

estimated to be ~12 GW (ref. 5). Researchers interested in the mapping and assessment of the impacts of solar eclipse can utilize the remote-sensing datasets together with *in situ* measurements to have a better insight of such rare spectacular events.

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MANU MEHTA*
PRAKASH CHAUHAN
PRAVEEN THAKUR
TAIBANGANBA WATHAM
RITIKA SRINET

*Indian Institute of Remote Sensing,
ISRO,*

*4-Kalidas Road,
Dehradun 248 001, India*

**For correspondence.*

e-mail: manu@iirs.gov.in

Natural occurrence of entomopathogens on the invasive fall armyworm, *Spodoptera frugiperda* (J.E. Smith) in South India

Biological invasions are quite frequent in recent years due to free trade and global warming. Fall armyworm (FAW), *Spodoptera frugiperda* which is a highly migratory polyphagous insect pest, has posed itself as a recent dreadful insect that invaded India in May 2018 on maize in Shivamogga and Davanagere districts of Karnataka, India¹. FAW is one of the major production constraints of maize crop across the globe. *Spodoptera frugiperda* was reported to cause 62.5% plant damage on maize in Hassan district of Karnataka². The management of *S. frugiperda* on maize and sorghum in India is currently achieved using chemical insecticides. However, biological control using entomopathogens is a viable alternative tool for its long term sustainable management and at the same time preserving environment and human health. Infection of FAW larvae by different entomopathogens has been reported earlier in India^{3–7}.

The present study explored the natural occurrences of native entomopathogens on FAW from some of the intensive maize growing regions of Karnataka and Tamil Nadu in order to develop them into microbial biopesticides in future. Survey on the occurrence of these natural entomopathogens was undertaken on maize fields during the crop *kharif* season of 2019–20 at Gauribidanur (13.61°N, 77.51°E), Yaluvahalli (13.37°N, 77.71°E) and Mallur (13.34°N, 77.81°E) villages of Chikkaballapura district in Karnataka and Palacode (12.29°N, 78.07°E), Pappa-

rapatti (12.20°N, 78.05°E), Kambainallur (12.20°N, 78.31°E) villages of Dharmapuri district; Udumalpettai (10.58°N, 77.25°E) of Thirupur district; Pollachi (10.66°N, 77.00°E) of Coimbatore dis-

trict in Tamil Nadu. Thirty maize plants (forty days old) on a random from each field in each village were observed to document the natural occurrences of FAW and their entomopathogens. Single

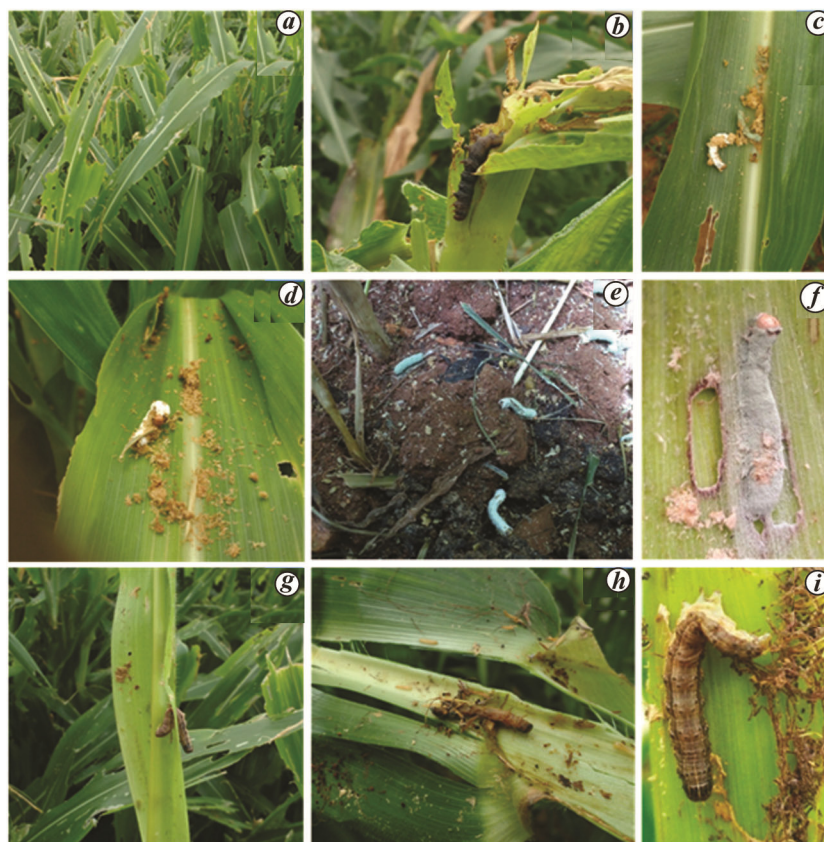


Figure 1. *a*, Fall armyworm (FAW) infestation in maize. *b*, Black coloured *Bacillus thuringiensis* infected FAW larvae. *c–f*, *Nomuraea rileyi* infected FAW larvae (white and green coloured body covering). *g–i*, NPV infected FAW larvae.

Table 1. Diversity in natural occurrence of entomopathogens associated with *S. frugiperda*

State	Karnataka	Tamil Nadu
Mean infestation fall armyworm (%)	63.72	60.23
Entomopathogens	<i>Nomuraea rileyi</i> Nucleopolyhedro virus <i>Bacillus thuringiensis</i>	<i>Nomuraea rileyi</i> Nucleopolyhedro virus <i>Bacillus thuringiensis</i>
Natural occurrence (%)	40.42 21.57 12.48	37.27 23.28 16.46
Diversity of entomopathogens on fall armyworm		
Shannon–Weiner Index (<i>H</i>)	1.09 1.09 1.07	1.09 1.09 1.08
Simpson’s Index (<i>D</i>)	0.33 0.33 0.34	0.33 0.33 0.34
Simpson’s index of diversity (1 – <i>D</i>)	0.66 0.66 0.65	0.66 0.66 0.65
Simpson’s Reciprocal Index (1/ <i>D</i>)	2.99 2.95 2.89	2.99 2.98 2.92
Evenness (<i>E</i>)	0.99 0.99 0.98	1.00 0.99 0.98
Dominance Index	0.63	0.63
Margalef Richness Index	0.69	0.46
Routledge beta – <i>R</i> index	1.33	1.00
Whittaker Index	1.24	1.00

The values of Shannon–Wiener index (*H*), Simpson’s diversity index (*D*), Simpson’s index of diversity (1 – *D*) and Simpson’s reciprocal index (1/*D*) indicate the even distribution of individuals, high species diversity and greater sample diversity in both the regions (Karnataka and Tamil Nadu). The value on evenness inferred that species observed in the regions were highly stable and rich in diversity. Beta diversity indices (Routledge beta – *R* index and Whittaker index) provided a link between species diversity in a region and state that the natural occurrence of entomopathogens was higher in Karnataka than in Tamil Nadu.

visit was made in each village. The average values on natural occurrences of FAW and their entomopathogens of different villages were presented. The number of total and infected larvae at each plant were counted manually and recorded. Occurrences of entomopathogenic fungal, bacterial and viral pathogens were identified based on the characteristic infection symptoms and further confirmation under phase contrast microscope (Olympus BX41). The extent of occurrence of FAW and different entomopathogens was calculated. Naturally occurring microbial pathogen species, alpha and beta diversity indices were analysed based on the Dominance Index (*D*) formula^{8–10}

$$D = \sum (n/N)^2 \quad D = \frac{\sum n(n-1)}{N(N-1)}$$

where *n* is the total number of individuals of each species, *N* the total number of organisms of all species. The value of *D* ranges between 0 and 1.

Margalef Richness Index (Mg) is calculated as species number minus one divided by the logarithm of the total number of individuals. This program uses the natural logarithm.

$$Mg = (S - 1)/\ln N,$$

where *S* is the total number of species recorded and *N* the total number of individuals summed overall *S* species.

Whittaker Index is $\beta = \gamma/\alpha$. Here gamma diversity is the total species diversity of a landscape and alpha diversity is the mean species diversity per habitat.

Microbial pathogens such as fungi, bacteria, nematodes and viruses have shown greater potential for the management of FAW¹¹. The present study

documented the natural occurrence of three major entomopathogenic organisms, viz. *Nomuraea rileyi*, SpfrNPV and *Bacillus thuringiensis* on the larvae of FAW. *Nomuraea rileyi* infected *S. frugiperda* larvae were completely covered with white dense mycelium in the beginning which later became pale green when it started sporulation (Figure 1 c–f). The larvae infected by SpfrNPV were soft and flaccid, hanged head down with prolegs attached to the plant parts (Figure 1 g–i). Oozing of body fluid was also noticed from the NPV infected larvae. The larvae infected with *B. thuringiensis* became black from brown (Figure 1 b). The above natural infection symptoms of the entomopathogens are in accordance with the earlier reports^{12–14}.

The results of the survey revealed the percentage of natural occurrences of entomopathogens *N. rileyi* (40.42%; 37.22%), SpfrNPV (21.57%; 23.28%)

and *B. thuringiensis* (12.48%; 16.46%) from the maize growing villages of Karnataka and Tamil Nadu respectively (Table 1). High occurrences of *N. rileyi* on *S. frugiperda* were observed in the present study which could be due to favourable environmental conditions such as rainfall, temperature and relative humidity prevailed during the *kharif* season. These findings are in accordance with the earlier reports³ which documented that the temperature, rainfall and relative humidity showed positive correlation with natural occurrences of *N. rileyi*.

Among the naturally occurring entomopathogens, *N. rileyi*, SpfrNPV and *B. thuringiensis* have gained greater significance to manage FAW^{3,7}. *Nomuraea rileyi* is a well-known potential lepidopteran infecting entomofungal pathogen, re-classified as *Metarhizium rileyi* according to multigene phylogenetics¹⁵. A good deal of diversity of entomopathogens was observed. The diversity of occurrences of *N. rileyi* was rich, even with high abundance in both the states followed by NPV and *B. thuringiensis*. The diversity, species distribution and abundance, richness and ratio of number of species were high in Karnataka than Tamil Nadu (Table 1). Increase in the richness of entomopathogens led to high level of FAW larval mortality. Hence, conserving entomopathogens diversity may lead to enhanced natural biological control.

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G. SIVAKUMAR^{1,*}
M. MOHAN¹
M. KANNAN²
K. ELANGO³
P. RAM KUMAR¹
T. VENKATESAN¹
R. RANGESHWARAN¹
MAHESH S. YANDIGERI¹
O. DHANYAKUMAR¹

¹ICAR-National Bureau of Agricultural Insect Resources, Hebbal,

Bengaluru 560 024, India

²Department of Nanoscience and Technology,

Periyakulam, Tamil Nadu Agricultural University, Coimbatore 641 003, India

³Horticultural Research Station, Tamil Nadu Agricultural University, Kodaikanal 624 103, India

*For correspondence.

e-mail: sivakumarg.nbaii@gmail.com