Chapter 1

Introductory Chapter: Moths

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http://dx.doi.org/10.5772/intechopen.79639

1. Moths

The moths (Insecta: Lepidoptera) are the group of organisms allied to butterflies, having two pairs of wide wings shielded with microscopic scales. They are usually brightly colored and held flat at sitting posture. The word moths are derived from Scandinavian word mott, for maggot, perhaps a reference to the caterpillars of moths. Furthermore, about 165,000 species of moths, including micro- and macro-moths are found worldwide, many of which are yet to be described (**Table 1**) [1–3].

Kingdom: Animalia
- **Subkingdom:** Invertebrata
  - **Super-Division:** Eumetazoa
    - **Division:** Bilateria
      - **Subdivision:** Ecdysozoa
        - **Superphylum:** Tactopoda
          - **Phylum:** Arthropoda Von Siebold, 1848
            - **Subphylum:** Atelocerata
              - **Superclass:** Hexapoda
                - **Class:** Insecta
                  - **Infraclass:** Neoptera
                    - **Subclass:** Pterygota
                      - **Superorder:** Endopterygota
                        - Unranked: Amphiesmenoptera

Unranked: Holometabola

Order: Lepidoptera Linnaeus, 1758

Examples:

- Micro-moths
- Macro-moths

Table 1. Taxonomic rank of moths [1].

1.1. History

Moths evolved long before butterflies, fossils have been found in Germany may be 200 million years old in the early Jurassic Period. Both types of lepidoptera (butterflies and moths), both adults and larvae are thought to have evolved along with flowering plants, mainly. In moths, the micro-lepidoptera tends to be more primitive in evolutionary terms than macro-lepidoptera [4]. Their fossils, some preserved in amber and some in very fine sediments. The earliest described lepidopteran taxon is *Archaeolepis mane*, a primitive moth-like species from the Jurassic, dated back to around 190 million years ago, and known only from three wings found in Dorset, Britain. The wings show scales with parallel grooves under a scanning electron microscope (SEM) and a characteristic wing venation pattern shared with caddis flies (Amphiesmenoptera: Trichoptera: ca. 14,500 described species) [5, 6].

1.2. Difference between moths with butterflies and skippers

Mostly, moths are dull-colored insects, with fat, hairy bodies, that fly at night, however, butterflies are brightly colored, delicate insects that fly during the day. Skippers are group of true butterflies but they are day flyers with fat fury bodies like moths [7]. In exception, many day-flying moths and a few butterflies and skippers fly in the early evening [8]. Moreover, a moth's antennae are long feathery (plumose). Further, butterflies have long thin antenna with clubbed tips. Furthermore, skippers have long thin antenna with clubs tapering to pointed hooks on the tip. In exception, several families of moths have antenna with clubs (Family: Castniidae), for example, the golden sun moth, *Synemon plana* Walker, 1854 [9]. However, moths fore- and hind-wings are held together with a structure called a frenulum. Moreover, butterflies and skippers wings are not joined. Further, in Australia with exceptions has only skipper in the world with a frenulum, for example, the regent skipper, *Euschemon rafflesia* (Macleay, 1827) (Family: Hesperiidae). It is only member of its genus, *Euschemon*, and Subfamily: Euschemoninae [10]. Moreover, many moths do not have a frenulum [11, 12]. Further, moths hold wings flat when resting. Furthermore, butterflies hold wings together above body. However, skippers' front-wings are held at a different angle to the back wings. In exception, many butterflies also rest with the wings flat [13]. Moreover, moth caterpillars spin a cocoon made of silk, around their body and pupate inside. Further, butterflies and skippers spin a pad of silk onto a stem or leaf then hang on the pad and form the pupae. In exception, many moths do not spin a cocoon and many butterflies and skippers spin a silken shelter attached with leaves (**Table 1** and **Figure 1**) [14].

Figure 1. Types of antenna: (a) butterfly antenna; (b) skipper antenna; (c) moth antenna [10].

1.3. Navigation

Moths are navigated for their movement especially for migration. As one study of the moth heart and barbs showed that many moths may use the earth's magnetic field to navigate. The migratory behavior of the silver-Y, *Autographa gamma* (Linnaeus, 1758) (Family: Noctuidae) showed that even at high altitudes, the species can correct their direction, if their direction may change by winds. However, they to prefer fly with the direction of wind. If the wind is favorable to their direction, then it is easy for them to navigate during flying. Moths exhibit a tendency to circle artificial lights repeatedly. This suggests that they use a technique of celestial navigation called transverse orientation. By maintaining a constant angular relationship to a bright celestial light, such as the moon light, they can fly in a straight line. Celestial objects are so far away, even after traveling great distances, the change in angle between the moth and the light source is negligible. Further, the moon is always in the upper part of the visual field. When a moth encounters a much closer artificial light and uses it for navigation, the angle changes noticeably after only a short distance. The idea that moths may be impaired with a visual-distortion is called a Mach-band by Henry Hsiao in 1972. He stated that they fly towards the darkest part of the sky in pursuit of safety, thus they are inclined to circle ambient objects in the Mach-band region [15].

1.4. Attraction to light

There are many possible explanations to attract moths towards lights, but the most common theory is that many moths use the moon to navigate at night. By keeping the moon in a particular position, the moth can fly in a straight line and in the direction it wants. Unfortunately, they confuse bright lights for the moon and when they get close to the light. They cannot navigate properly and end up flying round and round in decreasing circles until they reach the source of the light and are burnt due to high intensity of heat [16].

1.5. Migration

Moths migrate in order to avoid antagonistic environmental conditions, like cold weather, starvation, drought and extremely hot weather. The short distances migrations relatively common among them. Gradually they survive and may lay eggs here after their arrival, but after hatching, their offspring do not survive in winter. One spectacular migrant commonly seen every year, is the wonderful hummingbird hawk moth, *Macroglossum stellatarum* (Linnaeus, 1758) (Bombycoidea: Sphingidae). Most of the migrants frequently migrate in hotter summers and when there are southerly winds. Other distinguished migrants, which seen every year are the African death head hawk moth, *Acherontia atropos* (Linnaeus, 1758); Greater death head hawk moth, *Acherontia lachesis* (Fabricius, 1798); lesser death head hawk moth, *Acherontia styx* Westwood, 1847 and the convolvulus hawk moth, *Agrius convolvuli* (Linnaeus, 1758) (Sphingidae: Sphiginae). Some species, like the crimson specked, *Utetheisa pulchella* (Linnaeus, 1758) (Noctuoidea: Erebidae) only occur in some years, but may sometimes arrive in large numbers. Perhaps, the most exotic looking migrant is the oleander hawk moth, *Daphnis nerii* (Linnaeus, 1758), which only arrives in some years and even in very low numbers. Another very communal migrant is the silver-Y-moth, *Autographa gamma* (Linnaeus, 1758) (Noctuoidea: Noctuidae) recognized by clear metallic Y-shape on each forewing [17].

1.6. Beneficial moths

Many moth species are beneficial for mankind as well as their ecosystem, the examples are:

1.6.1. Bioindicator

Moths are being affected by climate change. Species have always evolved to adapt to changing conditions. The problem with man-made climate change is that it is happening so quickly that moths may not be able to evolve and adapt fast enough. There have already been some winners and some losers as a result of climate change. One moth which has suffered is the beautiful garden tiger moth, *Arctia caja* (Linnaeus, 1758) (Noctuoidea: Erebidae). Sadly, this species is predicted to decline even further. The scarlet tiger moth, *Callimorpha dominula* (Linnaeus, 1758) (Noctuoidea: Erebidae) is found in many habitats, including gardens, and flies during the daytime in June and July. It particularly likes damp places and is often associated Russian comfrey, *Symphytum uplandicum* Linnaeus, 1753 (Boraginaceae: Lamiales) a favorite food of the caterpillars. The lime hawk moth, *Mimas tiliae* (Linnaeus, 1758) (Bombycoidea: Sphingidae) is another example for the same (**Figure 2**) [18].

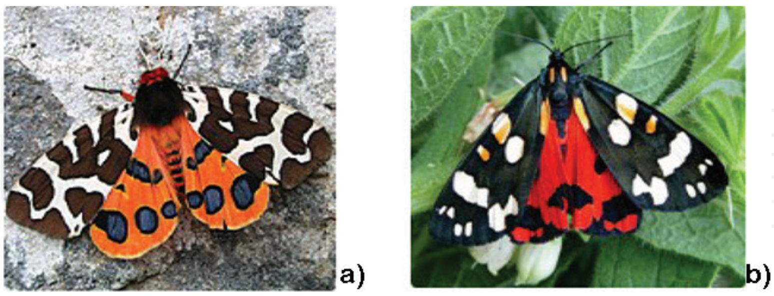

Figure 2. Insects as bioindicator: (a) the garden tiger moth, *Arctia caja* (Linnaeus, 1758) (Noctuoidea: Erebidae) and (b): the scarlet tiger moth, *Callimorpha dominula* (Linnaeus, 1758) (Noctuoidea: Erebidae) [18].

1.6.2. Useful products

Silk production (Sericulture) has a long history. Silk was discovered by Xilingji, wife of China's 3rd Emperor, Huangdi, in 2640 B.C. While making tea, Xilingji accidentally dropped a silkworm cocoon into a cup of hot water and found that the silk fiber could be loosened and unwound.

http://dx.doi.org/10.5772/intechopen.79639

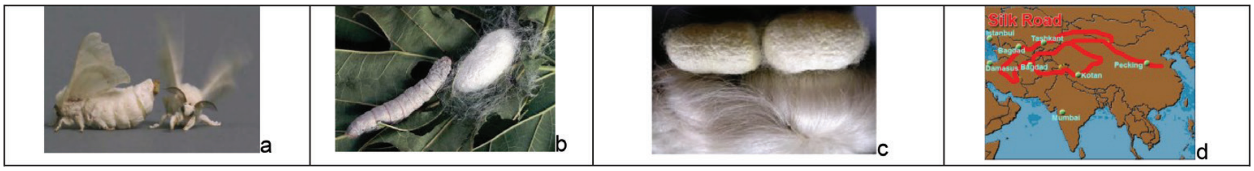

Figure 3. Sericulture: (a) adult silkworm, *Bombyx mori* (Linnaeus, 1758) (Bombycidae: Bobycinae; left: female; right: male); (b) *B. mori* Larva and silk cocoon; (c) silk strands and reeled from silk cocoons; (d) map of silk road [21, 22].

Fibers from several cocoons could be twisted together to make a thread that was strong enough to be woven into cloth. Thereafter, Xilingji discovered not only the means of raising silk worms, but also the manners of reeling silk and of employing it to make garments. Later sericulture spread throughout China, and silk became a precious commodity, highly sought after by other countries. Demand for this exotic fabric eventually created the lucrative trade route, the historically famous Silk Road named after its most important commodity [19]. The saturniids and bombycids yield silk of commercial value [20]. The silk moth, *Bombyx mori* (Linnaeus, 1758) (Bombycidae: Bobycinae) caterpillars are domesticated for silk. A number of wild moths such as *Bombyx mandarina* (Moore, 1872) (Bombycidae: Bobycinae) and *Antheraea Hübner*, 1819 species (Bombycidae: Sturniidae), besides others, provide commercially important silks (**Figure 3**) [21–23].

1.6.3. Food for other animals

Moths and their caterpillars are important food for many other species, including amphibians, small mammals, bats and many bird species. Moth caterpillars are especially important for feeding young chicks, including those of the most familiar garden birds such as *C. caeruleus* and great tit, *Parus major* Linnaeus, 1758 (Passeriformes: Paridae); robin, *Parus major* Linnaeus, 1758 (Passeriformes: Paridae); wren, *Troglodytes troglodytes* (Linnaeus, 1858) (Passeriformes: Troglodytidae) and blackbird, *Turdus merula* Linnaeus, 1758 (Passeriformes: Turdidae). Cuckoo, *Cuculus canorus* Linnaeus, 1758 (Cuculiformes: Cuculidae) specializes in eating hairy caterpillars, which most other birds avoid [24].

1.6.4. Pollinators and dispersal of seeds

Moths, including micro- and macro-moths are found worldwide are mostly feed on numbers of plant species. They travel flower to flower, plant to plant and place to place, therefore, they are responsible for pollination and dispersal of seeds for development of fruits and plants at different places, respectively [25].

1.6.5. Nutrients recyclers

Larvae of moths can cause damage to residential properties, like cloths, carpets, store grains just like termites may do. But they repay humans by performing a priceless service: helping us recycle decomposing dead materials. Decomposition may have an unpleasant ring to it but it is a fundamental process in a functioning ecosystem that is produced every year right on our own doorsteps. Larvae of moths wood eating are among the insect world's best decomposers organisms that digest dead matter [26].

1.6.6. Soil formation

Moths 93 species representing 10 families were recorded probing at soil and mud puddles. Observations of Gracillariidae and Lyonetiidae (97% males) are the first records at soil. Special mention is given those species of Geometridae and Notodontidae that pass large volumes of water through their gut as they drink from very wet substrates [26].

1.7. Camouflage

Moths show remarkable mimicry in different forms, which is still a challenge for evolution. Batesian mimicry is between palatable and non-palatable species, however, Mullerian mimicry, several equally unpleasantly tasting species share a color pattern and all species are mutually benefited, not only the mimic. They have significant economic importance.

The merveille-du-jour, *Griposia aprilina* (Linnaeus, 1758) (Family: Noctuidae) is a perfect match for lichen covered bark [27, 28]. The buff tip, *Phalera bucephala* (Linnaeus, 1758) (Family: Notodontidae) has gone one stage further and is not just the color of a twig, but the same shape too. A large group called the geometrids specializes in this disguise [29]. A few moths disguise themselves as distasteful, therefore, their predators will not even think of eating them. A moth looks just like a small bird dropping both in shape and color, the small bird lime moth, *Ponometia erastrioides* (Guenee, 1852) (Family: Noctuidae). Many moths use patterns that break up their outline, therefore, their moth shape is not recognized. A common garden moth or angle shades, *Phlogophora meticulosa* (Linnaeus, 1758) (Family: Noctuidae) combines several strategies (**Figure 4**) [30, 31].

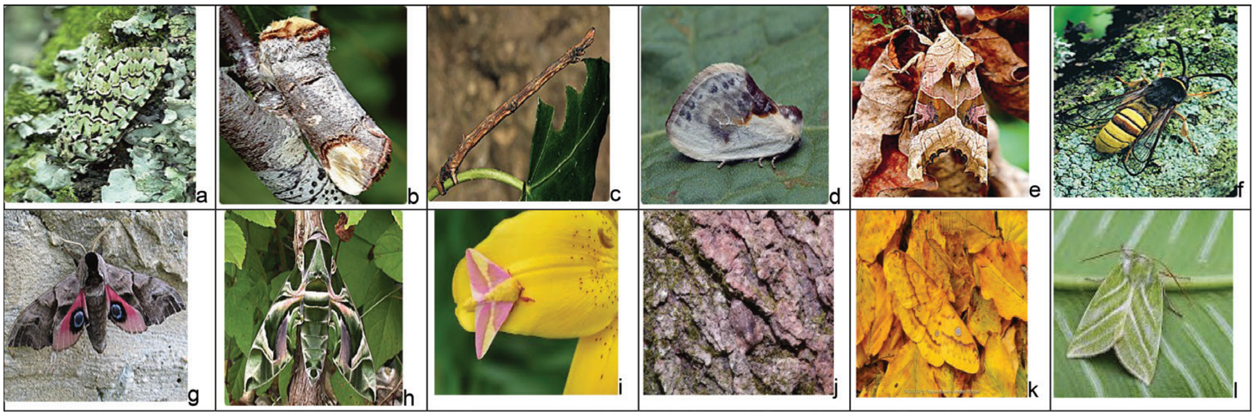

Figure 4. Camouflage in moths: (a) merveille-du-jour, *Griposia aprilina* (Linnaeus, 1758) (Family: Noctuidae); (b): buff tip, *Phalera bucephala* (Linnaeus, 1758) (Family: Notodontidae); (c) Caterpillar (Family: Geometrids); (d) small bird dropping moth, *Ponometia erastrioides* (Guenee, 1852) (Family: Noctuidae); (e) angle shades, *Phlogophora meticulosa* (Linnaeus, 1758) (Family: Noctuidae); (f) lunar hornet clearwing moth, *Sesia apiformis* (Clerck, 1759) (Family: Sesiidae); (g) eyed hawk moth, *Smerinthus ocellatus* (Linnaeus, 1758) (Family: Sphingidae); (h) oleander hawk moth, *Daphnis nerii* (Linnaeus, 1758) (Family: Sphingidae); (i) rosy maple moth, *Dryocampa rubicunda* (Fabricius, 1793) (Family: Saturniidae); (j) copper underwing moth, *Amphipyra pyramidea* (Linnaeus, 1758) (Family: Noctuidae); (k) squeaking silk moth, *Rhodinia fugax* (Butler, 1877) (female) (Family: Saturniidae); (l) green silver lines (*Pseudoips prasinana*) (Linnaeus, 1758) (Family: Nolidae) [27–30].

http://dx.doi.org/10.5772/intechopen.79639

1.8. Amazing moths

Moths use the tricks to avoid being eaten by their predators. Some members of the garden tiger moth, *Arctia caja* (Linnaeus, 1758) (Noctuoidea: Erebidae), which in the daytime use bright colors to warn predators that they taste bitter, and use squeaks in the dark to warn bats of their bad taste. The death's head hawk moth, *Acherontia atropos* (Linnaeus, 1758) (Sphingoidae: Sphingidae) makes squeaks, which apparently sound like those of a queen bee, fooling the worker bees into letting, it comes into their hive and eat their honey. The bee hawk moths, *Hemaris fuciformis* (Linnaeus, 1758) (Family: Sphingidae) have evolved to look just like bumble bees, *Bombus terrestris* (Linnaeus, 1758) (Hymenoptera: Apidae), predators think they can sting and will leave them alone. Female moths produce scents called pheromones to attract males, and the males use their antennae to pick up this scent as it wafts on the air. The male emperor moth, *Saturnia pavonia* (Linnaeus, 1758) (Family: Saturniidae) can often be seen following the scent towards females, and have been known to find them over distances of up to 5 miles. The caterpillar of the goat moth, *Cossus cossus* (Linnaeus, 1758) (Family: Cossidae) does not eat leaves but actually burrows into a tree trunk and eats the wood. Digesting wood is a slow process, therefore, the caterpillar takes 4 years to reach full size (**Figure 5**) [32, 33].

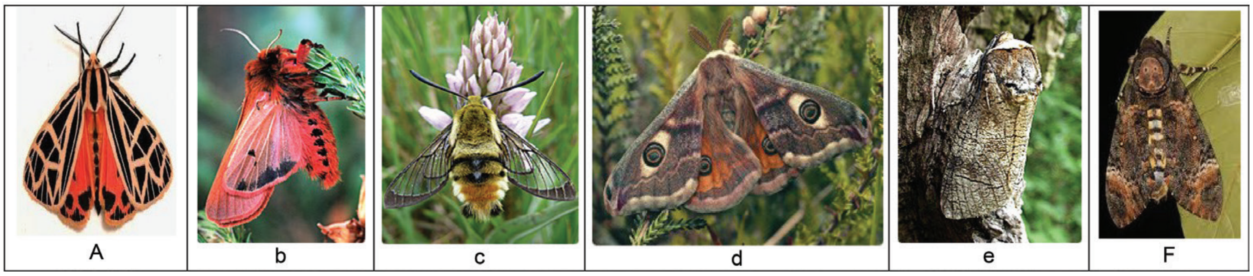

Figure 5. Amazing moth (a) banded tiger moth, *Apantesis vittata* (Fabricius, 1787) (Family: Arctiidae); (b) cinnabar moth, *Tyria jacobaeae* (Linnaeus, 1758) (Family: Eribidae); (c) bee hawk moths, *Hemaris fuciformis* (Linnaeus, 1758) (Family: Sphingidae); (d) emperor moth, *Saturnia pavonia* (Linnaeus, 1758) (Family: Saturniidae); (e) goat moth, *Cossus cossus* (Linnaeus, 1758) (Family: Cossidae); (f) lesser death head hawk moth, *Acherontia styx* Westwood, 1847 (Family: Sphingidae) [32].

1.9. Harmful moths: as pests

The larvae of many moth species are significant pests of agricultural crops and stored grains. They cause great losses to mankind. Some reports estimate that there have been over 80,000 caterpillars of several different taxa feeding on a single oak tree, *Quercus akoensis* Mull. (Fagales: Fagaceae). The major pest families are Tortricidae, Noctuidae and Pyralidae. Well-known species are the cloth moths, *Tineola bisselliella* (Hummel, 1823); *T. pellionella* Linnaeus, 1758, and carpet moth, *Trichophaga tapetzella* (Linnaeus, 1758) (Tineoidae: Tineidae), feeding on foodstuffs. They have also been found on bran, semolina, flour (e.g., wheatflour), biscuits, casein and insect specimens in museums [34]. The larvae of the Noctuidae, army worms, *Spodoptera frugiperda* (Smith, 1797) and corn earworm, *Helicoverpa* zea (Hübner, 1808)

(*Noctuoidea*: Noctuidae) can cause extensive damage to certain crops. The cotton boll worms, *Helicoverpa armigera* (Hübner, 1808) (*Noctuoidea*: Noctuidae) larvae are polyphagous. The variegated cutworms, *Peridroma saucia* (Hübner, 1808) (*Noctuoidea*: Noctuidae) are described as one of the most damaging pests to gardens. Throughout the world, the diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae) is considered the main insect pest of brassica crops, particularly, the cabbage, *Brassica oleracea* or variants L.; white cabbage (*capitata* var. *alba* L.); kales crops, *red Russian kale*, *Brassica napus L. subsp*. *napus* var. *pabularia* (DC.) Alef.; broccoli, *Brassica oleracea* L. (cultivar group: Italica); and cauliflower, *Brassica oleracea* L. (Brassicales: Brassicaceae). It has been known to completely destroy *B. oleracea* (*capitata* var. *alba*) and *B. napus*. In Kenya, *P. xylostella* has also been found feeding on peas, *Pisum sativum* L. (Fabales: Fabaceae) [35]. Pesticides can affect other species than the species they are targeted to eliminate and damaging the natural ecosystem [36].

1.9.1. Biological control of moths

Biological control is relatively permanent, safe, economic and environmental friendly [37]. The crops management practices include protects and encourages natural enemies and increases their impact on pests for conservation as a biological control method [38, 39]. The parasitoid stingless wasp, *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae) is an important egg parasitoid used for the control of the Mediterranean flour moth, *Ephestia kuehniella* (Zell, 1879) (Pyraloidae: Pyralidae); angoumois grain moth, *Sitotroga cereallela* (Olivier, 1789) (Gelechiioidae: Gelechiidae) and rice meal moth, *Corcyra cephalonica* (Stainton, 1866) (Pyraloidae: Pyralidae). *Sitotroga cerealella* originally proposed by Flanders [40, 41] is one of the most commonly used as fictitious host for rearing *Trichogramma sp*. The pyralid cactus moth, *Cactoblastis cactorum* (Berg, 1885) (Pyraloidea: Pyralidae) was introduced from Argentina-Australia, where it successfully suppressed millions of acres of prickly pear cactus, *Opuntia abjecta* Britton and Rose (Caryophyllales: Cactaceae: Opuntioideae). Another species of the Pyralidae, called the alligator weed stem borer, *Arcola malloi* (Pastrana, 1961) (Pyraloidea: Pyralidae) was used to control the aquatic plant known as the alligator weed, *Alternanthera philoxeroides* (Mart.) Griseb (Caryophyllales: Amaranthaceae) in conjunction with the alligator weed flea beetle, *Agasicles hygrophila* Selman and Vogt, 1971 (Galerucinae: Agasicles); in this case, two insects work in synergy and the weed rarely recovers [42].

1.9.2. Bacillus thuringiensis

Bacillus thuringiensis (Bt) var. *aizawai* and Bt var. kurstaki are very effective in controlling infestations of *P. xylostella* (Lepidoptera: Plutellidae). Bt var. *kurstaki* is widely used at a weekly interval and a rate of 0.5/ha. Bt kills the *P. xylostella* and does not harm beneficial insects [43].

1.9.3. Farmers' pesticide

Farmers produce their own homemade biopesticides by collecting diseased *P. xylostella* caterpillars (fat and white or yellowish or with fluffy mold on them), crushing and mixing them with water in a blender. Large tissue clumps are filtered out and the liquid is sprayed [44].

1.9.4. Neem, Azadirachta indica

The neem-based products, *Azadirachta indica* Juss 1830 (Sapindales: Meliaceae) give a good control of *P. xylostella* and are relatively harmless to natural enemies [45].

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