. montrouzieri* was found to be higher in Pudur village of Salem district (6.49%) and *S. epeus* (5.39%) followed by *Chrysoperla* spp. (4.24%), *Mallada* spp. (3.39%), in Kumarapalayam village of Coimbatore district*, B. sutralis* in Alampalayam village of Coimbatore district (2.54%), *A. cardoni* in Pudur village of Salem district (2.13%), *M. sexmaculatus* in Kalkurichi village of Namakkal district (2.01%) and *Oxyopes* spp. in Panaimadal village of Salem district (0.53%) (Tables 1, 2 & 5).

Mastoi *et al.,* [17] also documented *A. cardoni, B. suturalis, Chilocorus nigrita* Fabricius 1798 (Coleoptera: Coccinellidae), *C. montrouzieri*, *Nephus quadrimaculatus* Herbest 1783 (Coleoptera: Coccinellidae)*, Chrysoperla carnea* Stephens 1836 (Neuroptera: Chrysopidae), *Scymnus* spp., *S. epeus, Cyrtopeltis* spp. (Hemiptera: Miridae) as predators of *P. marginatus* in Malaysia. The predatory spiders, *Oxyopes* spp. was found feeding on various sucking pests including *P. marginatus* [18].

However, *S. epeus* was the only predator found associated with *F. virgata* in Anaikattipalayam village of Namakkal district (0.67%) and Akkichettipalayam village of Salem district (0.53%) (Tables 1, 2) whereas Mani and Krishnamoorthy, [19] documented S. *coccivora, Mallada boninensis* Okamoto (Neuroptera: Chrysopidae), *B. suturalis*, *S. epeus* and *M. sexmaculatus* as predators of *F. virgata* in India.

3.2 Diagnostic Characteristics of Predators Associated with the Mealybug Complex on Cassava

Based on the available literatures, the adult predators were identified and its diagnostic characteristics were described below:

3.2.1 *Hyperaspis maindroni* Sicard 1929 (Coleoptera: Coccinellidae)

Oval body with orange yellow coloured head and pronotum. Trident shaped stripes found on the pale cream coloured elytra (Plate 1a).

3.2.2 *Menocheilus sexmaculatus* Fabricius 1781 (Coleoptera: Coccinellidae)

Body is yellowish brown colour with a pair of transverse black coloured band on pronotum, longitudinal blackish band on the mid dorsal line of elytra junction, three pairs of zig- zag patch found on the elytra *viz.,* small inverted V-shaped anterior patch, W- shaped middle patch and nearly rounded posterior patch (Plate 1b).

3.2.3 *Cryptolaemus montrouzieri Mulsant* 1853 (Coleoptera: Coccinellidae)

Adult having orange coloured head, pronotum and blackish elytra with orange apices (Plate1c).

3.2.4 *Brumoides suturalis* Fabricius 1798 (Coleoptera: Coccinellidae)

Oval shaped body with yellowish brown pronotum. Three longitudinal black stripes present on the yellow elytra, two stripes on the sides of elytra and another one is found along the mid dorsal line of elytra junction, not touching posterior end of the body (Plate1d).

3.2.5 *Anegleis cardoni* Weise 1892 (Coleoptera: Coccinellidae)

The beetle is having yellow coloured elytra found with one black median stripe at the junction of elytra, one inwardly curved anterior stripe, outwardly curved posterior stripe and small rounded black spot on each elytron (Plate1e).

Table 1. Occurrence of the mealybug complex and their predators in Salem district, Tamil Nadu, India (January-September, 2021)

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Nappalaiyam 11^0 38’ 17.31” N 77^0 59’ 28.73” E	MVD-1	6	*P. manihoti*	86	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Chrysoperla* spp. *Mallada* spp. *S. epeus* *Diadiplosis* spp.	2.66 6.45 5.06 2.19 1.60 6.46 2.13 1.13	27.66
Pillukurichi 11^0 38’ 9.11’’ N 77^0 46’ 57.27’’ E	MVD-1	7	*P. manihoti*	53	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Mallada* spp.	1.06 3.19 2.13 1.06 2.13	9.57
Chokkanathapuram 11 ^{0} 36’ 21.03” N 78^0 32’ 49.31” E	MVD-1	10	*P. manihoti*	48	*B. sutralis*. *H. maindroni* *M. sexmaculatus* *Scymnus* spp.	1.13 1.60 1.60 0.53	6.45
Alagapuram 11 ^{0} 36’ 21.03” N 78^0 32’ 49.31” E	White Thailand	3	*P. manihoti*	16	*B. sutralis* *H. maindroni* *M. sexmaculatus*	0.53 1.06 2.13	3.72
Poolampatti 11 ^{0} 39’ 7.19” N 77^0 46’ 13.79” E	White Thailand	6	*P. manihoti*	40	*B. sutralis* *H. maindroni* *M. sexmaculatus* *S. epeus*	1.06 1.60 0.53 2.66	5.85
Ramanujapuram 11^0 37’ 25.83” N 78^0 41’ 12.65” E	White Thailand	4	*P. manihoti*	36	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Chrysoperla* spp.	1.60 1.06 1.06 1.06	4.79
Pudur 11 ^{0} 44’ 12.89” N 78^0 29’ 53.14” E	White Thailand	10	*P. marginatus*	42	*C. montrouzieri* *M. sexmaculatus* *B. sutralis* *A.cardoni* *Chrysoperla* spp. *S. epeus*	6.49 1.06 1.80 2.13 2.66 4.26	18.42

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Panaimadal 11 ^{0} 42' 53.12" N 78 ^{0} 28' 11.62" E	White Thailand	9	*P. marginatus*	32	*C. montrouzieri* *A. cardoni* *Chrysoperla* spp. *Oxyopes* spp. *S. epeus*	3.19 1.06 2.13 0.53 3.19	10.11
Akkichettipalayam 11 ^{0} 36' 19.44"N 78 ^{0} 32' 42.92" E	H-226	8	*P. marginatus*	36	*C. montrouzieri* *A.cardoni* *S. epeus*	2.26 0.53 1.60	5.45
			F. virgata	8	*S. epeus*	0.53	0.53
Narasingapuram 11 ^{0} 36' 33.48" N 78 ^{0} 32' 38.14" E	White Thailand	9	*P. marginatus*	8	-	-	-
Kattukottai 11^{0} 36' 25.40" N 78^{0} 40' 14.98'' E	Sree Jaya	7	*P. manihoti*	46	*Argiope* spp. *H. maindroni* *S. epeus.* *Mallada* spp	0.53 1.06 3.72 1.06	7.45
Manivizhundhan 11^{0} 37' 7.45'' N 78^{0} 41' 18.07''E	Kunguma Rose	8	*P. manihoti*	16	-	-	-

Table 2. Occurrence of the mealybug complex and their predators in Namakkal district, Tamil Nadu, India (January-September, 2021)

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Palanthinnipatti 11 ^{0} 29' 41.5" N 78 ^{0} 07' 29.4" E	MVD-1	4	*P. manihoti*	40	*M. sexmaculatus* *Scymnus* spp. *Chrysoperla* spp. *Mallada* spp. *S. epeus*	1.34 0.67 0.67 0.34 0.34	3.36
Palanthinnipatti 11 ^{0} 29' 31.3" N 78 ^{0} 07' 05.4" E	MVD-1	3	*P. manihoti*	36	*B. sutralis* *M. sexmaculatus* *Mallada* spp.	1.01 0.67 1.01	2.69
	White Thailand	2	*P. manihoti*	16	*B. sutralis* *M. sexmaculatus* *Mallada* spp.	0.34 0.34 0.66	1.34

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Alampatti 11 ^{0} 29’ 40.97” N 78^{0} 7’ 29.10” E	MVD-1	6	*P. manihoti*	90	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Mallada* spp. *Oxyopes* spp. *Cardiastethus* spp. *Geocoris* spp. *Diadiplosis* spp.	2.07 11.74 3.69 2.01 1.01 0.67 1.34 1.68 6.71	30.92
Pillanallur 11° 26' 42.0" N 78° 07' 22.8" E	MVD-1	4	*P. manihoti*	32	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Chrysoperla* spp. *Mallada* spp. *S. epeus* *Geocoris* spp.	0.34 6.04 1.01 1.34 2.01 1.34 1.34 1.01	14.43
	White Thailand	6	*P. manihoti*	18	*B. sutralis* *M. sexmaculatus* *Mallada* spp.	1.01 0.34 0.34	1.69
	Usivellai	3	*P. manihoti*	12	*Mallada* spp.	0.34	0.34
Munjanur 11 ^{0} 27’ 7.02” N 78^{0} 6’ 41.67” E	White Thailand	4	*P. manihoti*	48	*B. sutralis*. *M. sexmaculatus* *H. maindroni* *Scymnus* spp. *Chrysoperla* spp. *Mallada* spp. *Geocoris* spp. *Diadiplosis* spp	1.34 4.03 1.34 1.01 1.68 0.67 2.01 6.04	18.12
Anaikattipalayam 11 ^{0} 24’ 18.48” N 78^{0} 15’ 43.59” E	MVD-1	11	*P. marginatus*	34	*C. montrouzieri* *B. sutralis* *M. sexmaculatus* *A. cardoni* *Mallada* spp. *S. epeus*	1.34 0.67 1.68 1.68 1.68 2.01	7.96
			F. virgata	16	*S. epeus*	0.67	0.67

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Kalkurichi	MVD-1	12			*C. montrouzieri*	2.68	10.01
11 ^{0} 24’ 16.59” N			*P. marginatus*	26	*M. sexmaculatus*	2.01	
78^{0} 15’ 44.79” E					*A. cardoni*	1.34	
					Chrysoperla spp.	1.01	
					Mallada spp.	0.67	
					S. epeus	2.30	
			F. virgata	12	-	-	-
	Usivellai	6	*P. marginatus*	24	*C. montrouzieri*	2.01	8.47
					M. sexmaculatus	1.01	
					Scymnus spp.	1.01	
					Chrysoperla spp.	0.76	
					Mallada spp.	1.67	
					S. epeus	2.01	

Table 3. Occurrence of the mealybug complex and their predators in Erode district, Tamil Nadu, India (January-September, 2021)

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Merkuputhur	MVD-1	5	*P. manihoti*	74	*B. sutralis*	1.56	30.47
11^{0} 20’ 4.14’’ N					*H. maindroni*	10.94	
77^{0} 38’ 4.06’’ E					*M. sexmaculatus*	4.69	
					Chrysoperla spp.	1.95	
					Mallada spp.	2.34	
					S. epeus	0.79	
					Cardiastethus spp.	1.56	
					Geocoris spp.	1.56	
					Diadiplosis spp.	5.08	
Kannapalli		8	*P. manihoti*	64	*B. sutralis*	1.17	19.53
11^{0} 36’ 35.8’’ N	MVD-1				*H. maindroni*	3.91	
77^{0} 40’ 53.6’’ E					*M. sexmaculatus*	3.13	
					Mallada spp.	2.56	

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
					S. epeus	1.73	
					Cardiastethus spp.	0.78	
					Geocoris spp.	2.73	
					Diadiplosis spp.	3.52	
Guruvareddiyur 11^0 39' 2.43'' N 77^0 41' 2.19'' E	MVD-1	6	*P. manihoti*	62	*B. sutralis*	0.78	15.63
					H. maindroni	3.13	
					M. sexmaculatus	2.34	
					Scymnus spp.	1.18	
					Chrysoperla spp.	1.17	
					Mallada spp.	1.95	
					S. epeus	1.17	
					Geocoris spp.	0.78	
					Diadiplosis spp.	3.13	
Komarayanur 11^0 39' 2.43'' N 77^0 41' 2.19'' E	MVD-1	5	*P. manihoti*	67	*C.montrouzieri*	0.78	24.61
					H. maindroni	4.19	
					M. sexmaculatus	3.13	
					Scymnus spp.	3.23	
					Chrysoperla spp.	1.56	
					Mallada spp.	3.52	
					S. epeus	2.73	
					Geocoris spp.	0.78	
					Diadiplosis spp.	4.69	
Annamadu 11^0 34' 6.51'' N 77^0 35' 52.37'' E	MVD-1	6	*P. manihoti*	50	*C. montrouzieri*	0.78	5.37
					H. maindroni	2.34	
					M. sexmaculatus	1.17	
					Mallada spp.	1.08	
	YTP-2	6	*P. manihoti*	32	*B. sutralis*	0.39	4.39
					H. maindroni	1.56	
					M. sexmaculatus	0.48	
					Scymnus spp.	0.79	
					Chrysoperla spp.	1.17	

Table 4. Occurrence of the mealybug complex and their predators in Tiruppur district, Tamil Nadu, India (January-September, 2021)

Location	Variety	Age of the crop (months)	Mealybug species observed	Incidence of mealybug species (%)	Predators observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Madathukulam (Field.1) 10^0 34' 29.96'' N 77^0 21' 32.46'' E	Kollam 16	3	*P. manihoti*	48	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Mallada* spp. *S. epeus* *Diadiplosis* spp.	2.59 3.17 4..76 6.35 2.59 4.76	24.99
Vedapatti 10^0 34' 23.18'' N 77^0 21' 51.06'' E	Kollam 16	9	*P. manihoti*	46	*H. maindroni* *B. sutralis* *M. sexmaculatus* *Mallada* spp. *S. epeus* *Diadiplosis* spp.	5.76 2.17 3.18 6.36 1.59 6.35	25.39
Madathukulam (Field.2) 10^0 35' 17.74'' N 77^0 22' 0.17'' E	Kollam 16	3	*P. manihoti*	76	*H. maindroni* *B. sutralis* *M. sexmaculatus* *Scymnus* spp. *Mallada* spp. *Diadiplosis* spp.	4.17 1.59 4.76 1.59 3.17 6.35	21.63
Andigoundanur 10^0 47' 27.20" N 76^0 56' 20.75" E	Kolaraman	4	*P. manihoti*	16	*H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Mallada* spp. *Chrysoperla* spp. *Diadiplosis* spp.	7.76 4.94 1.59 2.59 3.17 7.94	27.99

Table 5. Occurrence of the mealybug complex and their predators in Coimbatore district, Tamil Nadu, India (January-September, 2021)

Location	Variety	Age of the crop	Mealybug species observed	Mealybug incidence (%)	Predator species observed	Relative abundance of individual predator (%)	Relative abundance of total predators (%)
Aalampalayam 11 ^{0} 12' 55.95" N 77^0 5' 36.09" E	MVD-1	4	*P. marginatus*	52	*C. montrouzieri* *B. sutralis* *M. sexmaculatus* *A. cardoni* *Chrysoperla* spp. *Mallada* spp. *S. epeus*	4.24 2.54 1.69 0.86 1.69 2.54 2.54	16.10
Kumarapalayam 11 ^{0} 12' 55.95" N 77^0 5' 36.09" E	MVD-1	4	*P. marginatus*	54	*C. montrouzieri* *B. sutralis* *M. sexmaculatus* *Chrysoperla* spp. *Mallada* spp. *S. epeus*	5.93 1.69 1.69 4.24 3.39 3.40	20.34
Devarayapuram 11^0 0' 11.30" N 76^0 48' 21.71" E	Kollam 16	3	*P. manihoti*	76	*B. sutralis* *H. maindroni* *M. sexmaculatus* *Scymnus* spp. *Chrysoperla* spp. *S. epeus* *Mallada* spp.	1.69 6.78 3.39 3.39 3.39 4.24 3.40	26.28
Insectary, TNAU 11^0 0' 58.49" N 76 55' 46.68" E	YTP-2	4	*P. manihoti*	32	*C. montrouzieri* *M. sexmaculatus* *Chrysoperla* spp. *Mallada* spp *S. epeus*	2.54 2.54 0.85 0.86 1.69	8.48
TNAU Orchard 11^0 0' 26.67" N 76^0 55' 55.49" E	YTP-2	8	*P. manihoti*	56	*C. montrouzieri* *B. sutralis* *M. sexmaculatus* *H. maindroni* *Scymnus* spp *Mallada* spp *S. epeus*	3.69 0.85 2.54 8.17 1.69 0.85 1.69	19.48
Thenkarai 10^0 58' 11.00" N 76^0 51' 2.61" E	Kolaraman	9	*P. marginatus*	40	*C. montrouzieri* *M. sexmaculatus* *A. cardoni* *Mallada* spp. *S. epeus*	2.54 1.69 0.85 1.69 2.54	9.32

3.2.6 *Scymnus* spp. (Coleoptera: Coccinellidae)

Adult having dark brown elytra with pubescence and testaceous brown apices (Plate1f)

3.2.7 *Chrysoperla* spp. (Neuroptera: Chrysopidae)

Adult having yellow median thoracic band on the thorax and a pair of net like wings. The pseudomedian vein (PSM) met with imago (im) and pterostigma found on the apex of the wings (Plate1g).

3.2.8 *Mallada* spp. (Neuroptera: Chrysopidae)

Short and ovate imago, Subcosta (Sc) and radial vein (R) are widely separated on the forewings and narrow in hindwings (Plate1h).

3.2.9 *Spalgis epeus* Westwood 1851 (Lepidoptera: Lycaenidae)

The adult is having whitish-grey wings with thin black stripes on the inner side of the wings (Plate1i).

3.2.10 *Diadiplosis* spp. (Diptera: Cecidomyiidae)

Antenna is having 12 flagellomeres and presence of strap like adult abdominal sclerites. Radial vein (R1) joins Costa (C) and forked Cubitus Anal vein (Cu A) present on the wings (Plate1j)

3.2.11 *Geocoris* spp. (Hemiptera: Geocoridae)

Body is broadly oval and having wide head with bulging eyes and four segmented antenna (Plate1k).

3.2.12 *Cardiastethus* spp. (Hemiptera: Anthocoridae)

Body is generally elongate oval and brown in colour. Dark brown antenna and hemelytra is paler than head and pronotum (Plate1l).

3.2.13 *Oxyopes* spp. (Araneae: Oxyopidae)

Light brown coloured body with elongated opisthosoma having long spines on its legs (Plate1m).

3.2.14 *Argiope* spp. (Araneae: Araneidae)

Brown coloured body baving pentagonal opisthosoma (Plate1n).

3.3 Assessment of Diversity Indices

Diversity indices form a significant part in the investigation of biodiversity and the indices will help us to study the diversity, richness and evenness of the species. The diversity of the predators associated with the mealybug complex in cassava were assessed through diversity indices *viz.,* Simpson's Index of Diversity (SID), Shannon's Weiner's Diversity (H'), Pielou's evenness value (E1) and Margalef's Index (α) and the results were presented in Fig. 1.

3.3.1 Simpson's index of diversity (SID)

SID is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. The present investigation revealed highest species diversity in Namakkal district as indicated by its SID value (0.90) and lowest diversity in Tiruppur district (0.75).

3.3.2 Shannon's Weiner's diversity (H')

H' is also a measure of diversity and analysis of the predator diversity indicated higher H' in Namakkal district (3.32) and lower H' value in Tiruppur district (1.54). Considering the SID and H', it was evident that the species diversity was maximum in Namakkal district and minimum in Tiruppur district.

3.3.3 Pielou's evenness value (E1)

Among all the districts surveyed, Namakkal district recorded maximum evenness value of 0.94 and Tiruppur district recorded minimum evenness pattern (0.79).

3.3.4 Margalef's index (α)

Margalef's index of species richness was high in Namakkal district (1.93) and low in Tiruppur district (1.67).

From the present studies, it can be concluded that the predators of mealybug complex were well distributed throughout the cassava ecosystem of surveyed districts and especially in Namakkal district as it had higher species diversity, richness and evenness. This results correlates with reports of Magurran [20] who explained that the species diversity increases with increase in species richness and species evenness. This might be due to minimum use of chemical pesticides or prevailing environmental condition which was congenial for the development and multiplication of predators or it may be due to the relative abundance of prey population in Namakkal district.

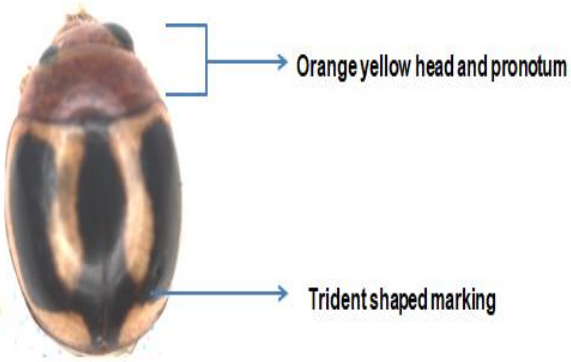

Plate 1a. ***Hyperaspis maindroni***

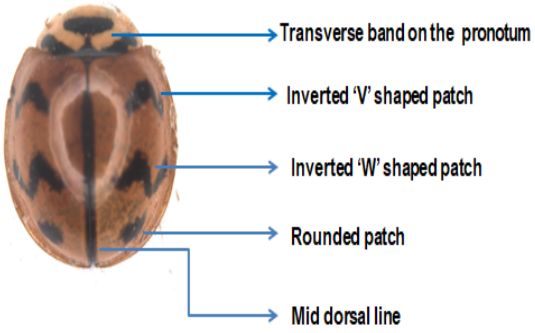

Plate1b. ***Menochilus sexmaculatus***

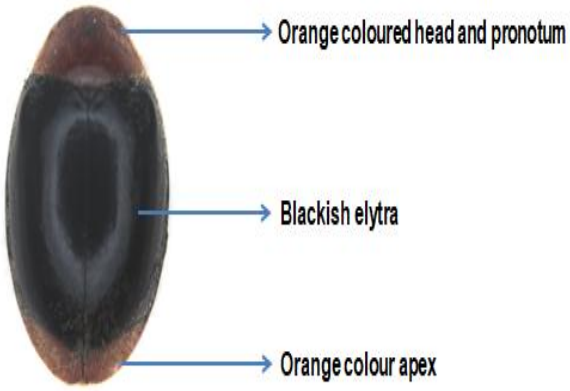

Plate 1c. ***Cryptolaemus montrouzieri***

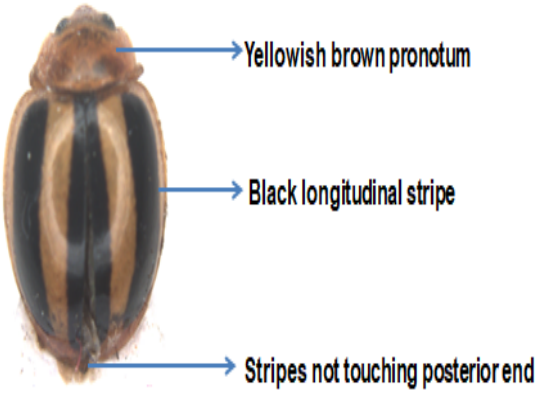

Plate 1d. ***Brumus sutralis***

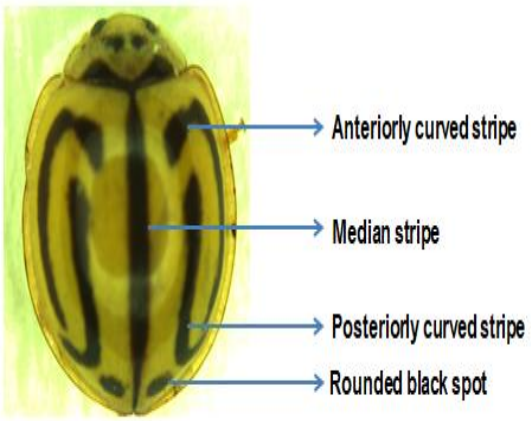

Plate1e. ***Anegleis cardoni***

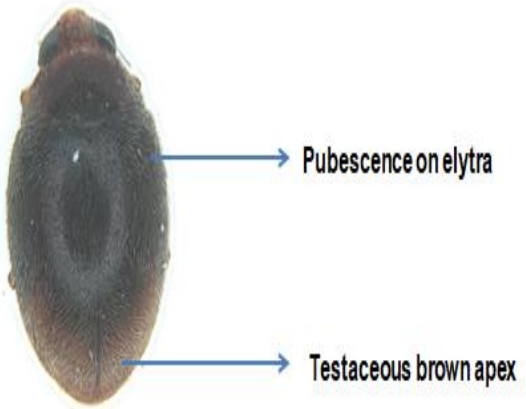

Plate1f. ***Scymnus*** **spp.**

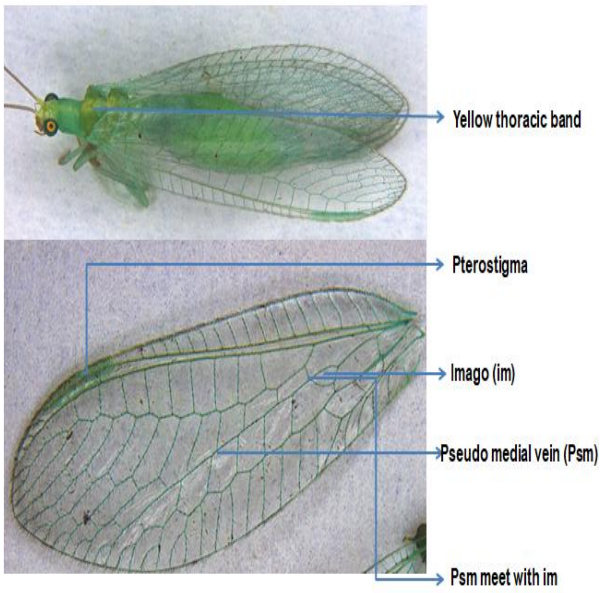

Plate 1g. *Chrysoperla* spp.

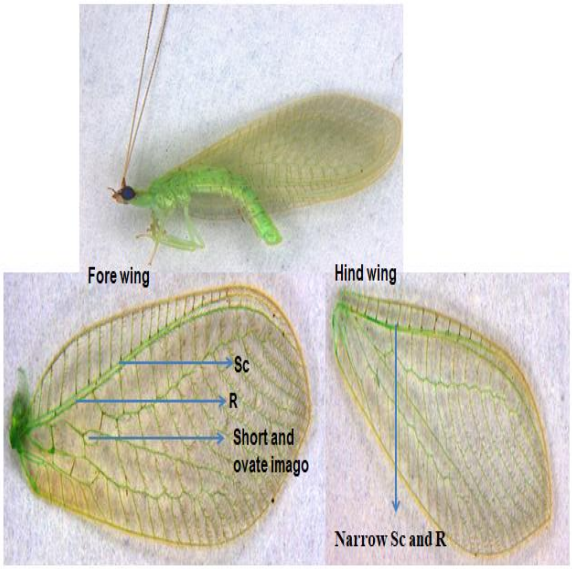

Plate 1h. *Mallada* spp.

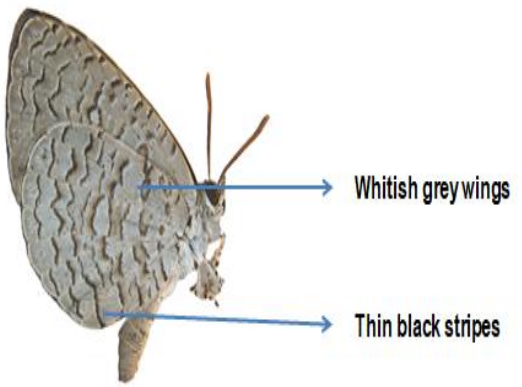

Plate 1i. *S. epeus*

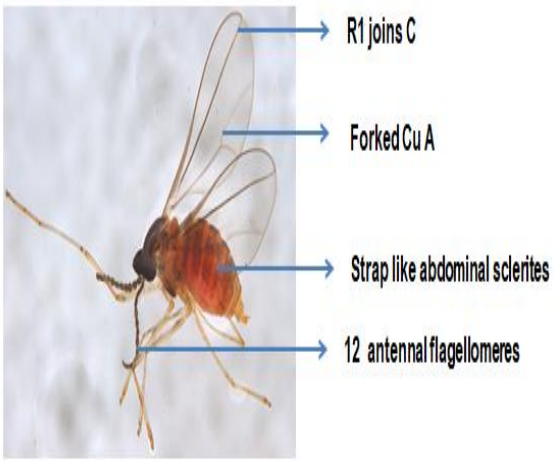

Plate 1j. *Diadiplosis* spp.

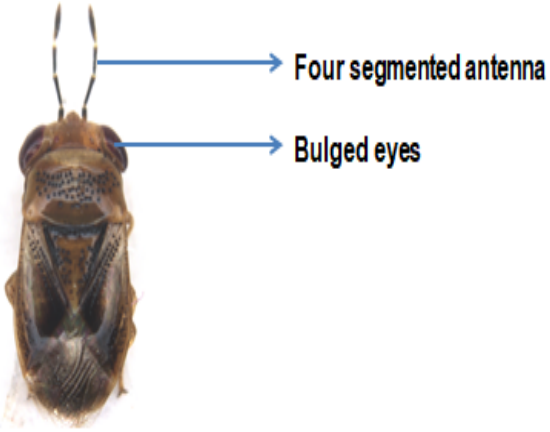

Plate 1k. *Geocoris* spp.

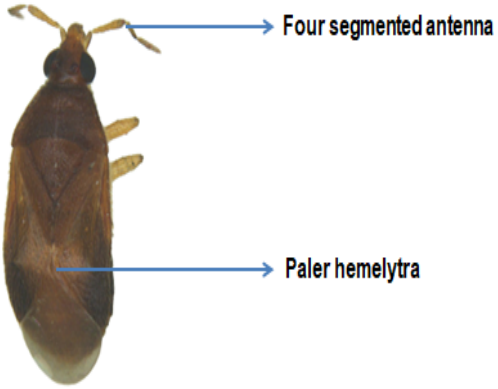

Plate 1l. *Cardiastethus* spp.

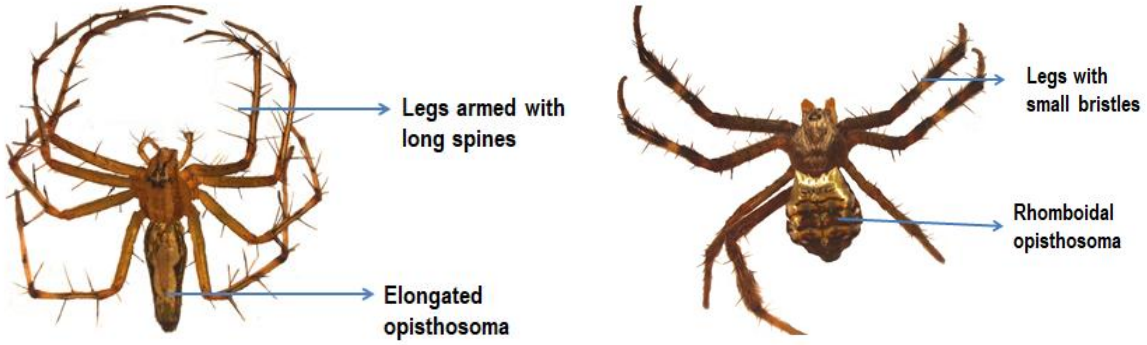

Plate 1m. *Oxyopes* spp. **Plate 1n. *Argiope* spp.**

Plate1. Predators associated with the mealybug complex on cassava

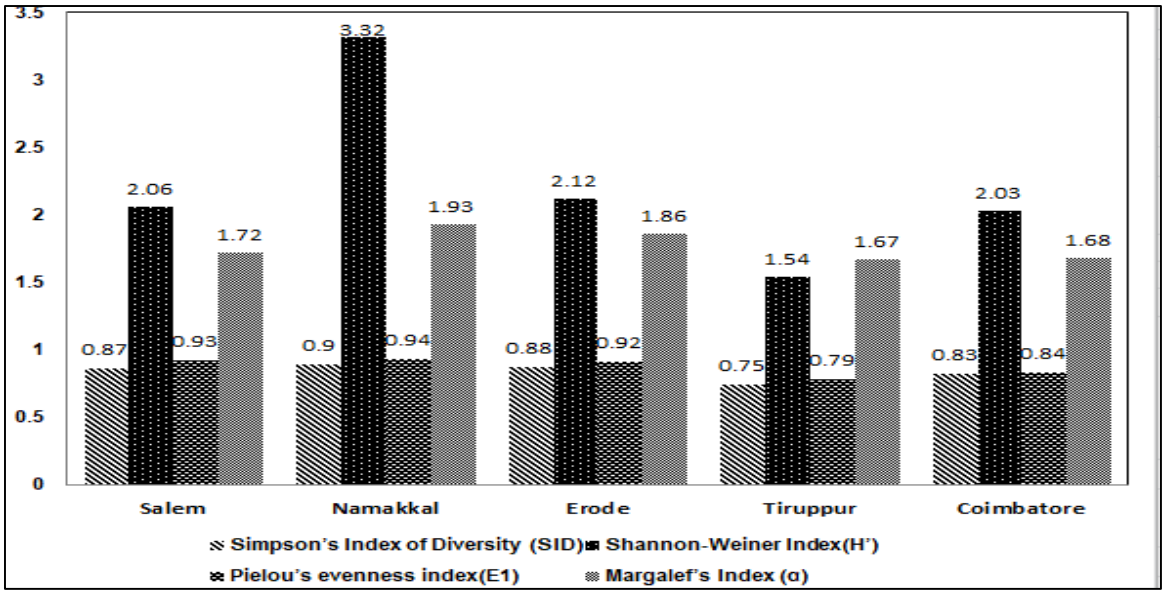

Fig. 1. Diversity of predators in cassava growing districts of Tamil Nadu, India

4. CONCLUSION

Our investigations revealed the prevalence of several predators associated with the mealybug complex on cassava. Further research on the predatory potential and then standardization of the mass culturing protocol for the most predominant predators will pave for designing indigenous natural enemies based biological control strategy for managing the mealybug complex on cassava.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the product because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ETHICAL APPROVAL

As per international standard or university standard ethical approval has been collected and preserved by the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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