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The Oriental Armyworm, *Mythimna separata* Walker (Lepidoptera: Noctuidae): A Review

Abstract

The Oriental armyworm scientifically referred to as *Mythimna separata* poses a significant threat to cereal crops across East Asia, South Asia, and Australia, resulting in notable agricultural losses. Recent reports indicate its widespread presence in 21 Asian countries and its establishment in Europe (Russia) and Oceania (Australia, Cook Islands, Fiji, New Caledonia, Norfolk Island, New Zealand, Papua New Guinea, Samoa, Solomon Islands, Tonga, and Vanuatu). This pest targets a wide range of host plants spanning 18 families, with the majority belonging to Poaceae (44 species), Brassicaceae (10), Cucurbitaceae (9), and Fabaceae (8), exacerbating agricultural damages. The voracious feeding habits of *M. separata* larvae lead to significant crop damage and reduced yields across various crops. Its adaptability to diverse environments and broad host range further amplifies its impact on agriculture. The challenges in predicting and controlling outbreaks stem from its strong flight capabilities, high reproductive rates of females, and voracious feeding behavior during later larval stages. Traditionally, insecticide application has been the primary method for controlling *M. separata*. However, concerns regarding health risks, ecological disruptions, rising costs, diminishing efficacy of some products, and adverse effects on non-target organisms and human health highlight the need for environmentally sustainable pest management strategies. Biological control, involving the utilization of natural enemies such as insects, viruses, fungi, bacteria, nematodes, mites, and spiders, has emerged as a vital approach for managing insect pests while preserving ecological balance. Given the complex challenges posed by *M. separata*, implementing a holistic approach that integrates biological control methods holds promise for effective pest management. This approach aligns with principles of environmental sustainability and biodiversity conservation within agro-ecosystems.

Keywords: *Mythimna separate*, Host, Biology, Biological control, Management

Introduction

Mythimna separata Walker, known as the Oriental armyworm, belongs to the Noctuidae family in the Lepidoptera order and is a significant polyphagous insect pest, particularly in cereal crops (Ali *et al*., 2016). Its presence in cereal crops is characterized by unpredictable patterns. The pest is active at night, displays distinct brownish-grey forewings with intricate patterns and has been documented in 27 countries, territories, and islands across humid tropics to temperate regions (Sharma and Davies, 1983). It attacks various host plants, including vegetables, cereals, fruits, and ornamentals, causing extensive damage, such as the complete consumption of hectares of plants within a single day (Cadapan and Sanchez, 1972). Severe damage during outbreaks has been reported in rice, wheat, sorghum, and millet across several countries (Sharma and Davies, 1983; Jiang *et al*., 2011; Koyama and Matsumura, 2019). Recent reports highlight its status as a major migratory pest of cereal crops in East Asia, South Asia, and Australia, leading to significant agricultural losses. The challenge in predicting and preventing outbreaks is attributed to the strong flight capacity, high reproductive potential, and voracious feeding habits of older larval instars (Ali *et al*., 2016). Recent studies have identified host plants that sustain adult moths during long-distance migration. This species poses a threat to various crops, particularly rice, which serves as a primary host (CABI, 2022). Larvae of *M. separata* exhibit voracious feeding habits, causing characteristic windowpane-like patterns on rice leaves and extensive damage to maize and sorghum crops (Jiang *et al*., 2014). Current management methods heavily rely on insecticides, but their repeated use can lead to pesticide resistance and harm to beneficial organisms, including pollinators, birds, and fish (Whitehorn *et al*., 2012; Godfray *et al*., 2014). Moreover, pesticide use contributes to environmental pollution, biodiversity loss, and disruption of ecosystem services (Karuppuchamy & Venugopal, 2016; Tiwari *et al*., 2018; McLaughlin & Mineau, 1995; Robinson & Sutherland, 2002). The fourth and fifth larval instars are the most damaging stages, defoliating host crops (Neupane *et al*., 1992). Consequently, there is growing pressure from consumers, media, and governments to reduce pesticide use in agro-ecosystems. However, currently, there are no viable alternatives to manage *M. separata* effectively. Thus, there is a critical need to develop cost-effective, non-chemical, and sustainable pest management methods. Integrated pest management strategies, including biological control and combining multiple approaches, are crucial for sustainable and effective control of this agricultural pest.

Distribution

Mythimna separata, a notorious agricultural pest, is infamous for its voracious appetite and its capacity to cause extensive damage to crops. Its widespread distribution across Asia poses a significant threat to food security in numerous countries. In China, it recurrently devastates crops such as corn and rice, while in India, known for its diverse agricultural landscape; it wreaks havoc on maize, sorghum, and millet fields. The Oriental armyworm's habitat spans from Asia to Australia, covering more the 27 countries and islands with diverse climates, ranging from humid tropical to temperate regions, Sharma and Davis (1983), Records of *M. separata* presence date back to various sources across different regions. In Afghanistan, Grist and Lever (1969) noted its occurrence, while in Australia, Anonymous (1967) reported its presence. In the USSR, Grist and Lever (1969) documented its existence. In China, numerous studies, including those by Chao and Chen (1947), Ma (1979), and Yinchang (1980), have confirmed its presence. Bangladesh, Japan, and New Zealand have also recorded sightings, as documented by various researchers while there are no reported occurrences from certain areas like Malaysia, Timur, Tasmania, and other islands within the specified latitudinal and longitudinal limits, *M. separata* is likely present throughout India. Several researchers, including Sharma and Davis (1983), have documented its presence across various Indian states, including Andhra Pradesh, Assam, Bihar, Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Karnataka, Kerala, Maharashtra, Manipur, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal.

Host range

Mythimna separata, recognized for its adaptability and insatiable appetite, exhibits a preference for a broad spectrum of plants vital for human sustenance and economic activities. Among its favored hosts are maize, rice, sorghum, wheat, and various grasses. Under favorable conditions, the oriental armyworm can also infest cotton, soybeans, and diverse vegetable crops. The pest's ability to feed on such a diverse range of plants presents formidable challenges to farmers and agricultural systems, necessitating vigilant monitoring and the implementation of integrated pest management strategies to mitigate its adverse effects on crop yields. The degree of yield reduction depends greatly on when the damage occurs and how the larvae gather in groups. Periodically, infestations of this pest result in total crop failure. The widespread occurrence and resulting losses can be attributed to various factors including expanded irrigation, shifts in farming practices with the adoption of high-yield crop varieties, increased fertilizer usage, and continuous farming. Countries such as India, Bangladesh, China, Japan, Australia, and New Zealand have suffered significant crop losses due to this pest's impact (Sharma and Youm, 1999). It travels with wind currents, and its migratory patterns have been well-documented in China and Japan Koyama, (1970; Nagano *et al*., 1972; Oku and Koyama, 1976). In the northern regions of India, it has been observed feeding on grassy crops and causing considerable sporadic damage (1979; Chaudhary and Singh, 1980; Singh and Manchanda, 1981). The stage of the crop when *M. separata* infestation occurs greatly influences crop yield losses, sometimes resulting in complete loss (Sharma, Sullivan, & Bhatnagar, 2002).

Table1. Host range of the Oriental armyworm, *Mythimna separata*

S.No	Scientific name	English name	Reference
1	*Arachis hypogaea L.*	Peanut	Cadapan and Sanchez 1972
2	*Gossypium arboreum L.*	Cotton	Gabriel 1997
3	*Linum usitatissimum L.*	Linseed	Plant wise Knowledge Bank 2019
4	*Phaseolus vulgaris L.*	Beans	Kuramitsu *et al*., 2016; Plant wise Knowledge Bank 2019
5	*Vigna radiata (L.)*	Mungbean	Catindig et al. 1994
6	*Avena sativa*	Oat	Bindra and Singh (1973)
7	*Glycine max (L.)*	Soybean	Koyama and Matsumura 2019;Yooboon *et al*., 2020
8	*Beta vulgaris L.*	Sugarbeet	Plant wise Knowledge Bank 2019
9	*Brassica juncea (L.)*	Mustard	Deang 1969; Gabriel 1997
10	*Brassica napus L.*	Rape / Rapeseed	Koyama and Matsumura 2019; Yooboon *et al*., 2020
11	*Brassica oleracea var.*	Broccoli	Deang 1969

	italica Plenck		
12	*Brassica rapa L.*	Turnip	Plant wise Knowledge Bank 2019
13	*Cajanus cajan L.*	Pigeon pea	Plant wise Knowledge Bank 2019
14	*Brassica oleracea var. botrytis L.*	Cauliflower	Deang 1969; Gabriel 1997
15	*Brassica oleracea var. capitata L.*	Cabbage	Koyama and Matsumura 2019; Yooboon et al. 2020
16	*Cynodon dactylon*	Bermuda grass	Kalode *et al*., (1971) Bindra and Singh (1973)
17	*Cucumis sativus L.*	Cucumber	Deang 1969; Cadapan and Sanchez 1972; Gabriel 1997
18	*Cannabis sativa L.*	Hemp	Plant wise Knowledge Bank 2019
19	*Echinochloa crus-galli L.*	Barnyard grass	Catindig *et al*., 1994; Plant wise Knowledge Bank 2019
20	*Hordeum vulgare*	Barley	Bindra and Singh (1973); Kuramitsu *et al*., 2016.
21	*Lactuca sativa L.*	Lettuce	Deang 1969
22	*Ipomoea batatas L.*	Sweet potato	Gabriel 1997
23	*Oryza sativa*	Rice	Dean 11978); Rawat and Singh (1979); Gangradee*t al*., (1980)
24	*Paspalum scrobiculatum*	Kodo	Fletcher (1917); Tripathi *et al*.,(1982)
25	*Cicer arietinum*	Chickpea	Mahto and Singh (1985)
26	*Saccharum officinarum*	Sugarcane	Singh and Manchanda (1981); Cadapan and Sanchez 1972; Gabriel 1997;
27	*Sorghum bicolour*	Sorghum	Cadapan and Sanchez 1972;Gabriel 1997.
28	*Triticum aestivum*	Wheat	Zhao *et al*., 2018; Koyama and Matsumura 2019; Yooboon *et al*., 2020
29	*Pisum sativum*	Pea	Prasad *et al*., (1985); Plant wise Knowledge Bank 2019
30	*Oryza sativa*	Rice	Sharma and Davis (1983); Kuramitsu *et al*., 2016

31	*Zea mays*	Maize	Sharma and Davies 1983; Kuramitsu *et al*. 2016., Zhao *et al*.,(2018)
32	*Raphanus sativus L. var. longipinnatus*	Radish	Kuramitsu *et al*., (2016)
33	*Pennisetum purpureum Schumach*	Napier grass	Cadapan and Sanchez 1972; Sharma and Davies 1983; Plant wise Knowledge Bank 2019
34	*Panicum miliaceum L.*	Millet	Koyama and Matsumura 2019; Yooboon *et al*., 2020
35	*Nicotiana tabacum L.*	Tobacco	Plant wise Knowledge Bank 2019
36	*Solanum tuberosum L.*	Potato	Koyama and Matsumura 2019; Yooboon *et al*., 2020
37	*Setaria italica (L.)*	Rye	Plant wise Knowledge Bank 2019
38	*Solanum lycopersicum L.*	Tomato	Deang 1969; Cadapan and Sanchez 1972
39	*Pennisetum glaucum L.*	Pearl millet	Cadapan and Sanchez 1972; Plant wise Knowledge Bank 2019
40	*Solanum melongena L.*	Eggplant	Koyama and Matsumura 2019; Yooboon et al. 2020

Outbreaks of Oriental Armyworm, *Mythimna separata*

The sudden increase in *M. separata*, leads to extensive crop damage during outbreaks, fueled by favorable environmental conditions and ample host plants. These outbreaks pose significant threats to agricultural productivity as the larvae exhibit voracious feeding behavior. Effective monitoring and integrated pest management strategies are crucial for mitigation Historical instances of *M. separata* outbreaks have been recorded across diverse locations and time frames. For example, Andhra Pradesh experienced outbreaks in 1977, 1978, and 1981, while Dharwad; Karnataka faced an outbreak in 1980/1981. Additionally, outbreaks occurred in Kullu, Himachal Pradesh in 1983, and in Hissar, Haryana, India. Various factors contribute to these outbreaks, including drought following rainfall, floods due to heavy precipitation, population migration, intensified fertilizer usage promoting insect proliferation, trash mulching facilitating oviposition and larval concealment, and specific temperature and humidity conditions before and during the outbreaks These attributions are supported by studies conducted by (Sharma and Davies 1983; Thakur *et al*., 1987).

The surge in migrant populations stands as a significant catalyst for outbreak occurrences, disrupting the equilibrium between natural predators and host populations. In India, outbreaks correlate with climatic events like heavy rainfall followed by drought, flooding, and the adoption of trash mulching in fields (Puttarudrnah and Usman, 1957). In China, December temperatures crucially influence outbreak size and timing. Dry conditions from January to April, coupled with elevated humidity during July to August, often result in severe subsequent generations (Anon, 1976). Population dynamics in Vietnam are intricately linked to relative humidity (RH) and rainfall, with outbreaks aligning with intense monsoon rains and floods. Bangladesh experiences outbreaks following droughts, while Fiji witnesses heavy rains preceding infestations (Grist and Lever, 1969). Japan suggests that the application of substantial manure favors armyworm outbreaks (Koyama, 1966).In monsoon regions, dry periods may constrain larval parasites and pathogens, while increased humidity and temperature facilitate extensive oviposition and accelerated development. This delicate balance of climatic conditions contributes to the cyclical nature of *M. separata* outbreaks. Understanding these triggers is paramount for implementing proactive measures in integrated pest management. The complex interplay between climate, agricultural practices, and regional conditions underscores the necessity for tailored strategies to curb outbreaks and minimize the economic and agricultural repercussions associated with the *M. separata* Researchers and policymakers must continually refine their understanding of these factors to devise effective and sustainable approaches in safeguarding agricultural systems from the impacts of *M. separata* outbreaks.

Nature of damage

The recently hatched larvae of *M. separata*initially target younger host leaves, later adopting a nocturnal feeding pattern. Furthermore, during the fifth and sixth instar stages, the larvae gather in groups and migrate in search of food, causing significant and seemingly abrupt outbreaks on crops. The armyworm, *M. separata*, is identified as a versatile and occasional pest according to (Chatterjee and Chakravarthy 1974). Inflicting substantial harm across various crops. In India, reports indicate that *M. separata* larvae have been responsible for extensive damage to sorghum and other cereal crops through defoliation (Sharma and Davies, 1983). Gahukar and Jotwani (1980).Highlighted the voracious feeding habits of larvae within the central whorls, particularly during the night, as they migrate between plants and fields once their food source is depleted. Despande and Matkar (1983) emphasized severe damage caused by larvae in the central whorls of maize plants, affecting leaves and the apical portion of the plant. Mote (1984) observed a high incidence of larvae (2-3 larvae/plant), resulting in approximately 55.92 per cent of plants being damaged, with some fields experiencing complete defoliation in the sorghum fields of Satara district, Maharashtra. Srivastava (1985) documented the armyworm larvae voraciously consuming sorghum leaves and causing extensive damage during the night, with migrations occurring between fields when food was scarce. Meksongsee and Chawanapong (1985) reported heavy feeding by armyworms on sorghum plants, leading to a ragged appearance of the sorghum leaves.

Biology of *Mythimnaseparata* on different host plants

The moth species *M. separata* undergoes a comprehensive metamorphic life cycle, progressing through stages of egg, larva, pupa, and adult. The larvae of *M. separata* are highly voracious, causing significant harm to diverse crops such as rice, corn, and other grasses. A thorough understanding of *M. separate's* biology is essential for developing effective strategies to manage this pest, thereby reducing its impact on crop yields and preserving agricultural productivity. The pre-oviposition period ranged from 2 to 5 days, during which females laid approximately 996 eggs on average. These eggs had an incubation period of 4 to 5 days (Sharma *et al*., 2002). Hamblyn (1959) observed that female *M. separata* deposited their eggs in sunlit, rugged pastures where there was adequate protection for both eggs and larvae. Female moths lay around 500 to 900 eggs, with a maximum of 1943 recorded (Hamblyn, 1959; Hsia *et al*., 1963). The egg stage lasted between 2 to 7 days (Avasthy and Chaudhary, 1965). Feakin (1971) observed eggs being laid between the leaf sheath and stem of rice plants. Bindra and Singh (1973)researched the behavior of M. separata and found that females laid eggs in soil. Singh and Rai (1977) reported that female moths typically deposited eggs either in overlapping rows or occasionally singly or in clusters within narrow spaces such as leaf sheaths in rice fields in Varanasi, India. In laboratory conditions, eggs were laid on paper or glass surfacesMeksongsee and Chawanapong (1985) discovered that female *M. separata* lay their eggs in clusters within the plant's whorl during nighttime, while Giraddi and Kulkarni (1985) observed egg laying in rows within the leaf sheath of sorghum. Bhattacharjee and Gupta (1971) described the eggs as broadly oblong, measuring about 0.5 mm long and 0.4 mm wide. Initially, the eggs are snowy white, but they darken to greyish or black upon hatching. Bindra and Singh (1973) noted that fresh eggs were round and light brown, gradually transitioning to pale yellow and ultimately black. Singh and Rai (1977) reported that the eggs were spherical, uniformly light-colored, changing to pale yellow and then blackish before hatching, with an average diameter of 0.6 mm. Patel (1979) described the eggs of *M. separata* as creamy white and round. Kulshrestha *et al*., (1970) and Kalode (1977) found the incubation period to be 4-6 days on sorghum, while Bindra and Singh (1973) observed a range of 4 to 19 days. Singh and Rai (1977) reported an incubation period of 2 to 3 days on maize and wheat. Tripathi et al. (1982) documented an incubation period varying from 4 to 22 days across different months. Generally, *M. separata* larvae were observed to undergo six larval instars, as noted by various researchers (Alam, 1960; Singh and Rai, 1977; Giraddi and Kulkarni, 1985), although Srivastava (1985) observed seven instars on sorghum. Singh and Rai (1977) reported a larval period of 14.25 to 18.50 days for *M. separata* on sorghum, passing through six larval instars Giraddi and Kulkarni (1985) documented that the newly emerged larva displayed a petite, cylindrical form, exhibiting an energetic demeanor with a pale white hue and tender skin. Their findings revealed that the initial larval stage ranged from 3 to 4 days, averaging 3.70 days in the first generation, and 3 to 5 days, averaging 4.00 days in the second generation. Singh and Rai (1977) described the second instar larvae as having a green body adorned with light brown parallel stripes along the dorsolateral aspect, along with a light brown head. They reported the duration of the second instar larvae to be approximately 2.6 days in laboratory conditions and 4.0

days under field conditions. The length of the larva ranged from 2.54 to 3.23 mm, with an average of 3.0 mm according to Giraddi and Kulkarni (1985), while Singh and Rai (1977) reported a length of 9.5 mm for armyworm larvae. Giraddi and Kulkarni (1985) further noted a significant alteration in body coloration during this stage, accompanied by an increase in size compared to the first instar larva. Singh and Rai (1977) observed that the larvae displayed a light brown hue, marked by longitudinal parallel stripes on their dorsolateral sides, along with a similarly colored head. They also noted that the third instar larvae typically lasted around 3.4 days in laboratory settings and 4.4 days under field conditions. Giraddi and Kulkarni (1985) described the third instar larva as elongated, featuring brownish longitudinal bands on its dorsolateral body, along with a light brown head. Singh and Rai (1977) additionally documented that the fourth instar larvae lasted approximately 2.6 days on average in laboratory settings and 4.0 days in the field. Giraddi and Kulkarni (1985) observed variation in the coloration of the instar within individuals, ranging from light green to dark green, accompanied by whitish-yellow mid-dorsal stripes. They noted the larval head to be yellowish-brown to dark brown, exhibiting a honeycomb-like structure. The length of the fourth instar larvae ranged from 8.00 to 11.00 mm, averaging 9.6 mm. Bhattacharjee and Gupta (1971) described the general body color of the larva as dark greenish, featuring a white mid-dorsal line extending from the anterior part of the prothorax to the distal end of the anal shield, followed by a dark band extending from the base of the sub-dorsal setae to the ventral margin of the spiracles.Giraddi and Kulkarni (1985) documented that the larvae exhibited colors such as green, dark brown, or black, with a dark brown honeycomb-patterned head capsule. They observed longitudinal colored bands on the sides and whitish-yellow stripes along the mid-dorsal region. The length of these larvae ranged from 18 to 20 mm, averaging 18.8 mm. Katiyar and Patel (1969) described the fully grown larvae as greenish-brown with a honeycomb-patterned pale orange head marked by dark lines, measuring between 37 to 42 mm in length. Patel (1979) observed that sixth instar larvae appeared greenish-brown to dark brown, with an average length and breadth of 34.46 mm and 5.12 mm, respectively, on sorghum. Giraddi and Kulkarni (1985) also reported the length of fully grown larvae as ranging from 33 to 39 mm, with an average of 36 mm, and noted variations in color from light brown to dark brown or black, with a dark brown honeycomb-structured head capsule. These larvae exhibited distinct brown bands on their sides and whitish-yellow along with dark brown stripes dorsally, resulting in an overall dark brown appearance. The total larval period ranged from 14 to 22 days on sugarcane (Avasthy and Chaudhary, 1965).Bindra and Singh (1973) observed varying larval periods on maize and wheat, ranging from 13-14 days in March-April, 20-26 days in April-May, 18-21 days in June-July, and extending to 88-100 days in October. Singh and Rai (1977) found the total larval period of *M. separata* to be 16.6 days in laboratory conditions and 21.4 days in field conditions. Patel (1979) reported a total larval period of 16.68 ± 0.73 days on sorghum. Girradi and Kulkarni (1985) observed that the overall duration of the larval stage ranged from 21 to 27 days, averaging at 23.10 days for the first generation and 23.00 days for the second generation when reared on sorghum. Sisodiya (2001) investigated the life cycle on different host plants, noting that the larval period varied: 22.56 days on maize, 24.52 days on wheat, and 25.95 days on sorghum under laboratory conditions. The developmental time for each larval instar ranged from 1.8 to 3.9 days, with pre-pupal and pupal stages lasting 1–2 days and 8–12 days, respectively (Sharma *et al*., 2002) Tripathi *et al*., (1982) found the pre-pupal period to be 1.0 to 2.0 days at Pantnagar. Sisodiya (2001) examined the pre-pupal stage on different host plants, noting periods of 2.09, 1.95, and 2.00 days on wheat, sorghum, and maize, respectively, under laboratory conditions. Pupation was observed among various substrates including dry leaves, stubble, tillers, and leaf whorls of maize, with pupal coloration transitioning from dirty white to dark brown (Bindra and Singh, 1973). Pupal length and breadth were reported as 16.5 ± 2.0 mm and 4.0 to 0.5 mm, respectively, with a reddish-brown coloration (Singh and Rai, 1977). The pupal period varied across different host plants and conditions, ranging from 7 to 11 days on sugarcane, 9.2 to 11.2 days on paddy, and 8.6 to 9.8 days on rice (Avasthy and Chaudhary, 1965; Kalode *et al.,* 1972; Singh and Rai, 1977).Patel (1979) reported a pupal duration of 7 to 10 days, averaging 8.68 ± 0.48 days on sorghum. Giraddi and Kulkarni (1985) noted a pupal period ranging from 11 to 15 days, with an average of 12.60 days for the first generation and 12 to 15 days for the second generation on sorghum. Sisodiya (2001) recorded pupal durations of 9.15, 11.05, and 10.05 days on maize, wheat, and sorghum, respectively. Adult M. separata were described as pale brown (Bindra and Singh, 1973), with medium-sized bodies and pale brown forewings and translucent grey hind wings (Singh and Rai, 1977). Female moths measured approximately 40.00 mm, while males measured around 35.00 mm in length with expanded forewings. The head and thorax of the adult moth were reported to be dark brown, with brownish to ochraceous forewings bearing a distinct oblique dark streak (Patel, 1979). Giraddi and Kulkarni (1985) described the adult moth as light brown with a thorax covered in scales. Overall, the post-embryonic development of M. separata was completed within 29–39 days (Sharma *et al*., 2002).

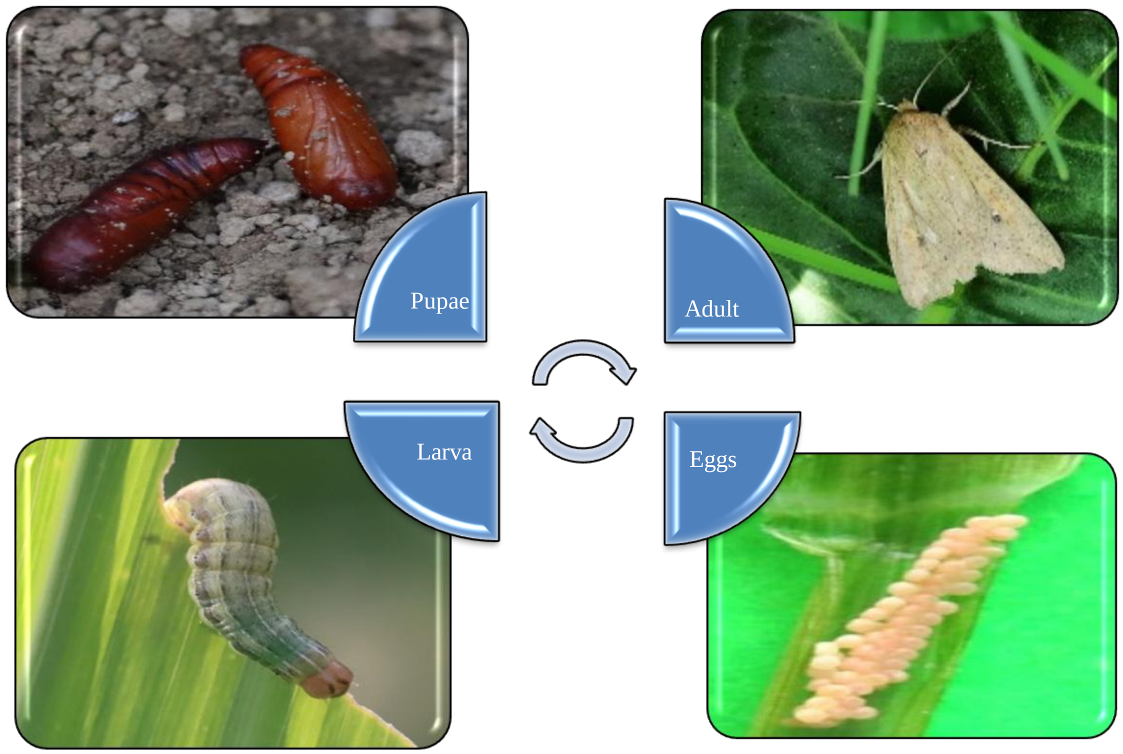

Fig.1 Life cycle of Oriental army worm *Mythimna separata*

Effect of climatic factors on different events of *Mythimna separata*

Several researchers have documented the impact of climatic factors on the reproduction, development, and survival of *M. separate*. In East Pakistan observed that the hatching period of eggs varied from 5 to 13 days which is influenced by prevailing temperatures and food availability. Larval coloration was mainly affected by temperature and food availability, with an extended period during winter and a shortened duration in warmer seasons. Chen *et al*., (1965) in China reported the potential impact of high temperatures on egg development. Iwao (1967) found that crowding influenced the coloration of *Leucania separata* larvae. In Japan, Sinchaisri and Tanaka *et al*., (1971) in Kyushu highlighted the oviposition ratio of *M. separata* in dried sorghum leaves. Bindra and Singh (1973)reported the year-round presence of *M. separata* larvae in the field, with variations in pre-oviposition, incubation, larval and pupal periods. The optimal temperature for survival and multiplication was identified as 20°C to 25°C. Metcalf and Flint (1973) mentioned the partially grown larval stage during winter. Berger (1984) in the USSR studied adaptations to seasonal rhythms, revealing threshold temperatures for each stage. Mulder and Showers (1986) in the mid-western USA observed reduced survival and feeding behavior at high temperatures. Smith (1986) in Australia reported peak fecundity and fertility at 20°C. Singh *et al*., (1987) noted temperature and humidity effects on reproductive biology, with January showing the longest oviposition period. Thakur *et al*., (1987) reported pupal wintering in the soil at Kullu, with larvae and adults absent during winter.

Biological control of Oriental Armyworm,*Mythimnaseparata*

The armyworm *Mythimnaseparata* (Lepidoptera; Noctuidae),Prevails in Asia, Australia, New Zealand, and the Pacific Islands and is widely distributed in India, moreover appears sporadically in epidemic proportions, during both the Kharif and Rabi seasons (Kalode*et al*., 1972). The use of pesticides has been the most common method for management of *M. separata*. Unfortunately, the pest has developed different resistance mechanisms to various pesticides families(Anderson *et al*., 2018) indiscriminate use of pesticides also lead to natural imbalance, environmental pollution and exorbitant monetary drain (Briggs, 1967; Burges and Hussey, 1971; Ignoffo, 1973). Such demerits of chemical insecticides necessitated the search for effective, safer, more specific, biodegradable, and less expensive agents to control insect pests. Total replacement of current pesticides from the market is impossible. Hence, there is a need for a holistic approach that integrates various biological agents, cultural practices, and conservation strategies. By adopting these measures, farmers can effectively manage armyworm populations, minimize crop damage, and reduce reliance on chemical pesticides. This sustainable approach not only safeguards agricultural yields but also preserves the ecosystem, ensuring a balanced and healthier agricultural environment for future harvests. The biological control of *M. separata*, involves a multifaceted approach encompassing various natural enemies, pathogens to manage its population and mitigate damage to crops. One of the key biological control strategies involves leveraging the natural predators and parasitoids of the oriental armyworm. Parasitic wasps and flies, such as species from the *Trichogramma*, *Cotesia*, and Tachinid families, play a pivotal role in the management of *M. separata*. These insects lay their eggs on the larvae of the armyworm, and upon hatching, the larvae feed on the host, ultimately leading to its demise. Additionally, predatory insects like ladybugs and lacewings actively consume armyworm eggs and young larvae, contributing to population control. Entomopathogenic fungi, nematodes and bacteria offer another effective avenue for biological control. *Beauveria bassiana*, a fungus, operates by infiltrating the armyworm's exoskeleton, causing infection and eventual mortality. *Bacillus thuringiensis* (Bt), a bacteria-based biopesticide, selectively targets specific insects like armyworms while posing minimal risk to other organisms, making it a valuable tool in biological control strategies. Because of the occurrence and abundance of entomopathogens in nature their high efficacy and specificity are considered to be the most likely alternative agents against the pests (Briggs, 1967; Burges and Hussey, 1971; Mathad, 1973). Entomopathogenic protozoans, fungi, bacteria, rickettsial, and viruses responsible for insect diseases constitute important natural factors in regulating pest population of *M. separata*(Steinhaus, 1954).Another effective alternative control strategy for this pest is use of Entomopathogenic nematodes. EPN members of the Steinernematidae and Heterorhabditidae family, are effective biological control agents *M. separata*and other agricultural pests(Karabörklü, Ayvaz, Yilmaz, Azizoglu, & Akbulut, 2015; Kepenekci, Hazir, & Özdem, 2015; Laznik, Tóth, Lakatos, Vidrih, & Trdan, 2010; Oreste, Baser, Ibouh, Verrastro, & Tarasco, 2017; Yuksel, Taskesen, Erarslan, & Canhilal, 2018).By leveraging the biological control agents, we can reduce reliance on chemical pesticides, thereby minimizing potential ecological harm and mitigating the risk of resistance development. The introduction of these natural enemies contributes to the overall resilience and balance of agroecosystems, fostering long-term pest management solutions. However, successful implementation requires a thorough understanding of the armyworm's biology and ecology, as well as continuous research to optimize the efficacy of biological control strategies. Integrating biological control measures into a comprehensive Integrated Pest Management (IPM) framework ensures a holistic and sustainable approach to managing Mythimna separata, promoting agricultural sustainability while preserving the health of the broader ecosystem

Table 2. Natural enemies of the *Mythimna separata*

Natural enemy	**Species**	**Reference**
Fungi	*Entomophthora* sp.	Cadapan and Sanchez (1972)
	Metarrhizum anisopllae	Gist and Lever (1969)
	Nomuraea rlleyi	Brodley (1979)
	Spicaria tumosorospus	Tseng shenn *et a1*., (1965)
	Spicana sp.	Cadapan and Sanchez (1972)
Bacteria	*Bacillus thuringiensis*	Sharma and Davis (1983).
	Bacillus cereus	Kushwaha and Gopinadhan (1972) Rangarajan *et a1*., (1968)
	Serratia marcescens	Kushwaha and Gopinadhan (1972)
Nematode	*Neoplectana* sp.	Sharma *et al*., (2002)
Virus	Nuclear polyhedrosis (NPV)	Tsai (1965) Battu *et a1*.,(1977) Sharma *et al*., (2022)
	NPV of *Prodenla latera* (F)	Hwang arid Ding (1975)
	Carabidae, Coleoptera	
	Calosoma australis Hop	Smith and Caldwell (1948)
	Carabus sp.	Chao and Chen (1947)
	Formicidae, Hymenoptera	
	Cataglypis bicolour	Khan and Sharma (1972)
	Pentatomidae, Hemiptera	
	Anedrallus spinidens F	Pawar (1976)
	Tenebrionidae, Coleoptera	
	Tribolium spp.	Katiyar and Patel (1969) Katiyar and Gargav (1971)

Insects	Vaspidae, Hymnoptera	
	Polistes chinensis orientalis	Hirose and Kakagi (1980)
	Polistes judwigae	Hirose and Kakagi (1980)
	Polistes olivaceus	Grist and Lever (1969)
	Trachiniae, Diptera	
	Brachymeria sp.	Tsung (1982)
	*Tetrastichus*sp.	Rizvi and Singh (1980) Tsung (1982)
	Exorista fallax	Lu and Lan (1986)
	Ichneumonidae, Hymnoptera	
	Diadegma sp.	Lu and Lan (1986)
	Amblyteles sp.	Rizvi and Singh (1980)
	Branchymeria lassue	Rizvi and Singh (1980)
	Braconidae, Hymenoptera	
	Braconoid rogas sp.	Lu and Lan (1986)
	Apanteles flavipes	Rao (1969)
	Apanteles glomeratrus	Khan (1946)
	Apanteles parbhanni	Rao (1969)
	Apanteles ruficrus	Tsung (1982); Sharma *et al*., (2002)
	Metopius rufus	Sharma *et al*., (2002)
	Desophyrus sp.	Sharma *et al*., (2002)
	Compoletis chlorideae Uchida	Sharma *et al*., (2002)
	Enicospilus sp.	Sharma *et al*., (2002)
	Dipteran parasitoids	
	Caecelia illota (Curran)	Sharma *et al*., (2002)
	Sturmiopsis inferens Townsend	Sharma *et al*., (2002)
	Palexorista solennis (Walker)	Sharma *et al*., (2002)
	Palexorista laxa (Curran)	Sharma *et al*., (2002)
	Megasellia sp.	Sharma *et al*., (2002)
	Acridotheres tristis L	Avasthy and Chaudhary (1965); Chaudhary and Singh (1980)
	Acridotheres fuscus, L	Grist and Lever (1969)

Birds		
	Bubulcus ibis L	Avasthy and Chaudhary (1965)
	Coracias benghalensis L	Bindra and Singh (1973) Chaudhary and Singh (1980)
	Corvus splendens L	Chaudhary and Singh (1980)
	Dicrurus macrocercus L	Bindra arid Singh (1970)
	Passer domesticus L	Tanaka (1975)

Conclusion

The oriental armyworm, *Mythimna separata*, is a notorious insect pest that poses a severe threat to agricultural crops, especially in the Asian continent. This nocturnal moth belongs to the family Noctuidae which causes widespread damage to a variety of crops in its larval stage. The life cycle of the oriental armyworm begins with the adult female moths laying eggs on host plants. The larvae, hatch from these eggs and undergo up to seven larval instars before reaching maturity. The pest has extensive host range, as it feeds on a variety of grasses and cereal crops.rice, maize, wheat, barley and millet are major host plants of this Pest. This widespectrum host range contributes to the pest's economic impact, causing heavy damage to crops and posing a constant threat for farmers. The complex life cycle of *M. separata*involves, femalemoths lay eggs on host plants and the emerging larvae go through several (up to seven) instars before their pupation in the soil. The larvae are damage causing stage of the pest, causing damage to crops during their feeding stage. The ability of the pest to migrate over long distances, aided by prevailing winds, adds to the challenges of managing and controlling its populations.

Management practices are employed to control *M. separata*.The approach constitutes various control methodstrategieslike chemical control, biological control, cultural practices. However, concerns regarding health risks, ecological disruptions, rising costs, diminishing efficacy of some products, and adverse effects on non-target organisms and human health highlight the need for environmentally sustainable pest management control. Biological control includes the use of Entomopathogens, natural enemies, such as parasitic and predators to keep *M. separata* populations in check. Sustainable and eco-friendly pest control methods are increasingly emphasized to strike a balance between protecting crops and maintaining a healthy ecosystem. In conclusion, controlling *M. separata* requires a comprehensive and integrated approach that considers the ecological balance of the farming system. By adopting sustainable practices and combining various control methods, farmers can mitigate the impact of *M. separata* infestations and safeguard their crops.

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