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WORLD REVIEW OF THE NATURAL ENEMIES AND DISEASES OF *SPODOPTERA LITURA* (F.) (LEPIDOPTERA: NOCTUIDAE)*

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Abstract — Published information was used to compile a summary of natural enemies (parasitoids, predators and diseases) reported attacking *Spodoptera litura* (F) under field conditions. Species (71) of insect parasitoids in seven families of Hymenoptera and two families of Diptera were listed as parasitoids of different stages of *S. litura*. Predatory insects (36) belonging to 14 families and 12 species of spiders from six families have been reported to feed on this species. Four protozoan, four fungal, seven bacterial, four each of viral and nematode species were also reported to be the pathogens of this species. Published information suggested that periodic releases of large number of egg parasites could help in suppressing populations of this pest. There is a considerable scope for increased attention to the role of natural enemies as component of integrated pest management programmes of *S. litura*.

Key Words: *Spodoptera litura*, natural enemies, diseases

Résumé — Compte rendu mondial des ennemis naturels et des maladies de *Spodoptera litura* (F.) (Lépidoptéres: Noctuides): Des informations publiées ont servi de source pour la compilation de ce compte rendu des ennemis naturels (parasites et prédateurs) et des maladies qui s'attaquent à *Spodoptera litura* (F.) en milieu réel. Soixante-neuf espèces d'insectes parasitoïd parmi sept familles des Hyménoptéres ainsi que de familles des Diptères sont classées comme parasites des différents stades de *S. litura*. Trente-six insectes prédateurs, appartenant à 14 familles et 12 espèces d'araingnées provenant de six familles se nourriraient de cette espèce. Quatre protozoares, quatre moisissures, sept bactéries, quatre virus et cinq nematodes seraient également des agents pathogènes de cette espèce. Les information publiées laissant à croire que des introductions périodiques des parasites des oeufs en grands nombres permettraient de supprimer la population de *Spodoptera*. Les ennemis naturels offrent des possiblités importantes pour jouer un rôle clé dans des programmes de lutte intégrée contre *S. litura*.

Mots Clés: *Spodoptera litura*, ennemis naturels, maladies

INTRODUCTION

The tobacco caterpillar, *Spodoptera litura* (F.) is one of the most important insect pests of agricultural crops in the Asian tropics. This species is widely distributed throughout tropical and temperate Asia, Australasia and the Pacific Islands (Feakin, 1973; Kranz et al., 1977). It is a polyphagous pest and known to cause severe damage to many crops including tobacco and groundnut in India (Moussa et al., 1960; Ayyanna et al., 1982).

The "green revolution" in Asia brought with it an increased awareness of the potential of insecticides for increasing the sustainability of rice production. Unfortunately, the involvement of farmers in insecticide related technologies did not proceed as fast as the rate of subsidy spread and the overspill of insecticide usage into the fields of legume growers and horticulturalists. Legume pests are increasing in

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economic importance all through Asia due to the destruction of natural control systems, and the build-up of insecticide resistance following the "spraymania" of many farmers. If this is to be counteracted, natural control needs to be given increased emphasis as a component of IPM approach. *S. litura* populations in groundnut fields (our study crop) are increasing in number and intensity, especially in fields where insecticides have been applied (Ranga Rao and Shanower, 1988; Stechmann and Semisi, 1984).

In the past, the control of arthropods depended mostly on inexpensive and efficient insecticides. But in recent years populations of many pests including *S. litura* have developed resistance to many commercially available pesticides (Ramakrishnan et al., 1984). Moreover, outbreaks of secondary pests, and the effect of pesticides on non-target organisms is becoming increasingly common. Because of these reasons, the control of arthropod pests is becoming increasingly difficult and it is vital that all biological alternatives to insecticides need to be given greater priority, both in research and application.

Although *S. litura* is known to cause substantial damage to a number of crops, there has been no attempt to review the literature on the role of natural enemies in regulating the abundance of this pest. The main purpose of this paper is to review the status of natural enemies of *S. litura* on global basis. *S. litura* is known to be attacked by many of natural enemies at various life stages. Altogether, about 131 species of natural enemies have been reported from different parts of the world (Table 1). The list of parasites, predators and diseases was compiled from published literature, and arranged in a systematic order that includes host stage attacked, scientific name, family and geographic distribution, followed by the most pertinent references (Table 2). The information furnished in this paper may suggest new sources of natural enemies for different geographic regions. It may also indicate the potential importance of different natural enemies which may be relevant to future biocontrol and IPM projects.

EGG PARASITOIDS

Four species of trichogrammatids, one scelionid and one braconid which had been reported as egg parasitoids of *S. litura*, *Chelonus* sp. and *Telenomus* spp., have also been reported as both egg and larval parasitoids. A total of 10 egg parasitoids have been reported from different parts of the host distribution (Table 2). Among the trichogrammatids, *T. australicum* and *T. chilonis* from India (Joshi et al., 1979; Patel et al., 1971), *T. japonicum* from Indonesia (Chu, 1979), *T. dendrolimi* from China (Chiu and Chou, 1976), are the most common. These species are often reported from eggs of several other hosts.

Mass releases of an indigenous egg-larval parasite *Chelonus helipae* in 1971–1973 in Anand, Gujarat, India, against *S. litura* in cauliflower crop proved ineffective in controlling the pest. During 1974, weekly release of *Telenomus remus* Nixon, an exotic egg-larval parasitoid, in a tobacco nursery did not result in any parasitism. However, five weekly releases of 50,000 parasites/0.2 ha and two releases of 15,000 parasitoids/0.2 ha in cauliflower, resulted in 60% parasitism (Patel et al., 1979).

Rao et al. (1979) observed 8% parasitization by *Chelonus blackburni* Cameron an egg/larval parasitoid of *S. litura* in Karnataka, India. An insect survey conducted in Jawa Timur, Indonesia revealed the occurrence of the parasitoids *Trichogramma japonicum* Ashm. and *Telenomus dignus* (Gah) attacking *S. litura* eggs (Chu, 1979). Chiu and Chou

Table 1. *Spodoptera litura* natural enemies and diseases worldwide

	Number of natural enemy species and diseases reported from different countries			
	Parasitoids	Predators*	Nematodes	Diseases
India	44	24	4	13
Australia	5	1	–	–
Japan	–	8	1	4
China	12	7	–	3
Indonesia	4	1	–	–
Western Samoa	8	4	–	–
Papua New Guinea	–	4	–	–
Philippines	1	–	–	–
New Zealand	1	–	–	2
Total	71	48	4	20

*Spiders are included.

Table 2. Natural enemies and diseases of *Spodoptera litura* (Fabricius)

Stage attacked/parasite/ predator/pathogen	Family	Geographic range	Selected references
PARASITES			
Egg			
Chelonus helipae Gupta	Braconidae	India	Patel et al. (1971)
Trichogramma australicum Girault	Trichogrammatidae	India	Joshi et al. (1979)
Trichogramma chilonis Ishii	Trichogrammatidae	India	Bhatnagar (1981) Zaz and Kushwaha (1983)
Trichogramma dendrolimi Mats.	Trichogrammatidae	China	Chiu and Chou (1976)
Telenomus dignus (Gah)	Scelionidae	Indonesia	Chu (1979)
Trichogramma japonicum Ashm.	Trichogrammatidae	Indonesia	Chu (1979)
Egg-larval			
Chelonus blackburni Cameron	Braconidae	Indonesia	Rao et al. (1979)
Chelonus carbonator Marshall	Braconidae	India	Rao and Satyanaraya (1984)
Chelonus formosanus (Sonan)	Braconidae	India	Patel et al. (1971) Rai (1974)
Telenomus remus Nixon.	Scelionidae	India	Joshi et al. (1979)
		India	Patel et al. (1979)
		India	Rao and Patel (1976)
		India	Zaz and Kushwaha (1983)
		New Zealand	Anon (1977)
		Western Samoa	Braune (1982)
Larval			
Apanteles sp.	Braconidae	Western Samoa	Braune et al. (1981)
		Western Samoa	Stechmann and Semisi (1984)
Apanteles near *A. ruficrus* (Hal.)	Braconidae	Western Samoa	Braune et al. (1981)
Apanteles sp. near *Colemani* Vier	Braconidae	India	Patel et al. (1971)
Apanteles sp. (*octonarius* group)	Braconidae	India	Joshi et al. (1979)
Apanteles chilonis Mats.	Braconidae	Indonesia	Chu (1979)
Apanteles colemani Viereck	Braconidae	India	Sathe (1987)
Apanteles marginiventris	Braconidae	Australia	Michael et al. (1984)
Apanteles plutellae Kurd.	Braconidae	China	Chiu and Chou (1976)
Apanteles prodeniae Viereck	Braconidae	India	Sathe (1987)
Apanteles ruficrus (Hal.)	Braconidae	China	Chiu and Chou (1976)
		Western Samoa	Braune et al. (1981)
		India	Zaz and Kushwaha (1983)
Apanteles kazak Telenga	Braconidae	Australia	Michael et al. (1984)
Bracon brevicornis Wesmael.	Braconidae	India	Thontadarya and Nangia (1983)
Cotesia (Apanteles) marginiventris (Cresson)	Braconidae	India	Jalali (1987)
Diadegma argenteopilosa Cameron	Ichneumonidae	India	Sathe (1987)
Echthromorpha sp.	Braconidae	India	Sathe (1987)
Enicospilus sp.	Braconidae	India	Sathe (1987)
Microgaster sp.	Braconidae	China	Xu and Yang (1983)
Microplitis sp.	Braconidae	India	Zaz and Kushwaha (1983)
Microplitis demolitor Wilk.	Braconidae	Australia	Hafez (1951)
Microplitis pallidipes Szepl.	Braconidae	China	Chiu and Chou (1976)
Microplitis prodiniae R.S.K.	Braconidae	India	Sathe (1987)
Microplitis tuberculifera (Wesm)	Braconidae	China	Chiu and Chou (1976)
Rogas sp.	Braconidae	India	Bhatnagar (1981)
Snellenius manilae (Ashm)	Braconidae	China	Chiu and Chou (1976)
Zele chlorophthalma Nees.	Braconidae	India	Bhatnagar (1981) Rao and Satyanaraya (1984)
Brachymeria lasus (Wlk.)	Chalcididae	India	Narendran and Joseph (1977)
Lasiochalcidia ? erythropoda Cameron	Chalcididae	India	Bhatnagar (1981)
Litomastix maculata Isheii	Encyrtidae	China	Sheng and Shen (1983)
Euplectrus sp.	Eulophidae	China	Chiu and Chou (1976)
Euplectrus gopimohani Mani.	Eulophidae	India	Patel (1944)
		India	Patel (1980)

Table 2 Contd.

Stage attacked/parasite/ predator/pathogen	Family	Geographic range	Selected references
Euplectrus near *E. xanthocephalus*	Eulophidae	Western Samoa	Braune et al. (1981)
Tetrastichus ayyari Rohwer	Eulophidae	India	Sathe (1987)
Trichospilus pupivora Ferri	Eulophidae	India	Sathe (1987)
Campoletes sp.	Ichneumonidae	India	Battu (1977)
Campoletes chlorideae Uchida	Ichneumonidae	India	Battu (1977)
		India	Sathe (1987)
		China	Chiu and Chou (1976)
Charops bicolor (Szepi)	Ichneumonidae	China	Chiu and Chou (1976)
Charops obstusus Morl.	Ichneumonidae	India	Patel (1980)
Hyposoter didymator Thunb.	Ichneumonidae	Australia	Michael et al. (1984)
Erioborus sp.	Ichneumonidae	India	Bhatnagar (1981)
Ichneumon sp.	Ichneumonidae	India	Anon. (1988)
Netelia ferruginea Cameron	Ichneumonidae	India	Sathe (1987)
Paniscus productus Brulle	Ichneumonidae	Australia	Hafez (1951)
Temelucha biguttula (Mats.)	Ichneumonidae	Indonesia	Chu (1979)
Fannia leucostica Smith	Muscidae	India	Zaz and Kushwaha (1983)
Actia nigritula Mall.	Tachinidae	Australia	Hafez (1951)
Parasarcophaga misera (Walk.)	Tachinidae	India	Bhattu (1977)
Peribaea orbata (Wideman)	Tachinidae	India	Jayanth and Nagarkatti (1984)
		Philippines	Rao and Patel (1976)
Strobliomyia aegyptia Vill.	Tachinidae	India	Bhatnagar (1981)
		India	Joshi et al. (1979)
		India	Patel et al. (1971)
Sturmia aequalis Mall.	Tachinidae	American Samoa	Hoyt (1955)
Tritaxys sp.	Tachinidae	Australia	Hafez (1951)
Winthemia near *dispar* (Macq.)	Tachinidae	American Samoa	Hoyt (1955)
Pre-pupal			
Chelonus sp.	Braconidae	Western Samoa	Braune and Kan (1981)
Pupal			
Brachymeria sp.	Chalcididae	India	Thontadarya and Nangia (1983)
Hybothoracini sp.	Chalcididae	India	Rao et al. (1981)
Sarcophaga albiceps Meigen	Sarcophagidae	India	Bhatnagar (1981)
Sarcophaga dux Thoms	Sarcophagidae	India	Joshi et al. (1979)
Sarcophaga peregrina (Robineauedesvoidy)	Sarcophagidae	India	Zaz and Kushwaha (1983)
Blepherella setigera Corti	Tachinidae	India	Joshi et al. (1979)
Winthemia sp.	Tachinidae	Western Samoa	Braune and Kan (1981)
PREDATORS			
Egg			
Chalcid wasp (unidentified)	Chalcididae	Western Somoa	Braune and Kan (1981)
Cardiocondyla nuda (Mayr)	Formicidae	Western Somoa	Braune and Kan (1981)
Tapinoma melanocephalum (F.)	Formicidae	Western Somoa	Braune and Kan (1981)
Liposcelis sp.	Liposcelidae	India	Zaz and Kushwaha (1983)
Egg-larval			
Chrysopa crassinervis Esben Peterson	Chrysopidae	India	Rao and Satyanaraya (1984)
Small red ants (unidentified)	Formicidae	Western Somoa	Braune (1980)
Nesidiocoris tenuis Reuter	Miridae	India	Patel (1980)
Conocephalus sp.	Tettigonidae	China	Deng and Jim (1985)
Larval			
Carabid beetles (unidentified)	Carabid	Japan	Ito et al. (1972)
Crickets (unidentified)		Japan	Ito et al. (1972)
Earwigs (unidentified)		Japan	Ito et al. (1972)
Casnoidea indica (Thnb.)	Carabidae	Indonesia	Chu (1979)
Chrysopa sp.	Chrysopidae	India	Sitaramaiah and Ramaprasad (1982)
Coccinella sp.	Coccinellidae	India	Sitaramaiah and Ramaprasad (1982)
Epilachna sp.	Coccinellidae	India	Cherian and Brahmachari (1942)
Dieuches sp.	Lygaeidae	India	Rao et al. (1981)
Oechalia consocialis (Bois.)	Pentatomidae	Australia	Richard (1964)

Table 2 Contd.

Stage attacked/parasite/ predator/pathogen	Family	Geographic range	Selected references
Andrallus spinidens (Fabricius)	Pentatomidae	India	Pawar (1976)
Cantheconidia furcellata Wolff.	Pentatomidae	China	Chu and Chu (1975)
	India	Kapoor et al. (1975)	
Platynopus melacanthus (Boisd)	Pentatomidae	Papua New Guinea	Hassan (1972)
Podisus maculiventris (Say)	Pentatomidae	Japan	Hokyo and Hawanthai (1975)
Coranus sp.? *atricapillus* Dist	Reduvidae	India	Sitaramaiah and Ramaprasad (1982)
Coranus curtis Stal.(?)	Reduvidae	China	Ren (1984)
Coranus spiniscutis Reuter	Reduvidae	India	Sitaramaiah and Ramaprasad (1982)
	China	Ren (1984)	
Euagoras sp.	Reduvidae	Papua New Guinea	Hassan (1972)
Harpactor costalis Stal.	Reduvidae	India	Sitaramaiah et al. (1975)
Helonotus exsugiens Stal.	Reduvidae	Papua New Guinea	Hassan (1972)
Pristhesancus femoralis Horv	Reduvidae	Papua New Guinea	Hassan (1972)
Rhinocoris squalis (Disk.)	Reduvidae	India	Rao and Satyanaraya (1984)
Rhynocoris fuscipes F.	Reduvidae	India	Cherian and Brahmachari (1942)
Sphedanolestes sp.	Reduvidae	India	Rao et al. (1981)
Paederus fuscipes Curt.	Staphylinidae	Indonesia	Chu (1979)
Icaria marginata Sauss.	Vespidae	India	Rao et al. (1981)
Polistes chinensis (F)	Vespidae	Japan	Nakasuji et al. (1976)
Polistes jaduigae D.T.	Vespidae	Japan	Nakasuji et al. (1976)
Polistes stigma Fabr.	Vespidae	India	Rao et al. (1981)
Ropalidia sp.	Vespidae	India	Joshi et al. (1979)
SPIDERS			
Larval			
Cheiracantium danieli Tikader	Clubionidae	India	Sitaramaiah et al. (1980)
Clubiona sp.	Clubionidae	India	Sitaramaiah et al. (1980)
Gnathonarium exsiccatus Bosenberg & Strand	Clubionidae	Japan	Nakasuji et al. (1973)
Olios punctipes Simon	Heteropodidae	India	Sitaramaiah et al. (1980)
Eldothorax insecticeps Bosenberg & Strand	Micryphantidae	Japan	Nakasuji et al. (1973)
Oxyopes sp.	Oxyopidae	India	Sitaramaiah et al. (1980)
Oxyopus wroughtoni Pocock	Oxyopidae	India	Sitaramaiah et al. (1980)
Marpissa sp.	Salticidae	India	Sitaramaiah et al. (1980)
Marpissa mandali Tikader	Salticidae	India	Sitaramaiah et al. (1980)
Phidippus punjabensis Tikader	Salticidae	India	Sitaramaiah et al. (1980)
Thomisus lobosus Tikader	Thomisidae	India	Sitaramaiah et al. (1980)
Thomisus prorectus Tikader	Thomisidae	India	Sitaramaiah et al. (1980)
VERTEBRATE PREDATORS			
Calotes versicolor Daudin	Bush lizard	India	Singh and Singh (1975)
Cuckoo birds 2 types	Bush lizard	India	Singh and Singh (1975)
Tree frogs (unidentified)		Japan	Ito et al. (1972)
Uromastix hardovickii	Reptius	India	Bhanotar and Srivastava (1985)
PATHOGENS			
Protozoa			
Larval			
Nosema sp.		India	Narayanan and Jayaraj (1979)
Nosema sp.		Japan	Watanabe (1976)
Nosema carpocapse Paillot		New Zealand	Malone and Wigley (1980)
Nosema liturae sp. n.		China	Li and Wenn (1987)
Nosema mesnili (Paillot)		China	Tsai et al. (1978)
Fungal			
Larval			
Aspergillus flavus Link.		India	Battu et al. (1972)
Beauveria sp.		India	Ramamurthy et al. (1967)
Beauveria bassiana (Balsamo) Vuillimin		India	Zaz and Kushwaha (1983)
Nomuraea rileyi (Farlow) Samson.		Japan	Asayama and Ohoishi (1980)
		India	Phadke and Rao (1978)
			Rao and Phadke (1977)

Table 2 Contd.

Stage attacked/parasite/ predator/pathogen	Family	Geographic range	Selected references
Bacteria			
Larval			
Bacillus cereus Frankland and Frankland		India	Kore and Bhide (1978) Oblisami et al. (1969)
Bacillus thuringinsis Berliner		India	Zaz and Kushwaha (1983)
Metarhizium anisopliae (Metchnikoff) Sorokin		India	Siddaramaiah et al. (1986)
Micrococcus sp.		India	Zaz and Kushwaha (1983)
Serratia marcescens Bizio		India	Ansari et al. (1987) Pandey and Rangarajan (1967) Zaz and Kushwaha (1983)
Streptococcus sp.		India	Zaz and Kushwaha (1983)
Streptococcus faecalis A.& H.		India	Battu et al. (1972) Zaz and Kushwaha (1983)
Virus			
Larval			
Baculovirus group		New Zealand	Longworth (1976)
Cytoplasmic polyhedrosis virus		Japan	Asayama and Osaki (1970)
Granulosis virus		China	Tsai et al. (1978)
		India	Battu et al. (1978)
		India	Narayanan (1985)
Nuclear polyhedrosis virus		India	Battu et al. (1972)
		India	Chari et al. (1985)
		India	Krishnaiah et al. (1985)
		India	Ramakrishnan and Tiwari (1969)
		China	Tai (1973)
		Japan	Okada (1974)
Nematode			
Larval			
Hexamermis spp.		India	Bhatnagar et al. (1985)
Stinernema feltiae (DD 136)		Japan	Kondo and Ishibashi (1984)
(Neoplectana carpocapsae Weiser)		India	Janardan Singh and Bardhan (1974)
Ovomermis albicans (Siebold)		India	Bhatnagar et al. (1985)
Pentatomimermis spp.		India	Bhatnagar et al. (1985)

(1976) reported that *T. dendrolimi* is an egg parasitoid of *S. litura* from Taiwan.

Braune (1982) found *Telenomus remus* Nixon to be a common egg-larval parasitoid of *S. litura* in Western Samoa with parasitism averaging 54%. Complete parasitization was observed only in small egg masses (up to 150 eggs) and the percentage of parasitization decreased with an increase in size of egg-mass. *T. remus* could oviposit only in host eggs on the surface of the host egg mass. Thus, the effectiveness of *T. remus* was limited on the large compact egg masses of *S. litura*.

LARVAL PARASITOIDS

Generally, the larval stage of *S. litura* is more prone to parasitism. Larval parasitoids of *S. litura* attack young to mature larvae and a few also attack eggs and larvae, and larvae and prepupae. Fifty-eight parasitoid species have been reported to attack the larval stage of this species. Of these, 47% were braconids, 19% ichneumonids, 16% tachinids, 10% eulophids, 3% chalcids, and 2% scelionids, encrytids and muscids. In general, 84% were Hymenoptera, and 16% Diptera.

In India, 32 different species of parasitoids have been reported as larval parasitoids of *S. litura*. Among these, *Apanteles* and *Bracon* sp. were the most commonly reported. In 1974, Rai surveyed vegetable crops in the state of Karnataka and found that 10% of larval mortality was caused by *Chelonus formosanus* (Sonan). Battu (1977), during a survey of castor and cauliflower in the Punjab, found that *Parasarcophaga misera* (Walk.) and *Campolitis* sp. also attack *S. litura* larvae. Jayanth and Nagarkatti (1984) reported the emergence of up to 12 tachinid parasitoids [*Peribaea orbata* (Wideman)] from a single *S. litura* larva in Karnataka state, India.

Rao and Satyanarayana (1984), during a pest survey of natural enemies of *S. litura* in Andhra Pradesh, India, reported *Zele chlorophthalma* Nees

as a larval parasitoid and *Lasiochacidia erythropodus* Nees as a pupal parasitoid.

Sathe (1987) in a survey for natural enemies of *S. litura* in Maharashtra region of India reported *Compoletes chloridae* Uchida and *Apanteles colemani* Viereck. During the same survey two new Braconid species (*Enicospilus* sp. and *Echthromorpha* sp.) were found responsible for the 5% parasitization of *S. litura* while *A. colemani* and *A. prodeniae* parasitized up to 20% larvae.

Laboratory tests to determine the effect of host plants on the degree of parasitism of *S. litura* larvae by *Cotesia (Apanteles) marginiventris* Cresson, showed least preference for larvae on tobacco (Jalali et al., 1987). Although 20% of the larvae were parasitized on tobacco leaves, female parasitoids became inactive after contact with the leaves and died within 1 hr suggesting that *C. marginiventris* would not be suitable for release against *S. litura* on tobacco. The most preferred host for the parasitoid was Khol rabi (56% parasitization).

Application of 2% neem (*Azadiracta indica*) kernel suspension to eggs of *S. litura* before and after parasitization by *Telenomus remus* Nixon had no effect on the development of the parasitoid in India (Joshi et al., 1982). Thus, neem seed kernel suspension was considered suitable in the integrated control of *S. litura* in tobacco nurseries.

Six parasitoid species, *Apanteles ruficrus* (Hal.), *C. marginiventris* (Cresson), *A. kazak* Telenga, *Compoletes chloridae* Uchida, *Hyposoter didymator* Thumb and *Telenomus remus* Nixon were introduced to Western Australia from overseas in 1978–1983 and released against *S. litura* and 11 other economically important pests. The highest level of parasitism by *A. ruficrus* was noticed in *Mythimna* sp. (80% and above; Michael et al., 1984).

In Western Samoa, Stechmann and Semisi (1984) collected information on *S. litura* damage levels in relation to natural populations of *Apanteles* sp. in the taro fields. They found that this pest is more severe on "Taro" crop where insecticides and herbicides were widely used, which perhaps created imbalance between the pest and its natural enemies. Barrion and Litsinger (1987) reported the presence of *Peribaea orbata* (Wideman) as a gregarious larval parasitoid on *S. litura*.

PUPAL PARASITOIDS

Relatively few pupal parasitoids have been reported from *S. litura* when compared to parasitoids of other life stages. Eight parasitoid species have been reported from the pupal stage of *S. litura*, one of them is a larval - pupal parasitoid (*Ichneumon* sp.) and one a prepupal parasitoid (*Chelonus* sp.; Table 2).

Lasiochalcidia erythropodus Cameron was reported as a pupal parasitoid of *S. litura* in Andhra Pradesh, India (Rao and Satyanarayana, 1984). However, Bhatnagar (1981) reported this species as a larval parasitoid.

PREDATORS

Altogether 36 predatory insects from 14 families and 12 species of spiders, representing six families were reported to feed on *S. litura* eggs, larvae and pupae in different parts of the world. Of the total predators reported to feed on *S. litura*, 50% of the insect predatory fauna and 83% of the spiders were from India (Table 1).

Sitaramaiah et al. (1975) from Andhra Pradesh, India, observed for the first time the reduvid *Harpactor costalis* Stal. predating on *S. litura* larvae in tobacco crops. Laboratory experiments revealed that the predator consumes an average of 63 *S. litura* larvae during its life span.

Nymphs and adults of *Andrallus spinidens* (F.) (pentatomid) were observed feeding on *S. litura* larvae in rice in Himachal Pradesh, India (Pawar 1976). Another pentatomid species, *Canthoconidia furcellata* (Wolf), was observed feeding on larvae of *S. litura* in tobacco nurseries in Andhra Pradesh, India (Kapoor et al., 1975). The biology of this predator was studied in the laboratory with a view to use *C. furcellata* in an integrated pest management programme for tobacco pests.

Nakasuji et al. (1976) observed a predatory wasp, preferentially selecting fifth and sixth instar larvae over early instars. The wasps were more active and attacked more larvae in fields with high larval density than those with low larval density. However, the percentage of predation was lower in the field with highest density of *S. litura* larvae.

Chu (1979), from a survey in Jawa Timur, Indonesia, reported a carabid beetle, *Casnoidia indica* (Thnb.) and a staphylinid beetle *Paederus fuscipes* Curt, feeding on *S. litura* and other economically important lepidopterous insects. Chu and Chu (1975) studied the effects of temperature on the growth of *C. furcellata* and found that 71, 216 and 134 C degree days were required for egg, nymph and adult stages, respectively. It was concluded that there are five to six generations per year of this predator in northern Taiwan.

Deng and Jim (1985) reported *Conocephalus* sp. (Tettigometridae) as new predator on egg masses of *S. litura* in Guangxi, China. This katydid was

successfully reared on artificial diet. Field releases of nymphs and adults of *Conocephalus* sp. were attempted against the control of *Scirpophaga incertulus* (Walk.).

DISEASES

Protozoa

Nosema carpocapse Paillot was found to infect *S. litura* larvae in New Zealand (Malone and Wigley, 1980), India (Narayanan and Jayaraj, 1979), Japan (Watanabe, 1976) and China (Tsai et al., 1978; Li and Wenn, 1987).

Bacteria

Seven bacteria are known to infect *S. litura* at larval stage in India (Table 2). Ansari et al. (1987) reported *Serratia marcescens* Bizio from Karnataka, India, attacking larvae of the noctuids *Helicoverpa armigera* Hübner and *S. litura*. In labortory tests, *S. litura* was found more susceptible to the bacterium than *H. armigera*. The bacterium was equally pathogenic when ingested through artificial diet or the natural food plant, but pathogenicity by contact application to the body of larvae was poor.

Zaz and Kushwaha (1983) found *Bacillus thuringiensis* Berliner (*B.t.*) to be an effective microbial insecticide against *S. litura* larvae in cauliflower fields in Rajasthan, India. Application of the *B.t.* in combination with endosulfan resulted in 85% larval mortality in the field.

Fungi

So far four fungi have been reported to infect *S. litura* and cause physiological disorders in larval growth and development. Asayama and Ohoishi (1980) from Japan and Phadke and Rao (1978) from India, investigated the pathogenicity of a green muscardine fungus *Nomuraea rileyi* (Farlow) Samson. Laboratory studies in India indicated that this fungus was harmless to eggs of an egg parasitoid, *Telonemus proditor* Nixon, on *Achea janata* L., and recommended the combined use of the fungus and the egg parasite in biocontrol programmes against *A. janata*. This may also apply to *S. litura* management.

Zaz and Kushwaha (1983) reported *Beauveria bassiana* (Balsamo) Vuillemin. infecting *S. litura* in cauliflower crops in Rajasthan. Siddaramaiah et al. (1986) reported an incidence of larval infection with *Metarhizium anisopliae* (Metchnikoff) Sorokin in groundnut in Karnataka. The infection first appeared in the second fortnight of June, was highest in mid-August, and decreased by November.

Virus

Viral diseases of this species have been reported from China, Japan, India and New Zealand. Among the viruses, nuclear polyhedrosis viruses are the most common and potent.

Krishnaiah et al. (1985) conducted field trials with a nuclear polyhedrosis virus against *S. litura* damage in black gram (*Vigna mungo*) fields in Andhra Pradesh, India. Two sprays of virus suspension containing 1.96×10^9 polyhedral inclusion bodies/ml at the rate of 1500 ml/ha. gave effective control similar to chemical insecticides tested.

Chari et al. (1985) evaluated the effectiveness of integrated management of natural enemies and viral diseases to control *S. litura* on tobacco seedlings in Gujarat, India. They concluded that a combination of biological control agents, insect growth regulators, antifeedants and a trap crop on all sides of a nursery is an ecologically sound procedure for the control of *S. litura*.

Narayanan (1985) from Karnataka, reported the occurrence of a granulosis virus in dead *S. litura* larvae. Eggs and all six larval instars were highly susceptible to the virus, the mortality was 100% in eggs and first to fifth instar larvae and 50% in the last larval instar. The disease killed older larvae more rapidly than the younger ones.

Nematodes

Four nematode species have been reported parasitizing *S. litura* in India and one of them has also been reported to be parasitizing *S. litura* in Japan.

Bhatnagar et al. (1985), found *S. litura* larvae parasitized by the mermithid nematodes, *Ovomermis albicans* (Siebold), *Hexamermis* sp., and *Pentatomermis* sp. They observed more nematode activity on alfisols than on vertisols. They also discussed the population dynamics and distribution of nematodes and the arthropod hosts. Kondo and Ishibashi (1984) explained the infectivity and propagation of entomogenous nematodes *Steinernema* sp. on *S. litura* from Japan.

CONCLUSIONS

Although 71 parasitoids and 48 predators are known to attack *S. litura* at different stages, most of these associations were incidental, either some species were rare or more closely associated with other hosts.

Among the pathogens, five protozoans, four fungi, seven bacteria, four viruses and four nematodes are known to infect the larval stage of *S. litura*. All reports of bacterial infections are from India.

Among the 10 species of egg parasitoids reported the genus *Trichogramma* was the most widely distributed in India, Indonesia and China. More larval parasitoids have been reported from *S. litura*, 83% of the parasitoids are hymenopterous and the remaining 17% were dipterous. The parasitoids that attack the pupal stage are relatively fewer in number. Only eight species have been reported, one of which was a larval pupal parasitoid and another prepupal parasitoid.

Altogether 48 species of insects and spiders were observed to predate on eggs, larvae and pupae of *S. litura*. Spiders account for 25% of the total predators.

In the past, the mass releases of egg and larval parasitoids for the control of *S. litura* in different crops in different geographical regions had achieved only partial success (Patel et al., 1979; Michael et al., 1984). Our personal observations in ICRISAT groundnut fields revealed more leaves with defoliator damage in insecticide applied fields than unsprayed areas (Wightman et al., 1990). Similar observations were also made during farmers' field surveys in the post-rainy season in Coastal Andhra Pradesh, India (Ranga Rao and Shanower, 1988). Stechmann and Semisi (1984) also shared the same opinion after surveying Taro fields in Western Samoa. In view of the development of insecticidal resistance and the destruction of the natural enemies and the polyphagous nature of this species, there is need to give more consideration to the role of natural enemies as a component in integrated approaches to manage this species.

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