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The Oriental Armyworm, *Mythimna separata* (Wlk.) Distribution, Biology and Control: A Literature Review

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The Oriental Armyworm, *Mythimna separata* (Wlk.) Distribution, Biology and Control: A Literature Review

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SUMMARY

The oriental armyworm, *Mythimna separata* (Wlk.), is one of the serious cereal pests in the Asian and Australian continents. It is widely distributed between 45° N and 45° S latitude and 60° E to beyond 170° W longitude, covering 27 countries/colonial territories/islands from humid tropical to temperate regions. Serious outbreaks have occurred in India, China, Japan, Australia, New Zealand, Fiji, Bangladesh, and Thailand. Various theories are quoted to explain the outbreaks. Exact yield loss estimates are not available, but heavy losses have been experienced in India, China, Japan, Australia, New Zealand, and Bangladesh. Insect development varies according to temperature and humidity. Populations have been monitored using light traps, molasses-baited traps, and dry sorghum leaves. Larval behaviour varies considerably in the solitary and gregarious phases. In China and Japan migration is reported.

Forty-two parasites, 16 predators, and 12 pathogens have been reported from the field. Male and female pheromones have been analysed. *Mythimna separata* feeds on 33 plant species belonging to 8 families. Differential varietal susceptibility occurs in wheat, rice, maize, and sorghum. A large number of chemicals give effective control.

Introduction

The oriental armyworm, *Mythimna* (*Leucania*) (*Pseudaletia*) *separata* (Wlk.) is a serious cereal pest in Asia and Australia (Butani, 1955; Chao and Chen, 1947; Hamblyn, 1959; Common, 1965). It is also commonly known as the southern armyworm, Chinese armyworm, paddy armyworm, sorghum armyworm, army caterpillar, ear-cutting caterpillar, and paddy cutworm. Other closely related noctuids of economic importance in Asia, Australasia, Africa, and America include *M. unipuncta* (Haw), *M. loreyi* (Dup.), *M. pseudo-loreyi* (Rungs), *M. phaea* (Hmps.), *M. polyrabda* (Hmps.), *M. pinna* (Saalm), *M. convecta* (Wlk.), *M. venalba* (Moore), *M. albistigma* (Moore.), *M. yu* (Guen.), *M. aspersa* (Snell.), *M. curvula* (Wlk.), *M. compta* (Moore.)†, *M. insularis* (Butl.), *M. irregularis* (Wlk.), *M. roseilinea* (Wlk.), *Spodoptera exempta* (Wlk.), *S. litura* (F.), *S. frugiperda* (J. E. Smith) and *S. littoralis* (Boisd.) (Davidson and Peairs, 1966; Nair, 1975; Avidov and Harpaz, 1969; Grist and Lever, 1969; Carnegie and Dick, 1972; Khasimudin, 1978; ICRISAT, 1980). The reports published from India on *M. unipuncta* are now known to concern *M. separata* (Ramamani and Subba Rao, 1965). *M. separata* was considered to be a serious pest of rice and a minor pest of wheat by Fletcher (1917). Its first outbreak was observed on sugarcane during 1953 in Bihar (Butani, 1955). Since then, *M. separata* outbreaks and serious damage have been reported in rice, wheat, sorghum, and millets in Asia and Australasia.

Distribution and outbreaks

Distribution

The oriental armyworm is widely distributed in Asia and Australia between 45° N and 45° S latitude and 60° E to beyond 170° W longitude, which includes 27 countries or islands ranging from humid tropical to temperate regions (Table 1 and Figure 1). It is recorded in Afghanistan, USSR, China, and Japan in the north, Western Australia and New Zealand in the south, and from Pakistan in the west to Western Samoa in the east. Although there are no reports of its occurrence from Malaysia, Timur, Tasmania, and other islands lying between the aforesaid limits, it is likely to be present in all the countries/islands of this region. It is probably present all over India (Figure 2). However, it has not yet been reported from Gujarat, Sikkim, Pondicherry, Goa, and islands in the Arabian Sea and the Bay of Bengal.

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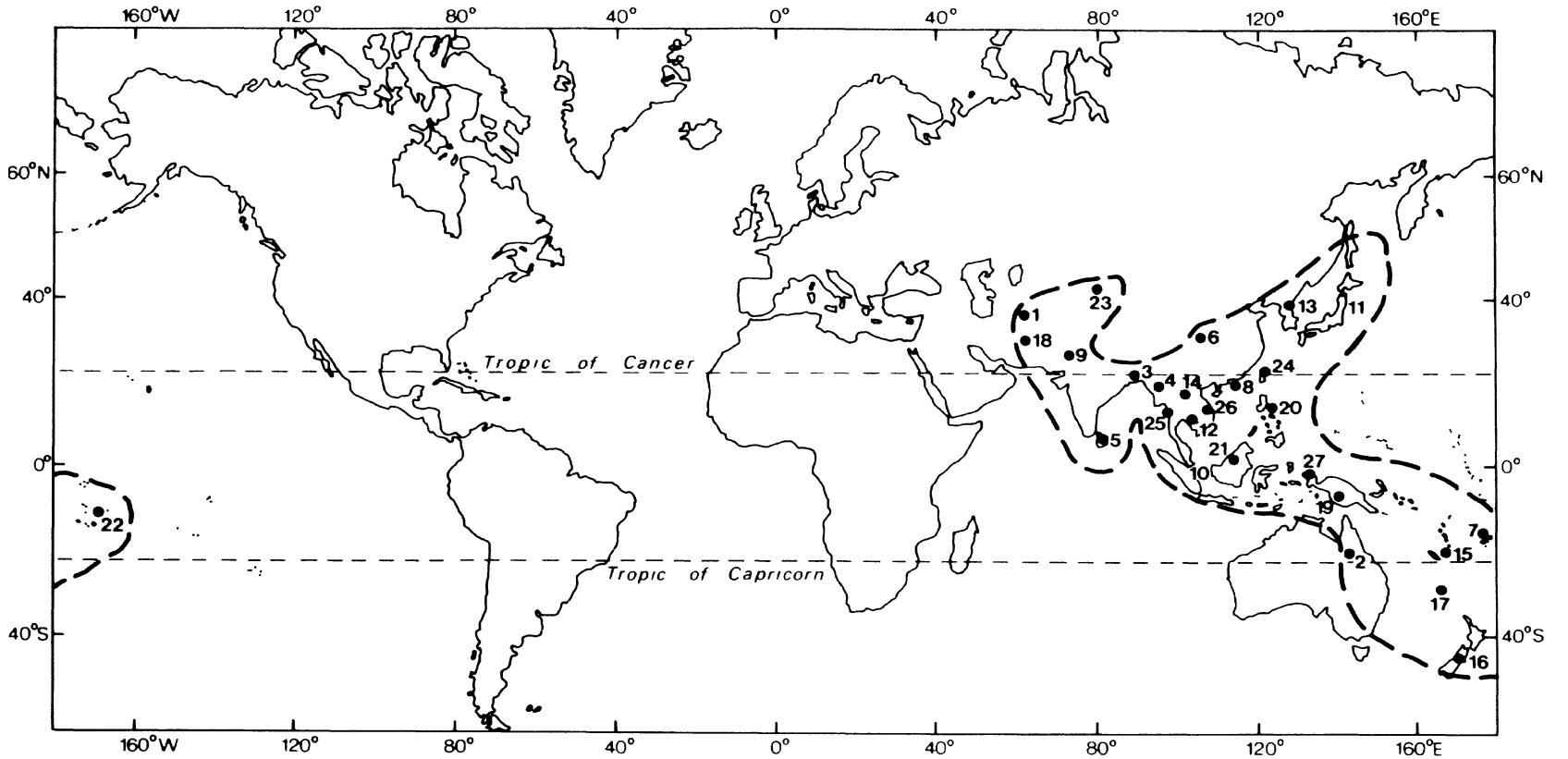
† Now *Viettenia compta* (Moore)



1 Afghanistan
2 Australia
3 Bangaladesh
4 Burma
5 Ceylon
6 China
7 Fiji
8 Hong Kong
9 India
10 Indonesia
11 Japan
12 Kampuchea
13 Korea
14 Laos
15 New Caledonia
16 New Zealand
17 Norfolk Islands
18 Pakistan
19 Papua and New Guinea
22 Philippines
21 Sabah (North Borneo)
22 Samoa (Western)
23 USSR
24 Taiwan
25 Thailand
26 Vietnam
27 West Irian

Fig 1 Distribution of *Mythimna separata* (Wlk.)

Table 1. Geographical distribution of the oriental armyworm, *M separata* Wlk

Country/Territory/Island	Reference
Afghanistan	Cotterell (1954) Anon (1967) Grist and Lever (1969)
Australia	Smith and Caldwell (1947) Common (1965) Anon (1967) Hitchock (1969 and 1974) Broadley (1979a and b) Learmonth (1980)
Bangladesh	Alam (1960, 1962, 1965 and 1967) Khan (1967) Anon (1967) Dean (1979)
Burma	Anon (1967)
China	Chao and Chen (1947) Chu *et al* (1961) Lin *et al* (1963) Lin and Chang (1964) Anon (1967) Anon (1967c) Kao 1976) Anon (1977a) Ma (1979) Yinchang (1980)
Fiji	Hinckley (1963) Anon (1967) Anon (1969) Lever (1969) Anon (1970)
Hong Kong	Anon (1967)
India Andhra Pradesh, Assam, Bihar Delhi, Haryana, Himachal, Jammu and Kashmir, Karnataka Kerala, Maharashtra, Madhya Pradesh, Manipur Orissa Punjab Rajasthan Tamil Nadu, Uttar Pradesh and West Bengal	Lefroy (1909) Fletcher (1914 and 1917) Ghosh (1924) Ramachandra Rao (1924) Hussain (1935) Narayanan (1953) Butani (1955) Puttardriah and Usman (1957) Kadam and Patel (1960) Kushwaha *et al* (1964) Ayyar (1963) Avasthy and Chaudhary (1965) Singh and Sinha (1965) Kushwaha and Jain (1966) Anon (1967) Bindra (1968) Saxena and Rawat (1968) Reddy (1968) Srivastava and Srivastava (1969) Katiyar and Patel (1969b and c) Pradhan (1971) Neelqund and Mathad (1972a and b) Khan *et al* (1972) Bindra and Singh (1973) Rai (1973) Kulkarni *et al* (1974) Pawar (1976) Bhatnagar and Davies (1976 1978, and 1979a and b) Singh and Rai (1977) Gopinadhan and Kushwaha (1978) Anon (1980) Chaudhary and Singh (1980) Kushwaha *et al* (1980) Krishnaswamy (1981) Singh and Manchanda (1981)
Indonesia	Mokrotovarov (1965) Anon (1967)
Japan	Iwao (1956 1958a and b 1959a and b 1962, 1963 1967a and b) Anon (1967) Gureva and Kryzhanovskii (1968) Kanda and Naito (1977, 1978, and 1979)
Kampuchea	Anon (1967)
Korea	Anon (1967) Lee *et al* (1970)
Laos	Dean (1978)
New Caledonia	Anon (1967) and (1978)
New Zealand	Hamblyn (1959) Anon (1967) Flower and Helson (1974) Valentine (1975)
Norfolk Islands	Anon (1967) and Holloway (1977)
Pakistan	Anon (1967) and Baloch (1978)
Papua and New Guinea	Anon (1967) and Barrett (1967)
Philippines	Anon (1967) Cadapan and Sanchez (1972)
Sabah (North Borneo)	Anon (1967)
Samoa (Western)	Anon (1967)
Sri Lanka	Anon (1967)
USSR	Klyuchko (1964) Anon (1967) Grist and Lever (1969)
Taiwan	Tu and Lin (1966) Anon (1967)
Thailand	Anon (1973 and 1974)
Vietnam	Anon (1962 and 1967)
West Irian	Anon (1967)

Outbreaks

Serious outbreaks of oriental armyworm had been reported in India (Ghosh, 1924 Butani, 1955, Tirumala Rao, 1956, Puttarudriah and Usman, 1957 Singh and Sinha 1965 Chaudhary and Ramzan, 1967, Sarup *et al* , 1969, Kalode *et al* , 1971 Verma and Khurana, 1971, Katiyar *et al* , 1972 Khan *et al* , 1972, Bindra and Singh 1973, Butter *et al* , 1979, Chaudhary and Singh, 1980, Patel, 1980, Singh and Manchanda, 1981) Japan (Nagano *et al* , 1971, Oku and Kobayashi, 1974 and 1977), China (Chao and Chen, 1947, Lin, 1963, Chen *et al* , 1965, Chin *et al* , 1965, Li *et al* , 1963 and 1965, Chin, 1979), Australia (Smith and Caldwell, 1947 and 1948, Common, 1965, Broadley, 1979a and b), and New Zealand (Hamblyn, 1959) It has also been reported in serious numbers from Bangladesh (Alam, 1960 and 1965, Khan, 1967 Dean 1979), Fiji (Anon , 1969, Lever 1969), and Thailand (Anon , 1973 and 1974)

Factors resulting in outbreaks

The arrival of migrant populations is one important factor leading to outbreaks, they create an imbalance between natural enemies and host populations, as well as bringing more individuals into a region

Various causes of armyworm outbreaks have been suggested In India, heavy rainfall followed by drought (Ghosh, 1924), flooding (Butani, 1955, Puttarudriah and Usman, 1957), and trash mulching of fields have been

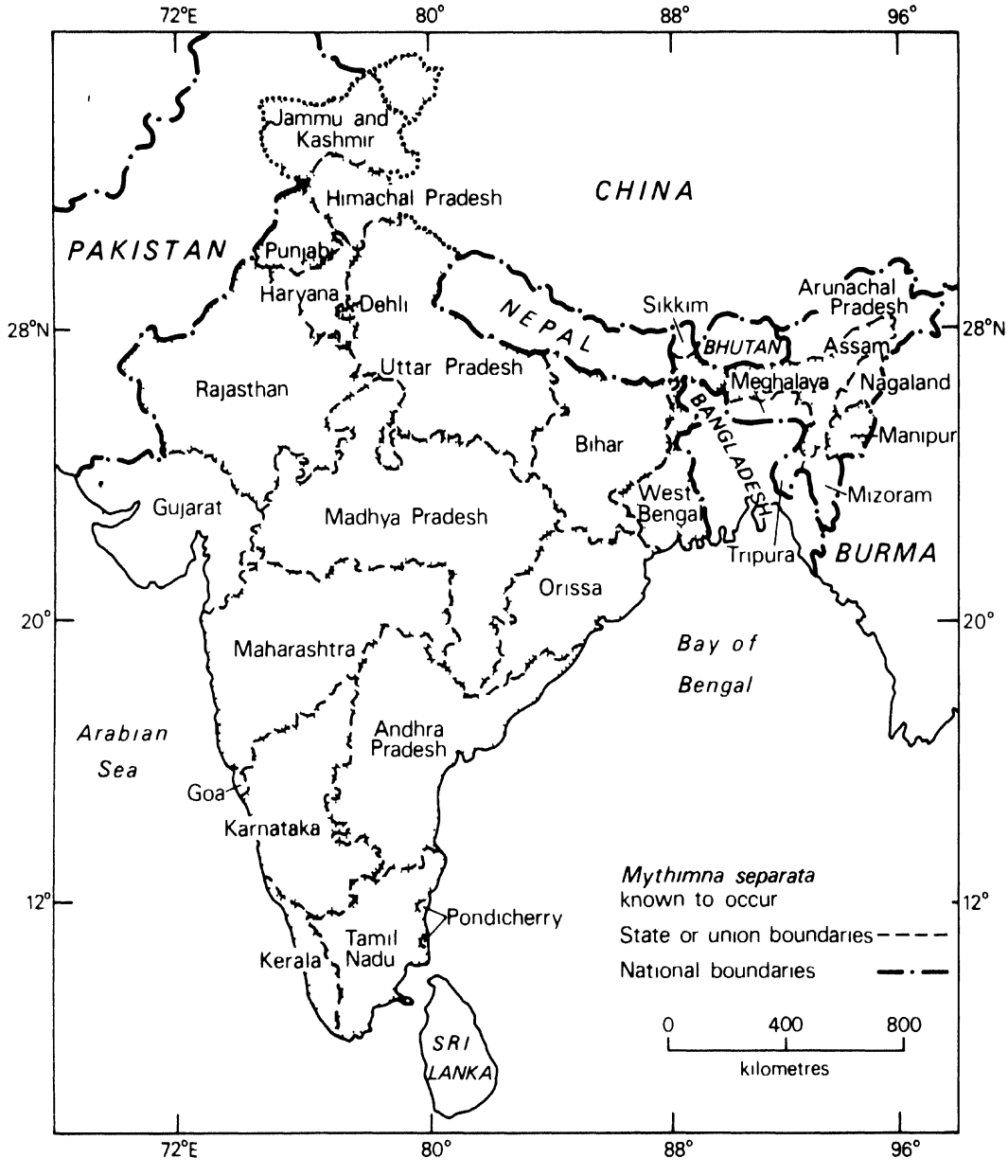


Fig 2 Distribution of *Mythimna separata* (Wlk) in India

suggested as contributory factors In China, the temperature in December affects the size and time of occurence of the infestations Dry weather during January–April and high humidity during July–August often results in serious outbreaks of subsequent generations (Anon , 1976c) The population size is influenced by relative humidity (r h) and rainfall (Chin, 1979) In Vietnam outbreaks coincide with heavy monsoon rains and floods In Bangladesh the outbreaks have been preceded by drought, while in Fiji heavy rains lead to outbreaks (Grist and Lever, 1969) It has been suggested that heavy manuring favours armyworm outbreaks in Japan (Koyama, 1966) In monsoon regions, the dry spells possibly restrict the larval parasites and pathogens The higher humidity and temperature there result in widespread oviposition and quick development

Crop losses

Crop loss estimates are not available from most of the countries listed in Table 1 However, heavy losses have been experienced in India, Bangladesh, China, Japan, Australia, and New Zealand In outbreak situations there may be heavy to complete loss of the crop over extensive areas The yield losses are influenced largely by the stage at which damage occurs and the gregarious behaviour of the larvae During 1956–57 the armyworm damaged over 48000 hectares of pasture in New Zealand (Hamblyn, 1959) Alam (1965) reported 100% damage on rice in Bangladesh During 1955 armyworm damage occurred on 22000 hectares of rice with a loss of over 40000 tonnes (Alam, 1960) Up to 36 6% sorghum heads were reported to be infested in Thailand during 1973 (Anon , 1973) Balasubramanian *et al* (1975) reported 47–53% infestation in finger millet and Singh and Manchanda (1981) reported 35–82 larvae/m² in rye Yield losses of 1641 kg/ha have been reported in paddy (Katiyar and Patel, 1969b) and 10–30% in wheat (Chaudhary and Singh, 1980) On different paddy cultivars grain losses have been observed to vary from 200 to 500 kg/ha, i e 3 6 to 22 0% of the total yield (Pophali *et al* , 1980) Alam *et al* (1980a) reported detailed studies on the population/damage levels and yield loss relationships in paddy They concluded that 15 larvae/hill at boot and panicle stages reduced the yield by 37 98 and 92 92% respectively With an increase of 1 larva/hill the yield decreased by 1 22 and 0 88 g/hill at the boot and panicle stages respectively With an increase of 1% in leaf area consumed the yield decreased by 0 07 and 0 88 g/hill at boot and panicle stages respectively

Biology and seasonal activity

Biology

The females lay 500–900 eggs, with a recorded maximum of 1943 (Hamblyn, 1959 Hsia *et al* , 1963) The egg stage lasts for 2–7 days (Avasthy and Chaudhary, 1965) Larval development is completed in 14–22 days (Puttarudriah and Usman, 1957, Avasthy and Chaudhary, 1965, Cadapan and Sanchez, 1972, Singh and Rai, 1977) The pupal period lasts for 8–9 days (Avasthy and Chaudhary, 1965, Singh and Rai 1977) Total development take 26–38 days (Avasthy and Chaudhary, 1965, Cadapan and Sanchez, 1972 Singh and Rai, 1977) Adults emerge at 20 00–23 00 h (Anon , 1976b) and survive for 4–5 days (Avasthy and Chaudhary, 1965) Mating takes place on the third and oviposition on fourth day after emergence (Kanda and Naito, 1979) To be able to pair, some adults need to feed on sugar while others do so without any feeding (Miyahara, 1978) Studies of the pest's nutrition have been conducted by Chin (1964), Chin *et al* (1964) and Quo and Liu (1964), and on histochemistry of spermatophore by Mu and Sun (1980)

The insect's development is influenced by temperature, humidity, and host plants (Li *et al* , 1963, Wu *et al* , 1964, Chin *et al* , 1964 and 1965, Sinchaisri and Sogawa, 1969, Hirai, 1975, Dhaliwal and Bains, 1978, Alam and Khatri, 1980) The lower threshold temperatures for development of eggs, larvae, and pupae have been found to be 10 2–10 4, 7 4–7 6, and 9 9–10 1°C respectively (Sinchaisri and Sogawa, 1969, and Wu *et al* , 1964) Chin *et al* , (1964) found that at 32 C, egg hatching decreased at 20% r h , for proper development 100% r h was optimum Th larvae did not survive at r h $< 60\%$ The rate of survival of the first instar larvae was influenced by the r h during egg stage At temperatures between 25 and 32 C, 90% of the eggs hatched at r h 22% None of the eggs hatched at 32–33 C (Chen *et al* , 1965) Survival of pupae and prepupae increased with r h (Chin *et al* , 1965) Fully grown larvae prefer high humidity (Bindra and Singh, 1973) The survival rate is higher on highly manured crops (Koyama 1966) Tanaka (1976) and Patel (1979a) studied the feeding rhythm of the larvae, feeding normally occurs during the night, the larvae hide in cracks during the day Hamblyn (1959) observed that during an outbreak the larvae remained on sunny slopes during the day time and fed mainly at night Patel (1980) observed some unusual behaviour on a warm, dry, and sunny day The larvae (third to fifth instar) marched towards walls and shady places inside the house at 14 00 h, some congregated on the mouth of earthen pots filled with water, at 19 00 h they moved back to the original fields

Adult populations can be monitored with light traps (Spitzer, 1970, Persson, 1977) or molasses baited traps (Koyama, 1968) The rate of oviposition can be determined by using dry leaves of sorghum for oviposition (Tanaka *et al* , 1971) Spitzer (1970) observed moth activity during winters in New Zealand and concluded that there is no winter diapause in the life cycle of this insect The larvae are present in the field throughout the year (Bindra and Singh, 1973, and Anon , 1974) Atwal (1976) reported that the larval period may be prolonged to 88–100 days in Punjab during winter

The armyworm has been reared on an artificial diet by Sato (1965), Hirai (1976), Kojima and Nakayama (1979), Hattori and Atsusawa (1980), and on haycubes of *Dactylis glomerata* by Kanda and Naito (1977)

Phase variation

Phase variation is an important characteristic of armyworm larvae Larvae reared under crowded conditions become darker than those reared in isolation (Iwao, 1956, 1958a and b, 1962, 1967a and b) The factor responsible for the darkening may result from the mutual stimulation of larvae (Iwao, 1962) The black pigment (indolemelanin) is produced in the integument when larvae are reared in crowded conditions Transection of the oesophageal connectives 21 h before the fifth moult led to the development of pale larvae (from larvae reared in crowded conditions) (Ikemoto, 1971b) Larvae reared under crowded conditions assume darker colouration independent of temperature, or r h Such larvae eat more food and develop more rapidly, giving rise to smaller pupae compared with those reared in isolation The darkening is induced by a limited food supply and reduced by subsequent isolation Crowded larvae are more tolerant of an unfavourable food supply and are more irritable (Iwao, 1956, 1958a and b, 1959a and b, and 1962) Crowding does not affect oviposition, fecundity, or adult colouration but adult longevity is extended The moths emerging from crowded larvae have a lower water content (Iwao, 1959b) The larvae of *M loreyi* develop at a slower rate under crowded conditions and do not become very dark and the adults from crowded cultures are short lived (Iwao, 1962) The black larvae of *M separata* are more responsive in an illuminated field (Iwao, 1963) The respiratory rate of the black larvae is higher than that of the pale larvae (Shibazaki and Ito, 1969) and black larvae withstand starvation much longer because they have a higher fat content than pale larvae (Iwao, 1967b) The pale larvae have more uric acid in the integument and less in the haemolymph than the black larvae immediately after moulting to the sixth instar (Ikemoto, 1973) At the time of pupation, the phenoloxidase activity becomes higher in black larvae than the pale larvae (Ikemoto, 1972) Ikemoto (1965) found that population density affects catalase activity

Pigmentation of the larvae is controlled by a hormonal factor (Ogura 1975a) originating from the brain and sub oesophageal ganglion (Ogura, *et al* , 1971, Ogura, 1976) Some stimulation is transmitted posteriorly through the oesophageal connectives to promote the release of a hormone or hormones from the sub oesophageal ganglion causing melanization (Ogura *et al* , 1971) Sub oesophageal ganglia cultured *in vitro* for 10 days continued to secrete a melanization and reddish colouration hormone (Ogura and Mitsuhoshi 1978) Implantation of sub oesophageal ganglia of *Bombyx mori* L pupae into isolated abdomens of armyworm larvae induced cuticular melanization Ganglia of pupae destined to lay diapause eggs produce more intensive melanization (Ogura and Saito, 1973) However, larval oesophageal ganglia, brain, and 1st thoracic ganglia of *B mori* do not induce melanization A ligature behind the thorax of crowded or isolated larvae causes black or reddish brown pigmentation in the anterior part after larval ecdysis Extirpation of brain, corpus allatum, or sub oesophageal ganglion reduce the degree of melanization in crowded larvae (Ogura, 1975b), while their implantation results in black pigmentation Thoracic and abdominal ganglia implantation induce light colouration (Ogura and Saito, 1972)

The injection of adenosine monophosphate (AMP) dibutyl, cyclic AMP, cyclic guanosine monophosphate (GMP), or dibutyl cyclic GMP into isolated abdomens of fifth instar larvae cause darkening of body color Injection of melanization and reddish brown coloration hormone (MRCH), together with theophylline, causes more intense melanization than MRCH alone Cyclic AMP may play a major role as an intercellular messenger of MRCH (Matsumoto *et al* , 1979) Integuments cultured *in vivo* show melanization when host animals moult into the final instar Cultured integuments are responsible for the MRCH secreted from the co cultured sub oesophageal ganglia (Ogura and Mitsuhoshi, 1979) Ikemoto (1971a) studied the non protein folin positive components in haemolymph in relation to melanin synthesis and Liu and Feng (1965) studied the blood sugar metabolism

Migration

Extensive studies carried out in China and Japan suggest that moths of this armyworm migrate, in China most research was devoted to this aspect during the period 1961–65 (Ma, 1979) Moths move to a more suitable habitat from unfavourable environments, and it has been concluded that the larvae do not undergo diapause The nuptial flight has been suggested as the initial cause of migration (Quo *et al* , 1963) Hwang and How (1966) suggested that the period before sexual maturity is the optimum time for long distance migration Lin (Chang Shan) (1963) sugges ted that the moths follow ascending, trans, and descending movements in China Lin and Chang (1964) proposed a model of the regularities of outbreaks and long distance seasonal migration Such movements have been attributed to cyclonic centres, cold front areas, and thunderstorms Li *et al* (1963 and 1965) considered that moths from South China are a source of early spring populations The date of first appearance of moths coincides with southerly winds with a > 70% coincidence (Lin *et al* , 1963) Increases in the number of moths occur on the same day at all locations (Lin *et al* , 1963 Koyama 1970) Outbreaks begin in the south and then appear in the central and north eastern regions (Chen *et al* , 1965), return migration occurs in summer or autumn Adults migrate to Chaoyang in

May and in the opposite direction in October (Anon., 1976c). Migrant moths have also been intercepted on ships voyaging between the Gulf of Chili and the Yellow Sea (Hsia *et al.*, 1963) and 500 km away from the mainland of Japan during 1968 (Asahina, 1968). Captures of moths with dyes have indicated that moths can fly 600–1400 km (Grist and Lever, 1969).

In Japan outbreaks have been attributed to migrating moths carried by south-easterly winds (Oku and Kobayashi, 1974 and 1978; Oku and Koyama, 1976). Oku and Kobayashi (1977) suggested the possibility of armyworm migration from China. Adults may migrate eastwards with the air currents (Oku and Kobayashi, 1977). Nagano *et al.* (1972) reported a method of forecasting outbreaks in Japan. In Fiji, all but three of the eleven outbreaks over the period 1939–65 occurred during the February–March period when rainfall exceeded 8 75 mm (Lever, 1969). There are no reports on the pest's possible migration in India, Australia, New Zealand, and other countries.

Natural enemies

A number of natural enemies have been recorded attacking the larvae and pupae (Table 2). In nature, up to 89% parasitism of the larvae has been reported (Katiyar and Gargav, 1971, Cadapan and Sanchez, 1972). *Apanteles ruficrus* (Hal.) is the most important parasite and it has been found to parasitise up to 50% of larvae in China (Anon. 1976c) and up to 86.7% in India (Butter, 1978). *A. ruficrus* has been successfully used in biological control in New Zealand (Simmonds, 1976; Simmonds and Bennet, 1977). Katiyar and Gargav (1971) reported up to 32% pupal parasitism.

Nuclear polyhedrosis virus (NPV) has been reported to cause extensive mortality of the larvae in nature (Neelgund and Mathad, 1972b, Tsai, 1965, Battu *et al.*, 1977). The NPV from this armyworm does not infect the silkworm, *Anthereae mylitta* (Dru) (Dhaduti and Mathad, 1979), and Indian honey bee *Apis cerana indica* F. (Dhaduti and Mathad, 1980) The gastric juices of albino rats inactivate the NPV (Kumar and Mathad, 1979).

Pheromones

The males of *M separata* have a scent brush on the first abdominal sternite, females have sacklike membranes between abdominal segments VII and VIII (Quo *et al.*, 1963). In males, the major male scent component is benzaldehyde, which functions as an arrestant (Clearwater, 1972). Hirai (1977 and 1980a and b) found benzyl alcohol in large amounts in male scents He also reported the presence of benzaldehyde, benzoic acid, and butyl alcohol. Benzyl and phenylether have been reported as the storage materials which release the aromatic pheromone (almond odour) upon hydrolysis (Clearwater, 1975). The metabolism probably occurs in two types of vesicles (Clearwater and Sarafis, 1973). Hirai (1980b) could not detect any chemicals from the hairs on male genitalia. Males stimulated by the presence of females produced smaller amounts of benzaldehyde and larger amounts of benzyl alcohol than the virgin males. During courtship, only benzaldehyde was detected in the air. In females, (Z)-11-hexadecanol and (Z) 11-hexadecenyl acetate have been isolated from the abdominal tip. These components in 9:1 and 1:1 ratios have shown phermonal activity in the laboratory (Takahashi *et al.*, 1979; Sato *et al.*, 1980). Sato *et al.* (1980) obtained high catches of males in a greenhouse with a mixture of acetate and alcohol components in 9·1 or 4.1 ratios with amounts in the range of 0.1 to 1.0 mg. The attractiveness of the mixture was equal to ten females.

Host range and host plant resistance

Host range

The oriental armyworm is a pest of Gramineae, it has also been reported to feed on plants belonging to such diverse botanical groups as rape, sugarbeet, hemp, nut grass, flax, and pea. It has been recorded feeding on 33 plant species and some unspecified graminaceous grasses (Table 3). The major hosts include important cereal crops; finger millet (*E. coracana*), barley (*H. vulgare*), rice (*O. sativa*), pearl millet (*P. americanum*), sorghum (*S. bicolor*), wheat (*T. aestivum*), and maize (*Z. mays*). Of the 33 reported host plants there are 1 Chenopodiaceae, 3 Cruciferae, 1 Cyperaceae, 23 Gramineae, 2 Leguminosae, 1 Linaceae, 1 Malvaceae, and 1 Solanaceae.

Table 2 Natural enemies of the oriental armyworm, *M separata* (Wlk)

Natural enemy	Reference
	1 Parasites
	Bethylidae Hymenoptera
Parasierola sp	Avasthy and Chaudhary (1963 1965 and 1966)
	Bombyliidae Diptera
Anthrax sp	Saxena (1965)
	Braconidae Hymenoptera
Apanteles flavipes (Cam)	Rao (1969)
Apanteles glomeratus (L)	Khan *et al* (1972)
Apanteles parbhani Rao	Rao (1969)
Apanteles ruficrus (Hal)	Khan (1946) Bhatnagar (1948) Rao (1953) Rao (1969) Katiyar and Rawat (1972) Mohyuddin and Shah (1977) Bindra and Singh (1973) Anon (1975 1976a and 1977b) Hill (1977) Cumber *et al* (1977) Butte (1978) Roberts (1979)
Apanteles sp	Chao and Chen (1947) Gopinadhan and Kushwaha (1978) Reddy and Davies (1979)
Disophrys sp	Katiyar and Rawat (1972)
Meteorus sp	Chao and Chen (1947)
Rogas (Rhogas) fuscomaculatus Ashm	Chao and Chen (1947)
Rogas sp	Katiyar and Rawat (1972) Bhatnagar and Davies (1979b)
	Chalcididae Hymenoptera
Brachymeria sp	Saxena (1965) Katiyar and Gargav (1971)
	Dermestidae Coleoptera
Anthrenus flavipes Lec	Kushwaha and Gopinadhan (1972) Gopinadhan and Kushwaha (1978)
	Encyrtidae Hymenoptera
Oencyrtus sp nr *major* Ferriere	Gopinadhan and Kushwaha (1978)
Eurytoma sp	Kushwaha and Gopinadhan (1972) Gopinadhan and Kushwaha (1978)
	Eulophidae Hymenoptera
Tetrastichus sp	Katiyar and Gargav (1971)
	Ichneumonidae Hymenoptera
Barichneumon solitarius Marl	Katiyar and Gargav (1971)
Cratichneumon sp	Rao *et al* (1969)
Enicospilus sp	Avasthy and Chaudhary (1965) Saxena (1965)
Itoplectis narangae Ahm	Rao *et al* (1976)
Meloboris leucania n sp	Kusigemati (1972)
Metopius rufus Cam	Bhatnagar and Davies (1979b)
Metopius pulchripes Cam	Katiyar and Gargav (1971)
	Mesostigmatidae Acarina
Dichrocheles sp	Davies (1969)
	Phoridae Diptera
Megaselia sp	Gopinadhan and Kushwaha (1978)
	Sarcophagidae Diptera
Sarcophaga orientoloides Senior White	Bindra and Singh (1973)
	Scelionidae Hymenoptera
Telenomus guangdongensis n sp	Wu *et al* (1979)
	Tachinidae Diptera
Actia monticola Mall	Cherian and Ananthanarayanan (1941)
Carcelia prima Baranov	Katiyar and Gargav (1971)
Compsilura sp	Broadley (1979b)
Conephalia (Pseudogonia) cinnerascens Rond	Avasthy and Chaudhary (1965)
Conephalia (Pseudogonia) rufifrons (Wied)	Katiyar and Gargav (1971)
Cuphocera varia (F)	Cherian and Ananthanarayanan (1941)
Cuphocera sp	Broadley (1979b)
Dolicholon paradoxum Brand & Berg	Avasthy and Chaudhary (1965)
Exorista fallax (Mg)	Khan *et al* (1972) Katiyar and Rawat (1972)
Goniophthalmus australis (Baranov)	Broadley (1979b)
Linnaemya vulpinoides Baranov	Avasthy and Chaudhary (1965)
Peribaea sp	Broadley (1979b)

Table 2–continued

Natural enemy	Reference
Pseudoperichaeta anomala (Villen)	Katiyar and Gargav (1971)
Sturmia ioconspicoides (Baranov)	Cherian and Ananthanarayanan (1941)
Thecocarcelia oculata (Baranov)	Katiyar and Gargav (1971)
	2 Predators
	(a) Birds
Acridotheres tristis L	Avasthy and Chaudhary (1956) Chaudhary and Singh (1980)
Acridotheres fuscus, L	Grist and Lever (1969)
Bubulcus ibis L	Avasthy and Chaudhary (1965) Chaudhary and Singh (1980)
Coracias benghalensis L	Chaudhary and Singh (1980)
Corvus splendens L	Bindra and Singh (1973)
Dicrurus macrocercus L	Chaudhary and Singh (1980)
Passer domesticus L	Bindra and Singh (1970) Tanaka (1975)
	(b) Insects
	Carabidae Coleoptera
Calosoma australis Hop	Smith and Caldwell (1948)
Carabus sp	Chao and Chen (1947)
	Formicidae Hymenoptera
Cataglypis bicolor (F)	Khan and Sharma (1972)
	Pentatomidae Hemiptera
Anedrallus spinidens F	Pawar (1976)
	Tenebrionidae Coleoptera
Tribolium sp	Katiyar and Patel (1969)
	Vespidae Hymenoptera
Polistes chinensis orientalis F	Hirose and Kakagi (1980)
Polistes judwigae D T	Hirose and Takagi (1980)
Polistes olivaceus (Deq)	Grist and Lever (1969)
	(c) Toads
Bufo sp	Avasthy and Chaudhary (1965)
	3 Pathogens
	(a) Bacteria
Bacillus thuringiensis	Alam (1967) Battu *et al* (1971) Bindra and Singh (1973) Shing *et al* (1979) Gopinadhan and Kushwaha (1978)
Bacillus cereus	Kushwaha and Gopinadhan (1972)
Serratia marcescens	Rangarajan *et al* (1968)
Streptococcus sp	Kushwaha and Gopinadhan (1972)
	(b) Fungi
Entomophthora sp	Cadapan and Sanchez (1972)
Metarrhizium anisopliae	Grist and Lever (1969)
Nomuraea rileyi	Broadley (1979b)
Spicaria tumosoroseus	Tseng sheng *et al* (1965)
Spicaria sp	Cadapan and Sanchez (1972)
	(c) Viruses
Virus disease	Alam (1962)
Nuclear polyhedrosis (NPV)	Neelgund and Mathad (1972b) Neelgund (1975) Manjunath and Mathad (1978 and 1979) Neelgund and Mathad (1978) Tsai (1965) Battu *et al* (1977)
NPV of *Heteronychus arator* (F)	Longworth and Archibald (1975)
NPV of *Prodenia litura* (F)	Hwang and Ding (1975)

Table 3. Host range of the oriental armyworm, *M. separata*

Common name	Scientific name	Reference
	Chenopodiaceae	
Sugarbeet	*Beta vulgaris*	Khan and Sharma (1971).
	Crucifereae	
Rape	*Brassica campestris*	Bindra and Singh (1973).
Chinese cabbage	*Brassica campestris* var. *capitata*	Grist and Lever (1969).
Turnip	*Brassica rapa*	Grist and Lever (1969).
	Cyperaceae	
Nutgrass	*Cyperus rotundus*	Kalode *et al.* (1971).
	Gramineae	
Oat	*Avena sativa*	Bindra and Singh (1973).
–	*Brachiaria muta*	Grist and Lever (1969).
Bermuda grass	*Cynodon dactylon*	Kalode *et al.* (1971); Bindra and Singh (1973).
Jungle rice	*Echinochloa colonum*	Gargav *et al.* (1972).
Japanese barnyard millet	*Echinochloa crusgalli*	Kalode *et al.* (1971).
Finger millet	*Eleusine coracana*	Rai (1973); Balasubramanian *et al.* (1975).
Goose grass	*Eleusine indica*	Kalode *et al.* (1971).
–	*Eriocaulon sexangulare*	Gargav *et al.* (1972).
Grasses		Nagano *et al.* (1972); Anon. (1978); Kanda and Naito (1978); Broadley (1979a).
Barley	*Hordeum vulgare*	Bindra and Singh (1973); Anon. (1976c).
Rice	*Oryza sativa*	Hinckley (1963); Wu (1963); Pschorn-Walcher (1964); Mokrotovarov (1965); Anon. (1969); Kulshreshtha *et al.* (1970); Chakrabarty *et al.* (1971); Kalode *et al.* (1971); Verma *et al.* (1971); Diwakar (1972 and 1975); Patel (1972); Anon. (1976d); Pawar (1976); Singh and Rai (1977); Dean (1978); Rawat and Singh (1979); Chu (1979); Gangrade *et al.* (1980).
Little millet	*Panicum miliare*	Grist and Lever (1969).
	Panicum proliferum	Kalode *et al.* (1971).
	Panicum scrobiculatum	Kalode *et al.* (1971).
	Panicum setigerum	Grist and Lever (1969).
Pearl millet	*Pennisetum americanum*	Kalode *et al.* (1971); Bindra and Singh (1973); Anon. (1976d).
Sugarcane	*Saccharum officinarum*	Butani (1955); Saxena (1965); Chaudhary and Ramzan (1967).
Rye	*Secale cereale*	Singh and Manchanda (1981).
Johnson grass	*Sorghum halepense*	Bindra and Singh (1973); Atwal (1976).
Sorghum	*Sorghum bicolor*	Kalode *et al.* (1971); Neelgund and Mathad (1972b); Anon. (1973); Doughton (1974); Bindra and Rathore (1965); Ironside (1979).
Foxtail millet	*Setaria italica*	Grist and Lever (1969).
–	*Setaria glauca*	Kalode *et al.* (1971).
Wheat	*Triticum aestivum*	Chu *et al.* (1961); Singh and Sinha (1965); Saxena and Rawat (1968); Bindra and Singh (1970); Bhattacharjee and Gupta (1971); Verma and Khurana (1971); Bindra and Singh (1973); Anon. (1976c); Chiang (1977).
Maize	*Zea mays*	Anon. (1962 and 1976d); Helson (1970); Rajagopal and Channa-Basavanna (1975 and 1977); Buxton (1976).
	Leguminosae	
Pea	*Pisum sativum*	Sharma *et al.* (1970).
Beans	–	Grist and Lever (1969).
	Linaceae	
Linseed	*Linum usitatissimum*	Tu and Lin (1966).
	Malvaceae	
Hemp	*Cannabis sativa*	Sinha *et al.* (1979).
	Solanaceae	
Tobacco	*Nicotiana tabacum*	Grist and Lever (1969).

Host plant resistance

As stated above, *M separata* is polyphagous, and crops such as sorghum, millets, rice, and maize are potential hosts (Kalode *et al* , 1971) It has been reported to prefer triple gene dwarf wheat varieties (Verma and Khurana, 1971) The larval population is influenced by plant characteristics such as plant height, number of tillers, and canopy Significantly lower numbers of larvae have been observed in the wheat genotypes UP–2002, Raj 1381, and WL–1533 (Butter *et al* , 1979) In rice the development is slower on seedlings than on older plants (Kalode *et al* , 1979) Lines R35–2750, R35–2752, R–2384, RP–9–4, RPW6–12, W–13400, RPW6–17, and Surekha have been reported to suffer < 10% yield loss compared with 22% in BKN–680–52 (Pophali *et al* , 1980) The differential susceptibility of maize genotpes has been observed in Thailand (Anon , 1973) In sorghum, Rangarajan *et al* (1974) reported genotypes R–16, R–24, 604, and CS–3541 to be less susceptible (< 16 3% damage) The hybrids were more susceptible than the varieties Kulkarni and Ramakrishna (1975) found that the genotypes line–141, E–303, NJ–1953, SB–803, 1–744, 296, 604, and E–302 manifested < 6% damage compared with 47 9% in Type 302 Hybrids 648 AX1075, SPH–4, 2077XCS 3541, and CSH–1 were also less susceptible in comparison with SPH–3 Lines SB–412, SB–803, SB–461, and CS 3541 have also been reported to be less susceptible (Kulkarni *et al* , 1978) The relative concentrations of cyanide in leaves do not affect the extent of armyworm damage (Woodhead *et al* , 1980)

Chemical control

In field trials a number of single insecticides and mixtures have been reported to control this insect They include BHC and aldrin (Butani, 1955), 1 1 or 1 2 dust mixture of DDT (5%) and BHC (0 5%) (Wei, 1959), dieldrin and DDT (Hamblyn, 1959), trichlorpon (2 5% dust) (Chang and Li, 1964), BHC and DDT dusts (Bindra and Rathore, 1965), BHC dusting (Saxena and Rawat, 1968) endrin (0 02%), phosphamidon (0 03%) and endosulfan (0 05%) (Purohit *et al* , 1971), chlorpyrifos (0 05%) (Kalode *et al* , 1972), ethyl parathion (0 05%) (Gargav and Katiyar, 1972), ultra low volume sprays of 96% malathion (0 85 litre/ha) (Singh and Mavi, 1972), trichlorphon, fenthion, and methyl parathion (Balasubramanian, 1973), trichlorphon, endosulfan, and DDT (Hitchock, 1974), leptophos (Mackay and O'Connor, 1976), BHC (10%) carbaryl (5%), and endosulfan (4%) dusts (Kishore and Jotwani, 1976), quinalphos and methyl parathion (0 5 kg/ha) (Patel *et al* , 1979) and carbaryl, BHC, and dichlorvos (Singh *et al* , 1980)

Methyl parathion, mevinphos, naled, EPN dichlorvos ethyl parathion, isodrin, phenthoate, trichlorphon, fenitrothion, diazinon, and azinphos ethyl have been found to be more toxic than DDT under laboratory conditions (Sarup *et al* , 1969) The addition of benzyl alcohol and cresol to gamma–BHC as a carrier have been found to increase the rate of penetration but not the final mortality of sixth instar larvae Urethane, iodo acetic acid, and acetophenone synergise the action of gamma–BHC Excitation of larvae with gamma BHC results in a rapid kill by DDT The greater resistance of sixth instar larvae to BHC has been attributed to a detoxification mechanism (Chang, 1964) Sinchaisri *et al* (1977) reported the LD_{50} values of four organophosphorus insecticides to fifth instar larvae Methyl parathion was the most toxic, however, phenthoate, which was least toxic, showed five times higher anti cholinesterase activity than methyl parathion Mixtures of *Bacillus thuringiensis* var *galleriae* and DDT did not produce appreciable effects on the larvae (Tsyan *et al* , 1963)

In China the antibiotic Blastidin has been found to be toxic when applied to the leaves of food plants (Anon , 1977a) Administration of catharidin produced pathological changes (Lu, 1964) Cartap (neurotoxin derived from marineworm, *Lubriconereis heteropoda*) is toxic to the larvae (Sakai *et al* , 1967) Cheng *et al* (1964) reported the effects of gamma BHC on haemolymph Treatment of adults with thiotepa (5%) reduced egg laying by half, and none of the eggs hatched, only a small percentage of eggs failed to hatch when treated males were mated with untreated females (Chang and Chiang, 1963) Triphenyl tinacetate has been reported as an antifeedant and is toxic to the larvae (Mathur and Saxena, 1972) Patel (1979b) studied the performance of sprayers and water volumes using fenitrothion at 1 kg ai/ha He found that a hand compression sprayer was significantly superior for the control of larvae (95%) than a mist blower (56%) Knapsack and foot sprayers also performed well The population reduction at low, medium, and high volumes was 83, 83 and 68% respectively

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