Key Oil Palm Pests and Their Managements

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Oil palm, *Elaeis guineensis* Jacq. (Arecales: Arecaceae), is a multipurpose plantation crop that is extensively grown in the humid tropics across Asia, Africa and the Americas for palm oil and other uses such as sauces, soap, wine, fertilizer (ashes), roofing (leaves), building material (trunk), medicines (roots), and ornamental purposes. Oil palm is attacked by numerous insect species globally, including defoliators, leaf/fruit scrapers, borers and sap feeders. The common oil palm pest management methods include synthetic insecticides, biopesticides, semiochemical lures, cultural practices, and integrated approaches.

Keywords: Borers; Defoliators; Leaf/Fruit scrapers; Sap feeders; synthetic insecticides; biopesticides; semiochemical lures; cultural practices; integrated pest management

1. Introduction

Oil palm, *Elaeis guineensis* Jacq. (Arecales: Arecaceae), is a multipurpose plantation crop that is extensively grown in the humid tropics across Asia, Africa and the Americas for palm oil and other uses such as sauces, soap, wine, fertilizer (ashes), roofing (leaves), building material (trunk), medicines (roots), and ornamental purposes. About 40% of all traded vegetable oil globally is palm oil, and this oleaginous species has the potential to produce 4–20 times more oil per hectare of land than any other oil crop. As such, oil palm production has rapidly grown more than 35-fold from only 2 million tonnes in 1970 to 71 million tonnes in 2018. There are more than 140 palm oil importing countries of which India, China and the United States of America lead the market with more than nine, five and one million tonnes of palm oil imports in 2017, respectively.

Although a wide range of tropical climates and soils in about 20 countries that lie between 10° N and 10° S of the equator are conducive for oil palm cultivation, Indonesia and Malaysia account for more than 84% of oil palm production globally. Palm oil production in Latin America, which accounts for 6.4% of global production, has increased by almost 60% in the last ten years to 4.6 million tonnes in 2020/21. In Africa, the oil palm belt runs from the southern latitudes of Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo, Benin, Nigeria, and Cameroon to Equatorial Guinea and the Congo.

Oil palm requires maximum and minimum temperature ranges of 29–33 °C and 22–24 °C, respectively; total annual rainfall of at least 2000 mm; and acidic sandy, fine clay or silty loam soils. Although peak palm oil yields of 12 t ha⁻¹ yr⁻¹ have been achieved in small plantations against a theoretically simulated yield potential of 18.5 t ha⁻¹ yr⁻¹, average oil palm productivity worldwide has stagnated around 3 t ha⁻¹ yr⁻¹. The suboptimal oil palm productivity is attributed to climatic factors such as rainfall and temperature, nutrient deficiency (especially potassium and nitrogen), unsuitable ground vegetation, soil characteristics (e.g., depth and structure), genotypes, pests and diseases, among other factors. The intensive monoculture of oil palm makes it highly susceptible to a range of indigenous insect pests due to reduced crop biodiversity which supports natural enemies of the pests.

2. Overview of Key Oil Palm Pests and Their Managements

Oil palm is attacked by numerous insect species globally. Twenty-five out of thirty-six of the species which defoliate oil palm are lepidopteran larvae, dominated by limacodids, nymphalids, psychids and elachistids. Other oil palm defoliators are coleopterans and tettigoniids. Oil palm borers are dominated by larvae of curculionids in the genus *Rhynchophorus*, but it is also bored by adult scarabids and larval brachodids and castniids. Oil palm sap suckers are dominated by members of the hemipteran family, Tingidae. Leaves of the oil palm are scraped and/or mined by chrysomelids.
2.1. Defoliators

Oil palm leaves contain a high content of indigestible cellulose fibers and a low nutritional value, therefore, a restricted number of insect orders such as Orthoptera, Phasmatoptera, Lepidoptera, Coleoptera, and Hymenoptera have evolved as palm defoliators [14]. The larval stages of these insects adapt to the low nutritive value of oil palm leaves by developing relatively slowly, always for more than a month. For example, larvae of the leaf defoliator *Leucothyreus femoratus* Burmeister (Coleoptera: Scarabaeidae) takes 92–113 days to develop [15]; those of *Acharia fusca* Stoll (Lepidoptera: Limacodidae) take 76–94 days [16]; and those of *Metisa plana* Walker (Lepidoptera: Psychidae) take 72 days [17]. There are, however, some oil palm defoliators with short larval durations, e.g., *Acia meyricki* Shashank and Ramamurthy (Lepidoptera: Depressariidae) with approximately 20 days [18]. The damage by defoliators is exacerbated by dry conditions, probably due to suppression of the activities of natural enemies such as entomopathogens, parasitoids and predators during dry spells [19].

2.1.1. Nettle and Slug Caterpillars

The nettle and slug caterpillars (Lepidoptera: Limacodidae) are the most-widespread oil palm defoliators in all oil palm growing areas of the world, with at least 22 species reportedly reaching outbreak levels and attacking different parts of the crown [20]. For example, damage by *Euprosterna elaeasa* Dyar (Lepidoptera: Limacodidae), and other Neotropical lepidopteran defoliators also facilitates the spread of oil palm *Pestalotiopsis* fungal pathogen [21]. The lifecycle of *E. elaeasa* has nine larval instars which feed on the mesophyll until the fourth instar, and then on the entire leaf blade thereafter [19]. *Euprosterna elaeasa* is commonly controlled using synthetic insecticides, although insecticide-resistance has been noted [19]. Essential plant oils, notably from *Cymbopogon martini* [19], insect growth regulators such as fenoxycarb, methoxyfenozide, pyriproxyfen, and tebufenozid [18], the nucleopolyhedrosis virus EuelNPV [22], and *Bacillus thuringiensis* Berliner (*Bt*) strains [19] have demonstrated toxicity and/or antifeedant activity against *E. elaeasa* at levels that are comparable or superior to conventional insecticides, under controlled trials, and are recommended for evaluation as components of integrated approaches against the pest in the field [20][21].

2.1.2. Bagworms

The bagworm family (Lepidoptera: Psychidae) which includes approximately 1000 described species in 300 genera and ten subfamilies is well reviewed by Rhainds and colleagues [22]. Embryonic development in bagworms is usually completed within a month under tropical and subtropical conditions. Upon hatching, phytophagous neonates either remain to feed on the mother host plant or disperse by wind, vehicles, animals, or humans, aided by silk threads which they secrete from their posterior openings. Before starting to feed, first instars construct a protective self-enclosing bag using plant tissue or organic and inorganic debris within which the larval development is completed. The destructive larval stage lasts for about 1–7 months under tropical and subtropical conditions. Prior to pupation, the larvae tightly attach the anterior portion of their bag onto a substrate. Most species of bagworms feed on a broad range of plants during their larval stages. Several species of bagworms have been reported attacking oil palm in Asia since the start of the plantation industry [23], and others such as *Clania tertia* Templeton and *Manatha conglacia* Haettenschwiler continue to expand their host range to become new serious pests of oil palm [24][25].

*Mahasena corbetti* Tams is one of the large bagworm species which is endemic to Malaysia, but it has spread across the Paleotropical region [24]. The pest reportedly causes 40–50% losses in oil palm yields in Malaysia and Indonesia if not managed, with severe infestation of preferred host plants such as Fabaceae and Arecaceae (including oil palm) being fatal [25]. Owing to its invasiveness and a wide host range comprising 37 plant genera from 21 families, *M. corbetti* is considered a quarantine pest in many countries such as India, Singapore, Sri Lanka and Malaysia, among others [25][26][27] [28]. Adult males of *M. corbetti* are black to brown with white scales on some of them; while females are wingless, cylindrical, and creamy-white with either no or greatly minimized appendages [22]. Larval feeding causes yellowing and subsequent dying and falling of leaves [26]. *Mahasena corbetti* is highly prolific, with each female laying over 3000 eggs, hence making the pest efficient at creating outbreaks [28]. It is quite difficult to control large *M. corbetti* outbreaks using aerial sprays of contact insecticides because its larvae cryptically feed on the abaxial surface of fronds which the insecticides cannot easily reach [28]. Therefore, palm trunk injections with systemic insecticides are required to effectively control the pest. Application of *Bt* to control *M. corbetti* has also not been effective [25]. Though laborious, hand-picking of *M. corbetti* larval bugs which actively move during bright sunlight can be effective against the pest [22].

Other bagworms, such as *M. plana* and *Pteroma pendula* Joannis are significant oil palm defoliators across Southeast Asia [22][23][24]. Application of both *Bt*-based biopesticide and synthetic insecticides (chlorantraniliprole, cypermethrin and flubendiamide) in Malaysia using a motorized backpack mist blower caused 70–83% mortality of *M. plana* and were able to suppress the pest population for a month after treatment [24]. In addition, several species of hymenopteran parasitoids...
such as *Apanteles* sp., *Dolichogenidea metases* (Nixon), *Brachymeria carinata* Joseph, *Goryphus bunoh* Gauld, *Pediobius anomalous* (Gahan), *Apanteles alveula* (Sumatra), *Cotesia* sp. and *Glypapanteles* sp.; as well as predators such as *Callimerus arcuter* Chapin (Coleoptera: Cleridae) and *Cosmolestes picticeps* Stål (Hemiptera: Reduviidae) reportedly attack the bagworms in Malaysia, indicating a high potential of their use in biological control of the devastating oil palm pest. However, further research is needed to develop efficient protocols for the mass production of these natural enemies.

The success of using these natural enemies against the bagworms will also require addressing other bottlenecks such as changing the attitudes of farmers who prefer chemical insecticides for their fast action and effectiveness, despite their hazardous impacts on human and environmental health. The effectiveness of the biocontrol agents against the bagworms may also be hampered by hyperparasitism, e.g., *Pediobius imbreus* (Walker) (Hymenoptera: Eulophidae) against *D. metasae* and their susceptibility to chemical insecticides, among other factors.

### 2.1.3. Other Defoliating Lepidopterans

Females of the palm moth *Stenoma impressella* Busck (Lepidoptera: Elachistidae) lay eggs on the adaxial frond surfaces. Early feeding by *S. impressella* larvae damages the abaxial frond surface, except for secondary veins. In later feeding, the entire leaf tissue, except for midveins, is consumed. *Rhysipolis* sp. (Hymenoptera: Braconidae) was identified as the most important natural enemy of *S. impressella* in South America, but the rate of parasitism is only 7–18%. Synthetic chemicals, e.g., teflubenzuron, chlorantraniliprole and flubendiamide cause 95–100% mortality of *S. impressella* in oil palm plantations.

The palm king *Amathusia phidippus* (L.) (Lepidoptera: Satyrinae) is a common defoliator of oil palm in Southeast Asia. The eggs are laid in a row, where larvae hatch in 6–7 days and voraciously feed on the underside of the leaf, from the tip towards the base. The larvae are greenish-grey to brown with longitudinal bands and a thick pile of reddish-setae, tufts of longer setae on the second and third abdominal segments, paired hornlike processes on the head and paired processes projecting from the anal segment. Chalcidoid wasps appear to be important parasitoids of *A. phidippus*.

The split-banded owlet *Opsiphanes cassina* Felder (Lepidoptera: Nymphalidae) is an important pest of oil palm in Central America, Colombia, Ecuador and Peru. A natural enemy complex of hymenopterous parasitoids and a nuclear polyhedrosis disease apparently regulate populations of *O. cassina*. Its larval populations have been controlled by applications of carbaryl. Although the control of adults with insecticide-laced honey baits is reportedly effective against *O. cassina*, the technique could be hazardous to many kinds of non-target organisms. The larva of another nymphalid species, *Opsiphanes invirae* Hübner has a bright green body marked by two thin longitudinal stripes of yellow-ochre, a pink head with two pointed extensions facing backward, and the last abdominal segment ending in a long, bifid and coniform tail. In Brazil, the mass production of the parasitoid wasp *Palmistichus elaéis* Delvare & LaSalle (Hymenoptera: Eulophidae) from alternative hosts has allowed inundative biological control of *O. invirae* populations in oil palm crops.

### 2.1.4. Leaf Beetles

Leaf beetles (Coleoptera: Chrysomelidae), with 37,000 described species and possibly up to 23,000 more to be described, are the third largest family in the order Coleoptera after Curculionidae and Staphylinidae. Chrysomelids are small to medium-sized beetles, often brightly colored, boldly patterned, or metallic, with hairs or scales in some species. Several species of leaf beetles attack oil palms in different parts of the world and are controlled using different methods. The entomopathogenic fungus *Metarhizium* sp. was used to control *Alumus humeralis* Rosenberg in Ecuador. Dense populations of *C. vagelineata* have been observed to diminish after heavy rains. Barrios et al. found field-collected *C. vagelineata* to be infected by *Lecanicillium lecanii* and *Metarhizium anisopliae*, which could be developed into biopesticides against the pest.

### 2.1.5. Grasshoppers

*Seginestidea novaeguineae* (Brancsik), *Seginestidea defoliaria* Uvarok and *Segestes decoratus* Redtenbacher (Orthoptera: Tettigoniidae) are pests of oil palm in Papua New Guinea. Meanwhile, *Valanga nigricornis* Burmeister (Orthoptera: Acrididae), *Sexava nubila* and *S. coriacea* (Orthoptera: Tettigoniidae) were reported as pests of oil palm in Indonesia. Grasshoppers often attack the younger fronds first, but dense populations can effectively defoliate the entire palm. Often, their damage is noticed before the insects themselves are seen. The nymphs and adults of endoparasite *Stichotrema dallatoreanum* Hofeneder (Strepsiptera: Myrmecolacidae) are potential classical biocontrol agents against these grasshoppers.
2.2. Fruit Scrapers

The oil palm fruit scraper, Demotispa neivai Bondar (Coleoptera: Chrysomelidae) is an important pest in commercial plantations and distributed in Central and South American countries [44]. Adults of D. neivai are reddish-brown, oval-shaped, dorsally flattened, and convex laterally [45]. Adults damage oil palm fruits, with a consumption rate of 12.35 mm² d⁻¹ per adult on exocarp [46]. The scraping by D. neivai feeding on the exocarp causes a gray corky appearance. The resultant drying of fruits affects palm oil production. The use of natural plant extracts such as Ricinus communis L., Citrus sinensis Oesbek, Nicotiana tabacum L., and Capsicum annuum L. are a valuable tool for controlling D. neivai [47]. Moreover, entomopathogenic fungal isolates of B. bassiana and M. anisopliae are effective against D. neivai with the potential to be used as biological control agents, hence reducing reliance on hazardous chemical insecticides [48].

2.3. Sap Feeders

Prominent oil palm sap feeders are true bugs (Heteroptera) in the families Miridae and Tingidae [9]. For instance, the spindle bug Carvalhoia arecae Miller and China (Hemiptera: Miridae) attacks young oil palms in nurseries [51,52]. Inorganic insecticides such as malathion 5% dust, phorate 10% granules, monocrotophos 0.15% spray, and lambda cyhalothrin 0.10% are effective in controlling the pest [53].

Among tingids, the lace bug Stephanitis typica (Distant) is the best-known sapsucker associated with palms in Asia through to New Guinea [57]. Females typically lay eggs concealed in a lipid substance and insert them deep in the abaxial surfaces of fronds. Nymphs hatch about 12 days. Stephanitis typica populations surge during dry periods. Stylets are inserted through the stomata, rupturing cell walls and terminating in the phloem [58]. Nymphs and adults feed on the lower surfaces of leaves, causing whitish-to-yellowish spots on the corresponding upper leaf surfaces. The feeding on the lower leaf surfaces leaves dark brown or black marks. Chemical insecticides are commonly used to control outbreaks of S. typica, but their effectiveness is questionable [9]. Stethoconus praefectus (Distant) (Hemiptera: Miridae) an obligate predator, and, two egg parasitoids namely Erythmelus panis and Anagrus sp. (Hymenoptera: Mymaridae) have been reported as natural enemies of S. typica in India [53].

Another notable tingid associated with oil palm is Leptopharsa gibbicarina Froschsn [9]. It is also the main vector of the Pestalotiotiposis fungal complex in oil palm in the Americas [59]. The females insert their eggs into leaf tissue along a major vein of the abaxial surface, usually covering them with excrement. Upon hatching, larvae mingle with the adults, maturing in 6 weeks. The adults live for more than a month. They are relatively more abundant in the dry season [54]. The bugs prefer upper and middle fronds, rarely attacking the older fronds. Leaf surfaces injured by lace bug feeding may be an entry point for pathogenic fungi, such as Pestalotiotiposis spp. Natural enemies of L. gibbicarina include Neuroptera, ants (especially Crematogaster spp.) and B. bassiana [55]. When these are not effective in maintaining low populations of the lacebug, an option is to treat the palm with a systemic insecticide [9]. Martinez et al. [9] reported that novaluron, teflubenzuron, and triflumuron are highly effective against L. gibbicarina.

Besides insects, at least 31 species of tetranychid mites suck sap from palms [9]. For instance, Retracrus elaeis Keifer (Acari: Eryophyidae), feeds on the abaxial frond surfaces of oil palms in tropical America [64]. This mite has been associated with severe yellowing of palm leaves. Foliar spraying with sulfur reduces its severity [56]. Another mite recorded on oil palm foliage in the American tropics is the red spider mite Tetranychus mexicanus (McGregor) (Acari: Tetranychidae), but its damage is minimal [9].

2.4. Borers

A palm borer makes a tunnel by chewing or burrowing into the stem, crown, unopened inflorescences, flowers, fruits, peduncles, petioles, fronds or roots of the palm tree. The major oil palm borers belong to orders Isoptera, Coleoptera and Lepidoptera [58].

2.4.1. Palm Weevils

Among the coleopterans, weevils (Curculionidae) are characterized by an elongated rostrum or snout with mandibles at the distal end for chewing host tissue or excavating oviposition sites [60]. The larvae, which are the most destructive stage, are protected from most predators, parasites and external abiotic factors as they cryptically feed inside the host tissues. The success of palm weevil borers may be due to their specialization as borers within the Areaceae and sometimes including other monocotyledons, such as sugarcane (Poaceae), banana (Musaceae) and pineapple (Bromeliaceae) [61]. Palm weevil borers fall into seven subfamilies: Dryophthorinae (Rynchophorinae), Cholininae, Baridinae, Erirhininae, Petalochilinae, Scolytinae and Platypodinae. In particular, palm-associated members of the Rynchophorinae are the
most damaging to palms worldwide. Four tribes within the Rhynchophorinae, i.e., Rhynchophorini, Sphenophorini, Diocalandrini and Orthognathini are the major borers of palms in general. Species in the weevil genera *Rhynchophorus* and *Dynamis* are most often referred to as ‘palm weevils’ and are relatively large insects, with adult length and width ranging from 3.5 cm to 5 cm and 1 cm to 2 cm, respectively, while the larvae are approximately 3.5–6.4 cm long and 1–2.5 cm wide. Adults of *Dynamis* species are usually glossy black, in contrast to *Rhynchophorus* species which can exist in varying colors. *Dynamis* and *Rhynchophorus* lay between 30 and 832 eggs in about a 42-day oviposition period.

No species of *Dynamis* has been reported on oil palm. However, oil palm is attacked by *Rhynchophorus palmarum*, *R. bilineatus*, *R. phoenicus*, *R. quadrangularis* and *R. ferrugineus*. The main pathway through which the weevils spread outside their native regions is the movement of infested palms. Early signs of oil palm infestation by weevils include notches at the base of fronds with frass and pupal cocoons, eccentric crown growth, holes at the base of the cut palms and symptoms resembling those of drought stress, e.g., wilting and yellowing. Cryptic larvae and adults that spend their entire life inside the palm tree may destroy the interior of the palm causing its collapse. Although visual inspection may allow early detection of signs of weevil attack on palms, palm infestation with *Rhynchophorus* is difficult to accurately detect prior to serious damage to the apical meristem. The females are attracted to and deposit eggs in palm sheaths and stems, where they lay eggs in damaged parts along the trunk or in petioles. Upon hatching, the apodal larvae begin feeding towards the interior of the palm and migrate towards the crown region where the larvae primarily develop while voraciously feeding on and irreparably destroying tissues in the trunk and subsequently leading to tree collapse. About 20 larvae are needed to cause a lethal infestation. A delay in destroying the palms allows weevils to emerge and spread to other palm trees.

*Rhynchophorini* are highly devastating pests. For example, the Gulf region of the Middle East, which accounts for nearly 30% of global palm production, has been threatened by *R. ferrugineus* since the mid-1980s. The economic burden due to the eradication of 1% and 5% of severely infested palms of 259,172 hectares was estimated to range from $5.18 to $25.92 million, respectively. Besides this, the indirect losses would increase several folds. Further, it is also estimated that savings due to thecurative treatment of palms in the early stage of attack at the above infestation levels and hectarage range from $20.73 to $103.66 million, respectively. Considering the above economic loss, it is important that countries where oil palm is grown strengthen the on-going management programmes against palm weevils.

The major components of integrated pest management (IPM) programme for palm weevil control include surveillance of the pest; maintaining plant and field sanitation; trapping adult weevils; preventive chemical treatment of wounds; filling the leaf axils of young palms with a mixture of insecticide and sand; curative chemical treatment of infested palms; and cutting and burning of severely infested palms. Adult populations of palm weevils can be monitored by pheromone traps, acoustic detection or infra-red systems. Abandoning oil palm fields over time makes them reservoirs for the weevils. Flood irrigation causes dampness at the base of the palm and its offshoots, creating a favorable environment for the weevils to lay their eggs. The chemicals used to control palm weevils include methidathion, oxydemeton-methyl, carbaryl, cypermethrin, deltamethrin dimethoate, chlorpyrifos, fipronil, imidacloprid and trichlorphon. Post-application monitoring is required to confirm successful control of the weevils which is characterized by cessation of oozing of sap from weevil-damaged parts. In regions with very high relative humidity, deeply damaged stems are treated by stem cleaning followed by filling these cavities with wet sand mixed with pesticide dust and the treated parts with a polyethylene sheet to retain humidity.

Early detection of *Rhynchophorus* weevil infestation followed by insecticide treatment may help palms to recover. However, palms in the latter stages of attack exhibit extensive tissue damage in the region of the apical meristem, often harboring several overlapping generations of the borers. These palms are difficult to treat, and they usually die. The lethal nature of this pest, coupled with the high value of the attacked palm species, warrants early action against the weevils.

Another weevil attacking bases of pruned oil palm fronds is *Metamasius inaequalis* (Gyllenhal) (Coleoptera: Curculionidae). Pitfall traps and palm tissue baited with aggregation pheromone and treated with insecticides are reportedly effective in controlling *M. inaequalis*. Additionally, *Temnoschoita quadriramulata* Gly. (Coleoptera: Curculionidae) is a borer of oil palms in nurseries and young plantations in Ghana. Inflorescences of older palms can be severely damaged, leading to significant tunneling through both dead and living tissue near the point of entry. Damage includes premature withering of fronds and necrosis of the terminal shoot. Young palms can be killed by damage to the crown and apical meristem by the activity of *T. quadriramulata*. The base-borer weevil, *Sparganobasis subcruciata* Marshall (Coleoptera: Curculionidae: Dryophthorinae) is also a lethal pest of oil palm in Papua New Guinea and Indonesia. Although *S. subcruciata* attacks the bases of only mature oil palms older than 10 years at low incidence, the
affected trees harbor hundreds of the weevil larvae, resulting in massive damage of the internal basal stem tissue and subsequent tree collapse.

2.4.2. Rhinoceros Beetles

Another destructive oil palm borer is the rhinoceros beetle *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae). The female lays up to 512 eggs in rotting stumps and rubbish piles. The eggs hatch in 8–12 days into white grubs taking 12–200 days to turn into pupae and then adults which can have a longevity of 100–270 days [26]. Young adults of *O. rhinoceros* bore and damage the crowns of healthy palms, penetrating 10–50 cm towards the center of the spear cluster and feeding on juice from host tissue. The major sign of palm infestation by *O. rhinoceros* is crushed tissue pushed out of the entrance of the burrow. The pest inflicts major damage to palms 1–3 years old (sometimes leading to death), while in healthy older palms the damage caused can be minor [27]. Field sanitation such as removal, burning, burial or destruction of dead standing palm logs, stumps and rubbish piles which are breeding sites for the beetles are helpful in managing the pest [26]. Although insecticides such as lambdacyhalothrin, cypermethrin, fenvalerate and chlorpyrifos are commonly used against *O. rhinoceros*, their effectiveness is limited due to the cryptic nature of the beetles inside the plant tissue [29]. A male-produced aggregation pheromone, ethyl-4-methyloctanoate [22], is widely used in mass trapping, monitoring and augmentation with biopesticides [28][29]. The use of biological control agents associated with *O. rhinoceros* is immense, including predators, parasitoids and entomopathogenic fungi, bacteria, and nematodes, but only a few biopesticides products are available in the market [28][29]. These reports highlight Rhadinovirus oryctes as a landmark success story of classical biological control of *O. rhinoceros*. Similarly, several fungal-based biopesticides such as *M. anisopliae* and Beauveria brogniartii (Sacc.) Petch, and entomopathogenic nematodes such as Heterorhabditis sp. are marketed for the control of *O. rhinoceros* [30]. However, the bulk of reports on natural enemies of *O. rhinoceros* are largely about their identification and efficacy bioassays under controlled conditions, but with limited commercial field application. For biopesticide products in the market, their potency may last long and are relatively easier and less costly to apply compared to chemical pesticides, but their scarcity raises their costs way above that of conventional pesticides [29].

The rhinoceros beetle, *Strategus aloeus* L. is a pest in oil palm plantations in the Americas. During the replanting of old palm trees by new palms, adult *S. aloeus* colonize palm trees. Adults attack young palms by tunneling into the soil near the palm trees, boring their way into the meristem of the plant. The collection of the immature stages on dead palms and chemical insecticides are the main methods of controlling *S. aloeus* [31].

2.4.3. Lepidopteran Borers

Aside from coleopterans, *Cyparissius daedalus* (Cramer) (Lepidoptera: Castniidae) is a major borer of oil palm in northern South America and the Amazon basin [32]. Each female lays about 265 eggs, and it takes about 17 days for larvae to hatch. The larval stage, consisting of 14 instars, takes up to 1 year and the pupal stage lasts about 35 days. The early instars bore into the fruits and peduncles of oil palm causing rotting of the affected parts. Later instars make shallow galleries between the petioles and the stem, causing premature frond abscission. In a few cases, palm death occurs when larvae bore the growing point of the palm. Oil palm becomes susceptible at about 5 years after planting. An egg parasitoid, *Oryctes rhinoceros* sp. (Hymenoptera: Encyrtidae), was isolated from eggs of *C. daedalus* in Peru, where it occasionally regulates its populations. Scouting plantations, pruning and destroying infested fronds and rotten fruit stalks are considered to be good preventive measures against *C. daedalus*.

*Sagalassa valida* Walker (Lepidoptera: Brachodidae) is a small, brown-banded moth, whose larvae cause significant damage to the roots of young oil palms causing up to 70% yield losses [33][34][35]. The larvae consume the entire central core of the infested quaternary and tertiary roots, starting from their apex. The short-lived adults move between surrounding forests and oil palm crops; hence, the greatest damage is at the forest-plantation borders [36]. Insecticide application is recommended for infestation levels, where 20% of the primary roots are attacked [14]. Cultural control methods involve keeping and maintaining clean borders between the plantation and the surrounding forest [32]. Mulching with empty bunches prevents the caterpillar from getting into the roots [14]. Biological control with the entomopathogenic nematode Steinernema carpocapsae is reportedly effective against *S. valida* in the laboratory and field trials [37], but reports of its practical use in managing the pest are scarce. The presence of the predatory ant Pachycondyla harpax (Fabricius) (Hymenoptera, Formicidae) reduces infestation by *S. valida* [14].

The African spear borer *Pimelephila ghesquierei* (Tams) (Lepidoptera: Crambidae) is a pest of oil palm in West Africa [38]. Two or three neonates penetrate the leaflets of the growing, unopened spears, forming galleries and mostly destroying the bases of young palms [52]. The caterpillars hatch from eggs laid at the base of the spear leaf and bore into it. The fronds may break off where the rachis has been weakened. Damage by *P. ghesquierei* greatly impacts young palms in nurseries
or in recent field plantings. Collection and destruction of pupae have been recommended to prevent population build-up in nurseries or young plantations. The pest mostly attacks stressed and/or shaded palms.

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