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Review

Global Advances on Insect Pest Management Research in Oil Palm

James P. Egonyu [1,*], John Baguma [2], Luis C. Martínez [3], Hari Priwiratama [4], Sevgan Subramanian [1], Chrysantus M. Tanga [1], Jacob P. Anankware [5], Nanna Roos [6] and Saliou Niassy [1]

[1] International Centre of Insect Physiology and Ecology (*icipe*), Nairobi P.O. Box 30772-00100, Kenya
[2] Kibaale District Local Government, Karuguuza P.O. Box 2, Uganda
[3] Department of General Biology, Federal University of Viçosa, Viçosa 36570-000, Brazil
[4] Crop Protection Division, Indonesian Oil Palm Research Institute, Medan 20158, Indonesia
[5] Department of Horticulture and Crop Production, University of Energy and Natural Resources, Sunyani P.O. Box 214, Ghana
[6] Department of Nutrition, Exercise and Sports, University of Copenhagen, Rolighedsvej 26, 1958 Frederiksberg, Denmark
* Correspondence: pegonyu@icipe.org

Abstract: Here, we review the advances in research on management of key oil palm insect pests 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. However, effectiveness, affordability, availability and impact of these methods on human and environmental health vary considerably based on the target insect and geographical location. The use of quarantine regulations to prevent the spread of invasive pests has also been applied with remarkable results. There are notable research advances in semiochemicals, bioacoustic detectors, nanotechnology, insect growth regulators, and entomophagy for better management of oil palm pests. We suggest the following research areas for improving effectiveness of oil palm pest management interventions: (i) exploration of semiochemical attractants for the majority of pests with no previous semiochemical work, and their integration in attract-and-kill devices laced with pathogenic microbes; (ii) expanding the application of digital sensing, predictive modeling and nano-technology in pest control strategies; (iii) developing effective technologies for mass trapping of edible insect pests for food or feed, especially among communities with a tradition of entomophagy; and (iv) strengthening regulatory frameworks for the management of quarantine oil palm insect pests.

Keywords: bioacoustic detectors; biological control; entomophagy; insect growth regulators; integrated pest management; nanotechnology; regulatory measures; semiochemical lures; synthetic insecticides

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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 [1]. About 40% of all traded vegetable oil globally is palm oil [1], and this oleaginous species has the potential to produce 4–20 times more oil per hectare of land compared to other oil crops [2]. 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 [2]. 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 [2].

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 [1,2]. 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 [3]. 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 [4]. 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 [5].

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} [6]. 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 [6,7]. 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 [7–10]. In this study, we review research advances in the management of key insect pests of oil palm globally, highlighting new research directions towards more effective management of the pests for improved oil palm productivity.

2. Overview of Key Oil Palm Pests and Their Managements

Oil palm is attacked by numerous insect species globally, of which 58 notable species with their destructive stages, distribution, life cycles and extent of damage are highlighted in Table 1. 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.

Table 1. Notable pests of oil palm in different parts of the world.

Type of Pest	Order	Family	Pest	Stage	Distribution	Life Cycle	Extent of Damage	Reference
Borers	Coleoptera	Curculionidae	*Rhynchophorus ferrugineus* Olivier	Larva	Native to Southeast Asia but with a recently expanded range to Europe, North Africa, and North and South America,	45–180 days	The attacked palm tree trunk is structurally weakened, making the plant liable to collapse.	[10–12]
			Rhynchophorus palmarum L.	Larva	North, Central and South America	45–180 days	The attacked palm tree trunk is structurally weakened, making the plant liable to collapse. The insect is a vector of the Red-Ring disease and is also associated with the Bud-Rot disease.	[11–13]
			Rhynchophorus phoenicis Fabricius	Larva	Central, eastern and southern Africa	45–180 days	The attacked palm tree trunk is structurally weakened, making the plant liable to collapse.	[10–12]
			Rhynchophorus quadrangulus (Quedenfeld)	Larva	West-Central Africa	45–180 days	The attacked palm tree trunk is structurally weakened, making the plant liable to collapse.	[10–12]
			Metamasius inaequalis Gyllenhal	Adult	Central and South America	–	Attacks the pruned frond bases.	[14]
			Rhynchophorus bilineatus (Montrouzier)	Larva	Eastern Indonesia, Papua New Guinea	–	Larvae live and feed inside oil palm trunk near the bud area. The attacked palm tree trunk is structurally weakened, making the plant liable to collapse.	[15]
			Temnoshoia quadrimaculata Scopoli	Adult	Democratic Republic of Congo and Ghana	33–52 days	Injury symptoms include premature withering of fronds and necrosis of the terminal shoot. Young palms can be killed by damage to the crown.	[16,17]
		Dryophthoridae	*Sparganobasis subcruciata* Marshall	Larva	Eastern Indonesia, Papua New Guinea	–	Larvae live and feed inside the basal part of the oil palm trunk making the plant liable to collapse.	[15,18]
		Scarabaeidae	*Oryctes rhinoceros* L.	Adult	Southern and Southeast Asia and the western Pacific Islands	115–162 days	Adults penetrate 10–50 cm down the center of the spear cluster to feed on juice from host tissue. In addition to the damage by the beetle, the burrows may provide secondary access by pathogens that can kill the palm.	[8]
			Strategus aloeus L.	Adult	South America	308 days	Burrow up to 50 cm in the soil just under the stem base of 1–3-year-old palms and then tunnel up into the base of the plant, sometimes moving into the stem above the soil line.	[19,20]
	Lepidoptera	Brachodidae	*Sagalassa valida* Walker	Larva	Brazil, Colombia, Ecuador and Venezuela	78–81 days	Root-boring results in premature frond death and poor rooting. Causes significant damage to the roots of young palms (2–6-year-old).	[8,21]

Table 1. *Cont.*

Type of Pest	Order	Family	Pest	Stage	Distribution	Life Cycle	Extent of Damage	Reference
		Castniidae	*Cyparissius daedalus* Cramer	Larva	Brazil, Colombia, Peru and Venezuela	217–493 days	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 trees become susceptible at about 5 years after planting.	[8,16,22]
		Crambidae	*Pimelephila ghesquierei* (Tams)	Larvae	West Africa	–	Two or three neonates penetrate the leaflets of the growing, unopened spears, forming galleries and mostly destroying the bases of young palms.	[8,17,23]
Defoliators	Coleoptera	Buprestidae	*Taphrocerus cocois* Bondar	Larva	Brazil	49 days	The larvae make mines in the fronds.	[24]
		Chrysomelidae	*Alurnus humeralis* Rosenberg	Larva/Adult	Colombia and Ecuador	334–532 days	This insect attacks spear leaves and young opened leaves.	[8,22]
			Gyllenhalius palmarum Maulik	Larva	Ghana and Nigeria	–	-	[8]
			Spaethiella tristis Boheman	Larva/Adult	Brazil, Colombia and Suriname	45 days	Adults feed on leaflets, making small longitudinal grooves. Larvae scrape only the undersides of leaflets. Damage can reach between 50–60% of leaf surface	[8,22]
		Scarabaeidae	*Adoretus compressus* Webb.	Adult	Southeast Asia	–	Adult feeds on leaflets of oil palm seedlings	[25]
			Apogonia expeditionis Ritsema	Adult	Southeast Asia	–	Adult feeds on leaflets of oil palm seedlings	[25]
			Leucothyreus femoratus Burmeister	Larva/Adult	Colombia	170 days	Adult cut irregular square or rectangular holes on leaves. Leaf consumption per adult is 13mm^2/day. Larvae also feed on roots.	[21,26]
	Lepidoptera	Depressariidae	*Acria meyricki* Shashank and Ramamurthy	Larva	India	33 days	Early instars feed on green parenchymatous tissues of the leaflets from the underside, leaving a thin parchment-like upper epidermis undamaged, while the later stages defoliate the leaves.	[27]
		Elachistidae	*Loxotoma elegans* Zeller	Larva	Brazil, Bolivia, Colombia and Panama	100–124 days	Damage begins with the lower leaves and can reach all the levels. Infestation symptoms include defoliation of the apical part and the center of the leaves.	[21,28]
			Stenoma cecropia Meyrick	Larva	Colombia	74–89 days	Leaf consumption by each larva is 40–50 cm^2	[21]
			Stenoma impressella Busck	Larva	Colombia, Ecuador, Guatemala, Honduras, Panama, Peru and Venezuela	60–67 days	A single larva consumes a mean of 40–50 cm^2 of leaf material. In later feeding, the entire leaf tissue, except for midveins, is consumed.	[8,29]

Table 1. *Cont.*

Type of Pest	Order	Family	Pest	Stage	Distribution	Life Cycle	Extent of Damage	Reference
			Antaeotricha phaeuneura Meyrick	Larva	Argentina, Brazil, Colombia and Ecuador	47 days	Larvae scrape the upper and undersides of the leaflet, causing progressive dryness, but the overall damage is minimal.	[7,22]
		Limacodidae	*Acharia fusca* Stoll	Larva	Colombia, Ecuador, Guyana, Honduras, Peru, Suriname and Venezuela	76–94 days	A single larva can consume 400 cm^2 of leaf area in a few days.	[30]
			Darna bradleyi Holloway	Larva	Southeast Asia	44–48 days	Causes severe damage to oil palm canopy at population density of 30 larva per frond	[25]
			Darna trima Moore	Larva	Southeast Asia	60 days	Causes severe damage to oil palm canopy at population density of 10–20 larva per frond	[25]
			Euclea diversa Druce	Larva	Brazil, Costa Rica, Colombia, Honduras and Peru	61–88 days	A single larva can consume 50–60 cm^2 of leaf area in a few days. Under favorable conditions, the pest can swarm and cause more damage	[7,22]
			Euprosterna elaeasa Dyar	Larva	Brazil, Colombia, Ecuador, Guyana, Mexico, Panamá, Peru, Suriname, Trinidad and Tobago, and Venezuela	64 days	A single larva consumes ~66 cm^2 in a few days, and the pest causes ~80% loss of plant canopy.	[31]
			Natada subpectinata Dyar	Larva	Argentina, Brazil, Colombia, Costa Rica, Paraguay and Suriname	35–106 days	Damage is uniform and, in some cases, they damage the whole blade leaving only the midrib of the leaflet.	[7,21]
			Sibine fusca Stoll	Larva	Colombia and Peru	78–103 days	A single larva can consume 400-600 cm^2 of leaflets.	[22]
			Talima straminea Schaus	Larva	Brazil, Colombia, Ecuador, Guyana and Mexico	120–160 days	Sporadic leaf scrapping, with minimal harm to the tree.	[7]
		Nymphalidae	*Amathusia phidippus* L.	Larva	Southeast Asia and the Malay Archipelago	60 days	Larvae are voracious feeders on the underside of the leaf, eating backwards towards the base from the tip of the leaf.	[8,32]
			Brassolis sophorae L.	Larva	Argentina, Brazil, Bolivia, Colombia and Ecuador	81–125 days	A single larva can consume 500-600 cm^2 of leaf area in a few days.	[7,21]
			Opsiphanes cassina Felder	Larva	Central America, Colombia, Ecuador and Peru	59–77 days	An individual larva may consume up to 800 cm^2 of foliar tissue	[8,21,33]
			Opsiphanes invirae Huebner	Larva	Brazil	59–77 days	Initially, the infestation occurs at the plantation edges, with subsequent spread to the entire area. Larvae disperse by passing from one plant to another, infesting all the area.	[7,11]

Table 1. *Cont.*

Type of Pest	Order	Family	Pest	Stage	Distribution	Life Cycle	Extent of Damage	Reference
		Psychidae	*Clania tertia* Templeton	Larva	Indonesia and Malaysia	120 days	A single larva can consume 4.8–5.4 cm^2 leaf area per day.	[34]
			Mahasena corbetti Tams	Larva	Southeast Asia	143–166 days	The severe defoliation can be lethal to infested trees and can cause 40–50% yield loss of oil palm in two years.	[35]
			Manatha conglacia Haettenschwiler	Larva	Indonesia and Papua New Guinea	–	Young larvae scrape the parenchyma.	[36]
			Metisa plana Walker	Larva	Indonesia and Malaysia	103.5 days	Causes high yield losses up to 43% in years	[37]
			Oiketicus kirbyi Guilding	Larva	Colombia, Costa Rica, Ecuador, Mexico and Trinidad and Tobago	235–320 days	First to third instars scrape the parenchyma but from fourth instar onwards, the larvae consume the entire leaf in circular patterns.	[7,8]
			Pteroma pendula Joannis	Larva	Indonesia and Malaysia	43–46 days	Cuts small holes which result in leaf desiccation with high infestation, with almost all fronds being affected and plantation dieback at severe infestation levels.	[25,38,39]
		Saturniidae	*Automeris liberia* Cramer	Larva	Central and South America	78–80 days	Larvae destroy the underside of the leaflets at any stage of the palm. Their stinging hairs are hazardous to nursery and landscape workers.	[7,21]
			Dirphia gragatus Bouvier	Larva	Colombia, Ecuador and Peru	60–166 days	A single larva can consume 400–600 cm^2 in a few days.	[21,40]
	Orthoptera	Tettigoniidae	*Segestes decoratus* Redtenbacher	Nymph/Adult	Papua New Guinea	-	Often attack the younger fronds first, but dense populations can effectively defoliate the entire palm. Their damage is noticeable before the insects themselves are seen.	[8]
			Segestidea defoliaria Uvarok	Nymph/Adult	Papua New Guinea	-	Same as *S. defoliaria*	[8]
			Segestidea novaeguineae (Brancsik)	Nymph/Adult	Papua New Guinea	-	Same as *S. defoliaria*	[8]
			Sexava coriaceae L.	Nymph/Adult	Eastern Indonesia	-	Similar to *S. defoliaria*	[41]
Sap suckers	Hemiptera	Cixiidae	*Haplaxius crudus* Van Duzee	Adult	Colombia, Mexico and USA	45 days	Vector of lethal yellowing disease.	[8,21]
		Miridae	*Carvalhoia arecae* Miller and China	Adult	India	-	Occupies the leaf axils of the youngest fronds and attack the spear leaf, which develops chlorotic streaks in the newly unfolded frond.	[42,43]
		Tingidae	*Leptopharsa gibbicarina* Froeschner	Adult	Colombia and Venezuela	62–75 days	Vector of *Pestalotiopsis* fungal complex through piercing and sucking of sap from leaves.	[44]
			Stephanitis typica (Distant)	Nymph/Adult	New Guinea and Tropical Asia	50 days	Stylets are inserted through the stomata, rupturing cell walls, terminating in the phloem, and penetrating to a maximum of 600 µm.	[17,45]

Table 1. *Cont.*

Type of Pest	Order	Family	Pest	Stage	Distribution	Life Cycle	Extent of Damage	Reference
Scrapers and Miner	Coleoptera	Chrysomelidae	*Cephaloleia vagelineata* Piceus	Larva/ Adult	Brazil, Colombia, Costa Rica, Guatemala, Honduras, Mexico and Venezuela	130 days	Adults scrape leaflets of young fronds before they are fully unfolded, forming fossae parallel to major veins; whereas larvae feed on surfaces of the rachis of spear leaves and young fronds causing necrosis.	[8,21,46]
			Delocrania cossyphoides Guérin	Larva/ Adult	South America to Panama	-	The larvae and adult beetles occur together on young foliage, both of them feeding on the abaxial epidermis of palm leaflets, starting near the midvein and extending laterally.	[47]
			Demotispa neivai Bondar	Larva/ Adult	Brazil, Colombia, Panama and Venezuela	270 days	Larvae and adults scrape green fruits causing wounds that turn greyish.	[22,48]
			Hispoleptis subfasciata Piceus	Larva/ Adult	Brazil and Colombia	104 days	Adult feeding makes grooves parallel to the midrib of the leaflet. Larvae mine inside the leaflet forming a gallery.	[8,21]

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 [8]. 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 [26]; those of *Acharia fusca* Stoll (Lepidoptera: Limacodidae) take 76–94 days [30]; and those of *Metisa plana* Walker (Lepidoptera: Psychidae) take 72 days [37]. There are, however, some oil palm defoliators with short larval durations, e.g., *Acria meyricki* Shashank and Ramamurthy (Lepidoptera: Depressariidae) with approximately 20 days [27]. 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 [8].

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 [49]. These caterpillars are controlled using a variety of approaches. Damage by *Euprosterna elaeasa*, and other Neotropical lepidopteran defoliators also facilitates the spread of oil palm *Pestalotiopsis* fungal pathogen [29]. 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 [31]. *Euprosterna elaeasa* is commonly controlled using synthetic insecticides, although insecticide-resistance has been noted [50]. Essential plant oils, notably from *Cymbopogon martinii* [51], insect growth regulators such as fenoxycarb, methoxyfenozide, pyriproxyfen, and tebufenozid [52], the nucleopolyhedrosis virus EuelNPV [53], and *Bacillus thuringiensis* Berliner (*Bt*) strains [52] 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 [44,53].

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 [54]. 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 [49], 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 [34,36].

Mahasena corbetti Tams is one of the large bagworm species which is endemic to Malaysia, but it has spread across the Paleotropical region [54]. 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 [35]. 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 [55–58]. 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 [56]. Larval feeding causes yellowing and subsequent dying and falling of leaves [59]. *Mahasena corbetti* is highly prolific, with each female laying over 3000 eggs, hence making the pest efficient at creating outbreaks [55]. 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 [23]. 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 [60]. Though laborious, hand-picking of *M. corbetti* larval bugs which actively move during bright sunlight can be effective against the pest [56].

Other bagworms, such as *M. plana* and *Pteroma pendula* Joannis are significant oil palm defoliators across Southeast Asia [37,61,62]. 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 [62]. In addition, several species of hymenopteran parasitoids such as *Apanteles* sp., *Dolichogenidea metesae* (Nixon), *Brachymeria carinata* Joseph, *Goryphus bunoh* Gauld, *Pediobius anomalus* (Gahan), *Apanteles aluella* (Sumatra), *Cotesia* sp. and *Glypapanteles* sp.; as well as predators such as *Callimerus arcufer* Chapin (Coleoptera: Cleridae) and *Cosmolestes picticeps* Stål (Hemiptera: Reduviidae) reportedly attack the bagworms in Malaysia [38], 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* [38] and their susceptibility to chemical insecticides [62], 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 [8]. 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 [8,63,64].

The palm king *Amathusia phidippus* (L.) (Lepidoptera: Satyrinae) is a common defoliator of oil palm in Southeast Asia [8]. 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* [8].

The split-banded owlet *Opsiphanes cassina* Felder (Lepidoptera: Nymphalidae) is an important pest of oil palm in Central America, Colombia, Ecuador and Peru [22]. 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 [22]. 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 [65]. In Brazil, the mass production of the parasitoid wasp *Palmistichus elaeisis* Delvare & LaSalle (Hymenoptera: Eulophidae) from alternative hosts has allowed inundative biological control of *O. invirae* populations in oil palm crops [66].

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 [67]. 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 (Table 1) and are controlled using different methods. The entomopathogenic fungus *Metarhizium* sp. was used to control *Alurnus humeralis* Rosenberg in Ecuador [68]. Dense populations of *C. vagelineata* have been observed to diminish after heavy rains [22,46]. Barrios et al. [46] 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

Segestidea novaeguineae (Brancsik), *Segestidea defoliaria* Uvarok and *Segestes decoratus* Redtenbacher (Orthoptera: Tettigoniidae) are pests of oil palm in Papua New Guinea [8]. Meanwhile, *Valanga nigricornis* Burmeister (Orthoptera: Acrididae), *Sexava nubila* and *S. coriacea* (Orthoptera: Tettigoniidae) were reported on oil palm in Indonesia [41]. They 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 [8]. The nymphs and adults of endoparasite *Stichotrema dallatorreanum* Hofeneder (Strepsiptera: Myrmecolacidae) are potential classical biocontrol agents against these grasshoppers [69].

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 [48]. Adults of *D. neivai* are reddish-brown, oval-shaped, dorsally flattened, and convex laterally [26]. Adults damage oil palm fruits, with a consumption rate of 12.35 mm^2 d^{-1} per adult on exocarp [48]. The scrapping 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* [70]. 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 [71].

2.3. Sap Feeders

Prominent oil palm sap feeders are true bugs (Heteroptera) in the families Miridae and Tingidae [8]. For instance, the spindle bug *Carvalhoia arecae* Miller and China (Hemiptera: Miridae) attacks young oil palms in nurseries [43,72]. 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 [73].

Among tingids, the lace bug *Stephanitis typica* (Distant) is the best-known sapsucker associated with palms in Asia through to New Guinea [8]. Females typically lay eggs concealed in a lipid substance and insert them deep in the abaxial surfaces of fronds. Nymphs hatch after about 12 days. *Stephanitis typica* populations surge during dry periods. Stylets are inserted through the stomata, rupturing cell walls and terminating in the phloem [17]. 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 [8]. *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 [74].

Another notable tingid associated with oil palm is *Leptopharsa gibbicarina* Froeschner [8]. It is also the main vector of the *Pestalotiopsis* fungal complex in oil palm in the Americas [52]. 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 [75]. 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 *Pestalotiopsis* spp. Natural enemies of *L. gibbicarina* include Neuroptera, ants (especially *Crematogaster* spp.) and *B. bassiana* [76]. When these are not effective in maintaining low populations of the lacebug, an option is to treat the palm with a systemic insecticide [8]. Martínez et al. [52] reported that novaluron, teflubenzuron, and triflumuron are highly effective against *L. gibbicarina*.

Besides insects, at least 31 species of tetranychid mites attack palms [8]. For instance, *Retracrus elaeis* Keifer (Acari: Eryophidae), feeds on the abaxial frond surfaces of oil palms in tropical America [75]. This mite has been associated with severe yellowing of palm leaves. Foliar spraying with sulfur reduces its severity [77]. 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 [8].

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 [16].

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 [78]. 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 Arecaceae and sometimes including other monocotyledons, such as sugarcane (Poaceae), banana (Musaceae) and pineapple (Bromeliaceae) [16]. Palm weevil borers fall into seven subfamilies: Dryophthorinae (Rhynchophorinae), Cholinae, Baridinae, Erirhininae, Petalochilinae, Scolytinae and Platypodinae. In particular, palm-associated members of the Rhynchophorinae 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 [16].

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 [16]. Adults of *Dynamis* species are usually glossy black, in contrast to *Rhynchophorus* species which can exist in varying colors [11]. *Dynamis* and *Rhynchophorus* lay between 30 and 832 eggs during a 42-day oviposition period [11].

No species of *Dynamis* has been reported on oil palm. However, oil palm is attacked by *Rhynchophorus palmarum*, *R. bilineatus*, *R. phoenicis, R. quadrangulus* and *R. ferrugineus* [11,12,15,79–82]. The main pathway through which the weevils spread outside their native regions is through the movement of infested palms [83]. 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 [84]. 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 [11]. 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 [16].

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 [85]. 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 the curative 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 [85]. 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 [82]. Adult populations of palm weevils can be monitored by pheromone traps, acoustic detection or infra-red systems [10,81,84]. Abandoning oil palm fields over time makes them reservoirs for the weevils [86]. Flood irrigation causes dampness at the base of the palm and its offshoots, creating a favorable environment for the weevils to lay their eggs [87]. The chemicals used to control palm weevils include methidathion, oxydemeton-methyl, carbaryl, cypermethrin, deltamethrin dimethoate, chlorpyrifos, fipronil, imidacloprid and trichlorphon [88]. 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 [84]. 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 [88].

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 [10].

Another weevil attacking bases of pruned oil palm fronds is *Metamasius inaequalis* (Gyllenhal) (Coleoptera: Curculionidae) [14]. Pitfall traps and palm tissue baited with aggregation pheromone and treated with insecticides are reportedly effective in controlling *M. inaequalis* [8]. Additionally, *Temnoschoita quadrimaculata* Gly. (Coleoptera: Curculionidae) is a borer of oil palms in nurseries and young plantations in Ghana [89]. 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. quadrimaculata* [16]. The base-borer weevil, *Sparganobasis subcruciata* Marshall (Coleoptera: Curculionidae: Dryopthorinae) is also a lethal pest of oil palm in Papua New Guinea and Indonesia [15,18]. 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 [90]. 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 [16]. 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 [91]. Although insecticides such as lambdacyhalothrin, cypermethrin, fenvelarate and chlorpyrifos are commonly used against *O. rhinoceros*, their effectiveness is limited due to the cryptic nature of the beetles inside the plant tissue [91]. A male-produced aggregation pheromone, ethyl-4-methyloctanoate [92], is widely used in mass trapping, monitoring and augmentation with biopesticides [93,94]. 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 [91,95]. These reports highlight *Rhabdionvirus 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* [95]. 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 [94].

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 [20] and chemical insecticides are the main methods of controlling *S. aloeus* [96].

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 [8]. 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, *Ooencyrtus* 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 [16,51]. 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 [97]. Insecticide application is recommended for infestation levels, where 20% of the primary roots are attacked [49]. Cultural control methods involve keeping and maintaining clean borders between the plantation and the surrounding forest [16]. Mulching with empty bunches prevents the caterpillar from getting into the roots [49]. Biological control with the entomopathogenic nematode *Steinernema carpocapsae* is reportedly effective against *S. valida* in the laboratory and field trials [16], 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* [49].

The African spear borer *Pimelephila ghesquierei* (Tams) (Lepidoptera: Crambidae) is a pest of oil palm in West Africa [8]. Two or three neonates penetrate the leaflets of the growing, unopened spears, forming galleries and mostly destroying the bases of young palms [17]. 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 [23]. Collection and destruction of pupae have been recommended to prevent population build-up in nurseries or young plantations [23]. The pest mostly attacks stressed and/or shaded palms [23].

3. Selected Research Advances on Sustainable Management of Oil Palm Pests

3.1. Semiochemicals

Semiochemicals are chemical signals which meditate behavior of organisms such as attraction to mates or host plants, and avoidance of non-hosts or natural enemies by insects [98]. They are widely used in insect pest control, e.g., as lures for monitoring, mass trapping and attract-and-kill strategies. These natural chemical signals are largely species-specific and less persistent in the environment; therefore, they are harmless to non-target insects and do not pollute the environment.

The use of semiochemicals in oil palm pest management programs as lures, repellents and mating disrupters is gaining popularity [10,86]. For instance, males of palm weevils produce aggregation pheromones that are applied in weevil trapping [14]. Palm weevil pheromones comprise 8, 9, or 10 carbon, methyl-branched, secondary alcohols. The major components of the aggregation pheromones of *R. ferrugineus*, *R. phoenicis*, and *R. palmarum* are (4S,5S)-4-Methyl-5-nonanol (ferrugineol), (3S,4S)-3-methyl-4-octanol (phoenicol), and (4S,2E)-6-methyl-2-hepten-4-ol (rhynchophorol), respectively [14]. Fermentation host-plant volatiles such as ethyl esters and ethanol strongly enhance the attractiveness of pheromones [14]. However, the pheromones attract more weevils than host-derived volatiles alone [81]. Pheromone-based mass trapping using one trap per acre has been successful in controlling *R. palmarum* in oil palm plantations in Central and South America [99]. Semiochemical lures appear to be superior in detecting the occurrence of palm weevils over the use of host–plant infestation symptoms [82,83]. Most palm weevil attractants lure more females than males [81], which could be attributed to the higher sensitivity of female antennae to the odors than those of males [100].

Besides palm weevils, *Oryctes rhinoceros* males produce an aggregation pheromone, (4S)-ethyl 4-methyloctanoate, which is synergized with fermenting oil palm fruit bunches to attract males and females [92]. Trapping adults of *O. rhinoceros* using one trap per two hectares and serviced biweekly lowers the weevil damage by over 90% and is less expensive than the application of insecticides [101]. The pheromone trap efficiency improves when the traps are elevated above the oil palm canopy level [102].

Furthermore, the female produced sex-pheromone components of two nettle caterpillars that defoliate oil palm in Southeast Asia, *Darna trima* (Moore) [(*S*)-2-methylbutyl (*E*)-7,9-decadienoate and (*E*)-2-hexenyl (*E*)-7,9-decadienoate] and *Darna bradleyi* Holloway [(*E*)-7,9-

decadienoate and isobutyl (*E*)-7,9-decadienoate] are synergistic attractants of males [103]. However, the application of these sex pheromones in the management of the nettle caterpillars is still scarcely documented.

The success of semiochemicals in pest management critically depends on the optimization of the technique to remove the target pests faster than they can reproduce [100]. This entails proper release mechanisms, catch retention mechanisms and proper trap densities and placement distances. The key limitations to the use of semiochemicals in pest management include lower efficiency in eliminating pests compared to conventional insecticides and costly equipment needed for their extraction and characterization.

Semiochemicals are also gaining prominence in pest control for their role in the dissemination of entomopathogenic microbes, e.g., fungi, bacteria and viruses through a mechanism termed attract-and-infect or auto-dissemination [104]. This concept has been attempted with the attraction of the oil palm pest *O. rhinoceros* and its infection with the entomopathogenic fungus *M. anisopliae* [49]. The medium-term research area is the evaluation of this technique in the dissemination of different pathogens against oil palm pests whose attractants have been identified. This can also be followed with other pests whose semiochemical attractants will be identified in the long run.

3.2. Bioacoustics and Other Signal Sensors

Insects that bore and hide inside trees exhibit different acoustical characteristics. Every activity of the insect produces some acoustic trait which is detectable using sensors. Oil Palm borers, especially larvae of *Rhynchophorus* spp. develop within the tree stem, damaging the vascular system and leading to the death of the infested tree. Early detection is normally a challenge as the infestation is concealed until the tree is severely damaged. The larval feeding/chewing activity and movements inside the palm tree produce sound with specific frequencies and spectra, which can help with the early detection of infestation for timely remedial actions to avert severe damage [105]. Manual filtering of external stimuli such as wind and ambient noise enables the detection of palm weevil infestation in an unshielded natural environment [106].

An acoustic *R. ferrugineus* detection system for field application in coconut accurately detected larval infestation by 97%, with a false-positive rate of about 8% [107]. Human and machine detection systems of *R. ferrugineus* larval infestation sound were 75% and 80% accurate, respectively [106]. The sensitivity was lower during the early phase of infestation (39% and 33%, respectively), and significantly improved as the larvae developed. Both larvae and adults of *Rhynchophorus* spp. can be detected acoustically [108]. Different types of acoustic detection systems have been used successfully to detect *R. ferrugineus* larval sounds in the laboratory and the field [109–112].

Besides acoustic sensing, Thermal Imaging Detection, which entails sensing temperature changes associated with pest infestation using an infrared camera, could be used in pest detection on the grounds that the temperature increases proportionately with the increase in the number of larvae inside the trunk [105]. Another promising automated pest infestation signal is the changes in volatiles emanating from infested trees. For instance, the odor of *Rhynchophorus*-infested trees produces a scented signal that dogs can be trained to detect but requires frequent retraining [111]. Moreover, it is possible to employ modern chemical sensors such as an electronic nose, which comprises a sensor array that is responsible for sensing the chemicals and algorithms which provide an analyzing software model in the system [112].

3.3. Entomophagy

Several insect pests are highly nutritious and are delicacies in many communities around the world, especially in Asia, Africa and Latin America. For example, *Rhynchophorus* species are among the most consumed insects worldwide because they are large, tasty, nutritious and abundant [8]. *Rhynchophorus phoenicis* and *R. quadrangulus* are a delicacy in African countries such as Cameroon, Ghana, Nigeria and Uganda and are rich in proteins, fats and minerals [113–115]. In Suriname and Ecuador, *R. palmarum* is a delicacy, which is eaten either raw or cooked [8]. *Oryctes* spp. are also widely consumed in Africa, South America and Asia [116–118]. Among numerous edible insects in Peru are larvae of *C. daedalus* which are gathered by the Ashaninka communities during seasonal outbreaks [118].

Based on the above accounts of harvesting wild insect pests of oil palm in some communities around the world, we envisage that promoting the culture of insect consumption in these communities could serve multiple purposes of crop protection and improvement of human nutrition. However, these edible insect pests are harvested from the wild using rudimentary methods. The practice of cutting and splitting up infested palm trees to extract edible insects from traditional collectors is destructive and unsustainable, hence necessitating the development of techniques for luring the insects into a trap for either consumption or captive mass rearing to produce the edible stage of the insects [81].

3.4. Host Plant Resistance

Host-plant resistance entails the intentional use of resistant crop varieties to reduce the impact of a pest on crop yield or quality. Four major steps are involved in developing and dissemination of pest resistant crop varieties namely (i) evaluation of crop germplasm for resistant genotypes; (ii) assignment of resistance phenomena to the desired categories such as antibiosis, antixenosis, and tolerance; (iii) introduction of genes responsible for resistance; and (iv) integration of resistant varieties into pest management strategies [119].

de Oliveira et al. [7] reported that oil palm genotypes influenced its susceptibility to defoliators, with interspecific crosses between oil palm and its close relative *Elaeis oleifera* (Kunth) such as genotype Deli × Lamé being more susceptible to the leaf-eaters compared to crosses involving different varieties of oil palm. The high susceptibility of the genotype Deli × Lamé was of great concern as the variety is popularly grown worldwide due to its high yields. Further research on the mechanisms of resistance of some oil palm genotypes to pests will be helpful in developing resistant varieties with additional good attributes such as high yield. This can be enhanced by transgenic breeding, which has already been initiated for the speedy development of oil palm varieties with desirable traits including pest-resistance [120]. Host plant resistance will lead to a reduction in pesticide use, hence reducing pesticide residues in the environment and leading to increased activity of beneficial organisms

3.5. Nanotechnology

Nanotechnology research and development involves understanding and controlling matter at the nanoscale (i.e., approximately 1–100 nm) for novel applications in different fields such as information technology, security, medicine, transportation, energy, food safety, environmental science and agriculture [121]. Although its utilization in the oil palm industry is still limited, nanotechnology has immense promise for early pest detection, monitoring of pest spread and improvement in pesticide formulations for more efficiency and reduced toxicological impacts [122]. For instance, encapsulation of pesticides with nanoparticles reportedly reduces the rate of application by 10–15 times compared to classical formulations, hence proportionately reducing the amount of pesticides used to control pests [123].

Although 90% of nano-based patents and products still come from only seven countries, namely, Germany, France China, Japan, South Korea, Switzerland, and USA, there are already several insecticides encapsulated with nanoparticles from silver, silica, copper, iron and carbon for the control of insect pests/vectors such as mosquitoes, beetles, weevils, aphids and white flies [124]. It is also hypothesized that nanomaterials can be combined with a global positioning system (GPS) and remote sensing to develop crop pest detectors and monitoring systems based on spectral images [121]. The longer persistence, enhanced transport and higher toxicity of nanoparticles may however result in harmful impacts on the environment such as contamination and detrimental impacts to non-target organisms [124], which need to be continuously evaluated.

3.6. Insect Growth Regulators

Developing compounds that provide more environmentally friendly insect pest control has been a challenge. Insect growth regulators (IGRs) are synthetic insect hormones that are employed as insecticides to regulate the populations of harmful insect pests by interfering with their growth and development processes such as molting. They are less toxic to non-target organisms [125]. For instance, fenoxycarb, methoxyfenozide, pyriproxyfen, and tebufenozide are lethal to *E. elaeasa* larvae, with more than 55% mortality [44]. Other IGRs derivate of benzoylphenyl ureas were also used for the control of *L. gibbicarina* [52]. Novaluron, teflubenzuron, and triflumuron are reportedly highly effective against *L. gibbicarina* nymphs [52]. The reports demonstrate that IGRs can be investigated and applied in the management of other oil palm pests. However, similarities in biochemical processes among vertebrates and invertebrates may result in the limited development of insect growth regulators [126], as there could be a possibility of the synthetic hormones interfering with the biochemical processes of non-target organisms.

3.7. Geospatial Predictive Modeling

The use of predictive techniques such as Geographic Information System (GIS), Remote Sensing (RS) and Global Navigation Satellite System (GNSS) to collect, map, and analyze data on the current and potential future distribution of insect pests is a growing agricultural practice in modern times [127]. Proactive identification of locations and/or seasons that are suitable for pest establishment or outbreak enables timely and appropriate decision-making on preventive or rapid response interventions, e.g., surveillance, monitoring, quarantine or curative control. Using ecological niche modeling approaches, Fiaboe et al. [79] successfully predicted the known distribution of *R. ferrugineus*, including the single North American occurrence point of Laguna Beach, California. Based on these models, the authors predicted all areas that are suitable for *R. ferrugineus* establishment around the world. This approach is worth emulating in the prediction of the spread and outbreaks of other oil palm pests for more effective management.

In Colombia, the use of GIS and spatio-temporal analysis concepts in the "campaign of defoliators", have offered advantages in the implementation of IPM to monitor oil palm pest populations [50]. In this sense, the detection of foci or areas of regional influence, identification and categorization of damage patterns, use of different control methods, evaluation and forecast of insect movements, population demographic explosions, and localized application of chemical insecticides have been integrated into the GIS technology. This is generating regional action plans, demonstrating that control of defoliating insect pests can serve to generate dividends, which are reflected in the reduction in pest management costs.

4. Regulatory Management of Oil Palm Pests

The movement of infested palms plays a key role in aiding the spread of invasive pests to new regions [10,85]. For instance, the rapid spread of *R. ferrugineus* in North Africa was attributed to ineffective quarantine regimes, weak enforcement, and difficulty in early detection of the pest [128]. Therefore, strict pre- and post-entry quarantine regulations such as stopping the importation of palm offshoots from already infested countries are highly important in preventing the spread of invasive oil palm pests.

Regulatory strategies helped to prevent the spread of *R. ferrugineus* in Mauritania and Morocco, restricting it to the original foci of the infestation [128]. In 1996, Spain published an order detailing provisional measures for preventing the spread of *R. ferrugineus* in the country [129]. These included the prohibition of the importation of all Palmaceae from non-European Union (EU) countries, compulsory use of the EU Plant Passport for any movement of Palmaceae originating within the EU and eradication measures, including chemical treatments, pheromone trapping and destruction of infested specimens both in public and private gardens. In 2000, these restrictions were extended to all *Rhynchophorus* species; and referred to all specimens belonging to the Palmaceae family with an upper diameter of greater than 5 cm, with the exception of seeds and fruits [130].

The explosive spread of *R. ferrugineus* in Europe in 2004 prompted the EU to publish the Commission Decision 2007/365/EC on emergency measures for curbing its spread [131]. The decree prohibited the introduction and spread of *R. ferrugineus* into the EU and laid down strict requirements for importing plants that are susceptible to the pest. It required member states to adopt measures to protect themselves against the introduction and spread of *R. ferrugineus* such as conducting official annual surveillance and notifying the Commission and the other Member States about their findings. Penalties were set out that were to be applied in case of infringement. This decision was modified in October 2008 [132] and August 2010 [133]. The main modifications were: (i) palms to be only imported from areas where they have been grown throughout their life either in a country where *R. ferrugineus* is not known to occur, or in *R. ferrugineus*-free areas. Otherwise, palms should have been grown during a period of at least one year prior to export in a place of production subjected to official inspections certifying that no signs of *R. ferrugineus* presence have been observed; (ii) plants to be accompanied by a plant passport and, if originating from an infested area, they should have been grown for two years prior to the movement in a site with complete physical protection against *R. ferrugineus*, and no signs of its presence should have been observed during official inspections; and (iii) establishment of demarcated areas within the EU infested countries including the infested zone plus a buffer zone of at least 10 km beyond the boundary of the infested zone. Extensive monitoring and appropriate measures against *R. ferrugineus* aimed at its eradication should be carried out within these areas. The above measures helped in the successful eradication of *R. ferrugineus* in the Canary Islands [10] and Spain [128]. However, the pest has still been continuously detected within the EU probably due to (i) poor techniques for early detection of infested palms; (ii) shortage of a sound quarantine treatment against the weevil; (iii) the problem of involving homeowners within the process; (iv) the risks related to the employment of mass trapping in uninfested areas; and (v) the dearth of highly effective, environmentally safe plant protection strategies (biological control, semiochemicals, soft pesticides) suitable for public areas such as gardens, parks and avenues [10]. The lessons learned from the EU regulations against the spread of *R. ferrugineus* need to be considered in improving the efficiency of regulatory measures for the management of invasive oil palm pests in the region and developing regulatory frameworks for other oil palm growing regions of the world.

5. Conclusions and Future Research Directions

In this review, different control methods against key oil palm pests have been highlighted and advances in research on their management analyzed. We conclude that a large diversity of insect pests are serious bottlenecks to optimal productivity of oil palm globally and few have been well managed and studied. Therefore, knowledge of the biology and ecology of these insects is necessary to establish control programs, particularly for those species that can cause quantitative/qualitative damage during plant vegetative and reproductive phases. The traditional techniques used to manage these pests include:

1. Application of synthetic insecticides;
2. Biological control techniques such as entomopathogens (e.g., fungi, bacteria and nematodes), predators and parasitoids;
3. Monitoring and mass trapping with semiochemicals;
4. Cultural practices, and occasionally,
5. A combination of the different techniques in an integrated pest management approach.

Although some of these approaches are effective, others may be ineffective, unaffordable, unavailable or negatively impact on human and environmental health. In addition to re-emphasizing the need for intensification of the integrated pest management approaches for more effective management of these pests, research and development effort is especially required in:

1. Exploration of semiochemical attractants for the majority of pests with no previous semiochemical work, and integration of the chemical lures with microbial pathogens in the attract-and-infect technique;
2. Expansion of the application of modern pest management techniques such as digital sensing, predictive modeling and nano-technology;
3. Developing effective technologies for mass trapping of edible oil palm insect pests for food or feed, especially among communities with a tradition of entomophagy.;
4. Strengthening quarantine regulatory frameworks and building requisite human resource capacity for their implementation in the management of invasive oil palm insect pests.

In the future, the challenge will be to implement new alternatives that promote biological control, identify new molecules that act as semiochemicals or growth disruptors, produce pest-resistant materials, and develop new biotechnological tools to produce high-quality products with greater efficiency in controlling oil palm pests in sufficient quantities at low cost. Moreover, due to their incorporation into agroecosystems, it is important to evaluate the compatibility of these methods with others for the conservation, inoculation or release of biological control agents.

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References

1. Murphy, D.J.; Goggin, K.; Paterson, R.R.M. Oil palm in the 2020s and beyond: Challenges and solutions. *CABI Agric. Biosci.* **2021**, *2*, 39. [CrossRef]
2. Ritchie, H.; Roser, M. Forests and Deforestation. Available online: https://ourworldindata.org/forests-and-deforestation (accessed on 30 June 2022).
3. Kuepper, B.; Drost, S.; Piotrowski, M. *Latin American Palm Oil Linked to Social Risks, Local Deforestation*; Chain Reaction Research: Washington, DC, USA, 2021.
4. Obahiagbon, F.I. A review: Aspects of the African oil Palm (*Elaeis guineesis* Jacq.) and the implications of its bioactives in human health. *Am. J. Biochem. Mol. Biol.* **2012**, *2*, 106–119. [CrossRef]
5. Pirker, J.; Mosnier, A.; Kraxner, F.; Havlík, P.; Obersteiner, M. What are the limits to oil palm expansion? *Glob. Environ. Change* **2016**, *40*, 73–81. [CrossRef]
6. Woittiez, L.S.; Van Wijk, M.T.; Slingerland, M.; Van Noordwijk, M.; Giller, K.E. Yield gaps in oil palm: A quantitative review of ontributing factors. *Eur. J. Agron.* **2017**, *83*, 57–77. [CrossRef]

7. de Oliveira, T.A.; Martins, I.C.F.; Silva, J.G.; Lemos, W.P. Oil palm age and genotype interfere with defoliator lepidopteran infestation. *Arq. Inst. Biol.* **2021**, *88*, e00472020. [CrossRef]
8. Howard, F.; Moore, D.; Giblin-Davis, R.; Abad, R. *Insects on Palms*, 1st ed.; CABI Publishing: Oxon, UK, 2001.
9. Hushiri, A.; Abdu, M.; Nambiappan, N.; Hisamuddin, E.; Bidin, M.N.I.Z.; Ghazali, R.; Subranian, V.; Sundram, S.; Parveez, G.K.A. Oil palm economic performance in Malaysia and R & D progress in 2018. *J. Oil Palm Res.* **2019**, *31*, 165–194. [CrossRef]
10. Giblin-Davis, R.M.; Faleiro, J.R.; Jacas, J.A.; Pena, J.E.; Vidyasagar, P. Biology and management of the red palm weevil, *Rhynchophorus ferrugineus*. In *Potential Invasive Pests of Agricultural Crops*; Pena, J., Ed.; CAB International: Wallingford, UK, 2013; pp. 1–34.
11. Wattanapongsiri, A. A revision of the Genera *Rhynchophorus* and *Dynamis* (Coleoptera: Curculionidae). Ph.D. Thesis, Oregon State University, Corvallis, OR, USA, 1996.
12. Hallett, R.H.; Crespi, B.J.; Borden, J. Synonymy of *Rhynchophorus ferrugineus* (Olivier) 1790 and *R. vulneratus* (Panzer) 1798 (Coleoptera, Curculionidae, Rhynchophorinae). *J. Nat. Hist.* **2004**, *38*, 2863–2882. [CrossRef]
13. Plata-Rueda, A.; Martínez, L.C.; Fernandes, F.L.; Ramalho, F.S.; Zanuncio, J.C.; Serrão, J.E. Interactions between the Bud Rot disease of oil palm and *Rhynchophorus palmarum* (Coleoptera: Curculionidae). *J. Econ. Entomol.* **2016**, *109*, 962–965. [CrossRef]
14. Giblin-Davis, R.M.; Oehlschlager, A.C.; Perez, A.; Gries, G.; Gries, R.; Weissling, T.J.; Chinchilla, C.M.; Peña, J.E.; Hallett, R.H.; Pierce, H.D.; et al. Chemical and behavioral ecology of palm weevils (Curculionidae: Rhynchophorinae). *Fla. Entomol.* **1996**, *9*, 153–167. [CrossRef]
15. Priwiratama, H.; Prasetyo, A.E.; Pradana, M.G.; Rozziansha, T.A.P.; Susanto, A.; Desmier de Chenon, P. Weevil stem borer and mesocarp-eating beetle: New threat to oil palm plantations in Indonesia. In Proceedings of the PIPOC International Palm Oil Congress, Kuala Lumpur, Malaysia, 9–21 November 2019; pp. 67–81.
16. Giblin-Davis, R. Borers. In *Insects on Palms*; Howard, F.W., Moore, D., Giblin-Davis, R.M., Abad, R., Eds.; CABI Publishing: Oxon, UK, 2001.
17. CABI. Invasive Species Compendium. Available online: www.cabi.org/isc (accessed on 5 June 2022).
18. Dewhurst, C.F.; Pilotti, C.A. First record of the base-borer weevil, *Sparganobasis subcruciata* Marshall (Coleoptera: Curculionidae: Dryopthorinae), from oil palm ('*Elaeis guineensis*' Jacq.) in Papua New Guinea and its association with decaying stem tissue. *Aust. Entomol.* **2012**, *39*, 197–207.
19. Cortés, C.V.; Pérez, S.M.; Aldana de la Torre, R.C.; Mesa, E.; de Olivera, H.G. Pathogenicity level of entomopatogenic fungus from *Metarhizium* genera on *Strategus aloeus* larvae (Coleoptera: Scarabaeidae), under laboratory conditions. *Palmas* **2011**, *32*, 30–40.
20. Pallares, C.H.; de la Torre, J.A.A.; de Lucas, P.R.; Calvache, H.H.; Luque, J.E.; Correa, N. Análisis del comportamiento y comunicación química intraespecífica en *Strategus aloeus* (L.) (Coleoptera, Scarabaeidae-Dynastinae). *Palmas* **2000**, *21*, 185–194.
21. Aldana de La Torre, R.C.; Montes Bazurto, L.G.; Barrios Trilleras, C.E.; Matabanchoy Solarte, J.E.; Beltrán Aldana, I.J.; Guerrero, M.R.; Pardey, A.E.B. *Guía de Bolsillo para el Reconocimiento de las Plagas más Frecuentes en la Palma de Aceite*; Cenipalma: Bogotá, D.C., Colombia, 2017.
22. Genty, P.; Desmier de Chenon, R.; Morin, J.P. Ravageurs du palmier à huile en Amérique latine—Las plagas de la palma aceitera en America Latina—Oil palm pests in Latin America. *Oléagineux* **1978**, *33*, 325–417.
23. Howard, F.W.; Abad, R.G. Lepidoptera. In *Insects on Palms*; Howard, F.W., Moore, D., Giblin-Davis, R.M., Abad, R., Eds.; CABI Publishing: Oxon, UK, 2001.
24. Ferreira, J.M.S.; Warwick, D.R.N.; Siqueira, L.A. *Cultura do Coqueiro no Brasil*; EMBRAPA–SPI: Aracajú, Brazil, 1994.
25. Susanto, A.; Purba, R.Y.P.; Prasetyo, A.E. *Hama dan Penyakit Kelapa Sawit*; Pusat Penelitian Kelapa Sawit: Medan, Indonesia, 2010.
26. Martínez, L.C.; Plata-Rueda, A.; Zanuncio, J.C.; Serrao, J.E. *Leucothyreus femoratus* (Coleoptera: Scarabaeidae): Feeding and behavioral activities as an oil palm defoliator. *Fla. Entomol.* **2013**, *96*, 55–63. [CrossRef]
27. Saravanan, L.; Kalidas, P.; Phanikumar, T.; Dwarakakumar, D.; Gupta, A.; Arunkumar, R. Life history, phenology, host range and natural enemies of *Acria meyricki* Shashank and Ramamurthy (Lepidoptera: Depressariidae): An emerging defoliator of oil palm, *Elaeis guineenis* Jacq. In India. *Phytoparasitica* **2020**, *48*, 427–454. [CrossRef]
28. Monroy, S.M.M.; Aldana, J.A.; Mesa, E.; Aldana de la Torre, R.C.; Cortés, C.V.; de Oleveira, H.G. Pathogenicity level of different isolates from *Beauveria* on *Loxotoma elegans* larvae: An oil palm leaf eater at the East Colombian region. *Palmas* **2011**, *32*, 47–55.
29. Martínez, L.C.; Plata-Rueda, A. Lepidoptera vectors of *Pestalotiopsis* fungal disease: First records in oil palm plantations from Colombia. *Int. J. Trop. Insect Sci.* **2013**, *33*, 239–246. [CrossRef]
30. Martínez, L.C.; Plata-Rueda, A.; Zanuncio, J.C.; Serrão, J.E. Life history traits and damage potential of an invasive pest *Acharia fusca* (Lepidoptera: Limacodidae) on oil palm. *Ann. Entomol. Soc. Am.* **2014**, *107*, 1086–1093. [CrossRef]
31. Alvarado, H.; de La Torre, R.A.; Barrera, E.; Martínez, L.; Bustillo, A. Ciclo de vida y tasa de consumo de *Euprosterna elaeasa* Dyar (Lepidoptera: Limacodidae) defoliador de la palma de aceite. *Rev. Palmas* **2014**, *35*, 41–51.
32. Mathew, G.; Pulikkal, U.K. Biology of the palm king *Amathusia phidippus*, an extremely rare and endangered butterfly of peninsular India. *J. Bombay Nat. Hist. Soc.* **2009**, *106*, 118–120.
33. Hernández-Martínez, M.; Sánchez-Soto, S.; Romero-Nápoles, J.; García-López, E.; Pérez-Flores, J. Efficiency of three trap designs for the capture of *Opsiphanes cassina fabricii* in *Elaeis guineensis*. *Agro Product.* **2016**, *9*, 34–38.
34. Rozziansha, T.A.P.; Priwiratama, H.; Susanto, A. Existing and emerging bagworms in oil palm plantation in Indonesia. In Proceedings of the Fourth IOPRI-MPOB International Seminar: Existing and Emerging Pests and Diseases of Oil Palm Advances in Research and Management, Bandung, Indonesia, 13–14 December 2012.

35. Hisham, N.B. Study of Duration Larvae Stage Bagworm (Lepidoptera: Psychidae) on *Michelia champaca* Trees In Ex-Situ and In-Situ Rearing and Its Species Identification. Bachelor's Thesis, University Malaysia, Kota Samarahan, Sarawak, Malaysia, 2012.
36. Murgianto, F.; Edyson, E.; Setyawan, Y.P.; Tamba, L.M.; Ardiyanto, A.; Siregar, A.H. First report of an ice cream cone bagworm *Manatha conglacia* Haettenschwiler (Lepidoptera: Psychidae) in oil palm plantations of Central Kalimantan, Indonesia. In Proceedings of the International Conference on Tropical Agrifood, Feed and Fuel (ICTAFF 2021), Virtual, 7 January 2022.
37. Kok, C.C.; Eng, O.; Razak, A.R.; Arshad, A.M. Microstructure and life cycle of *Metisa plana* Walker (Lepidoptera: Psychidae). *J. Sustain. Sci. Manag.* **2011**, *6*, 51–59.
38. Cheong, Y.L.; Sajap, A.S.; Hafidzi, M.N.; Omar, D.; Abood, F. Outbreaks of bagworms and their natural enemies in an oil palm, *Elaeis guineensis*, plantation at Hutan Melintang, Perak, Malaysia. *J. Entomol.* **2010**, *7*, 141–151. [CrossRef]
39. Pierre, E.M.; Idris, A.H. Studies on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations in Teluk Intan, Perak (Malaysia). *Asian Myrmecol.* **2013**, *5*, 163–176.
40. Zenker, M.M.; Specht, A.; Fronza, E.; Poletto, G.; Marcon, F.; Formentini, A.C.; Gedoz, M. Biology and life table of *Dirphia araucariae* (Lepidoptera: Saturniidae): A herbivore of potentially high impact on *Araucaria angustifolia*. *Zoologia* **2013**, *30*, 143–150. [CrossRef]
41. Desmier de Chenon, R.; Sudharo, P.; Poelongan, Z.H. Nettle caterpillars and grasshoppers of oil palm in Indonesia. In Proceedings of the International Conference on Pests and Diseases of Importance to the Oil Palm Industry, Kuala Lumpur, Malaysia, 18–19 May 2004; pp. 75–95.
42. Kantharaju, S.; Thippeswamy, N.; Siddalingappa, C.; Yalavar, H.V. Incidence of arecanut spindle bug, *Carvalhoia arecae* Miller and China (Heteroptera: Miridae). *Environ. Ecol.* **2011**, *29*, 143–147.
43. Yeshwanth, H.M.; Prathapan, K.D. First report of the occurrence of the arecanut spindle bug, *Mircarvalhoia arecae* (Miller & China) in the Andaman and Nicobar Islands. *J. Trop. Agric.* **2014**, *52*, 82–84.
44. Martínez, L.C.; Plata-Rueda, A.; Serrão, J.E. Effects of insect growth regulators on mortality, survival, and feeding of *Euprosterna elaeasa*. *Agronomy* **2021**, *11*, 2002. [CrossRef]
45. Tigvattnanont, S. Studies on the bionomics and local distribution of some lace bugs in Thailand. II: *Stephanitis typicus* (Hemiptera: Tingidae). *Kaen Kaset.* **1990**, *18*, 200–212.
46. Barrios, C.; Castillo, N.; Bustillo, A.; Méndez, A. Biología del raspador de la flecha, *Cephaloleia vagelineata* Pic. (Coleoptera: Chrysomelidae), plaga de la palma de aceite en Colombia. *Palmas* **2018**, *39*, 59–65.
47. Mariau, D. Leaf beetles of oil palm (*Elaeis guineensis*) and coconut palm (*Cocos nucifera*). In *New Developments in the Biology of Chrysomelidae*; Jolivet, J.A., Santiago-Blay, M., Schmitt, P., Eds.; SPB Academic Publishing: Hague, The Netherlands, 2004; pp. 603–612.
48. Martínez, L.C.; Plata-Rueda, A. Biological aspects and food consumption of fruit scraper of oil palm, *Demotispa neivai* (Coleoptera: Chrysomelidae). *J. Oil Palm Res.* **2014**, *26*, 47–53.
49. Corley, R.H.V.; Tinker, P.B.H. *The Oil Palm*, 5th ed.; Wiley-Blackwell: West Sussex, UK, 2016; 626p, ISBN 9781405189392.
50. Martínez, L.C.; Hurtado, R.; Araque, L.; Rincón, V. Avances de la campaña regional para el manejo de la información de insectos defoliadores en la zona central. *Palmas* **2009**, *30*, 51–61.
51. Hernández-Lambraño, R.; Caballero-Gallardo, K.; Olivero-Verbel, J. Toxicity and antifeedant activity of essential oils from three aromatic plants grown in Colombia against *Euprosterna elaeasa* and *Acharia fusca* (Lepidoptera: Limacodidae). *Asian Pac. J. Trop. Biomed.* **2014**, *4*, 695–700. [CrossRef]
52. Martínez, L.C.; Plata-Rueda, A.; Serrão, J.E. Effect of benzoylphenyl ureas on survival and reproduction of the lace bug, *Leptopharsa gibbicarina*. *Insects* **2021**, *12*, 34. [CrossRef] [PubMed]
53. Zeddam, J.L.; Cruzado, J.A.; Rodriguez, J.L.; Ravallec, M. A new nucleopolyhedrovirus from the oil-palm leaf-eater *Euprosterna elaeasa* (Lepidoptera: Limacodidae): Preliminary characterization and field assessment in Peruvian plantation. *Agric. Ecosyst. Environ.* **2003**, *96*, 69–75. [CrossRef]
54. Rhainds, M.; Davis, D.R.; Price, P.W. Bionomics of bagworms (Lepidoptera: Psychidae). *Annu. Rev. Entomol.* **2009**, *54*, 209–226. [CrossRef]
55. Leong, T.M.; Lim, K.K.P. Record of the bagworm moth, *Mahasena corbetti* Tams in Singapore (Lepidoptera: Psychidae). *NiS* **2012**, *5*, 1–5.
56. Firake, D.M.; Behere, G.T.; Arnscheid, W.R.; Kumar, R.; Ngachan, S.V. First report of coconut case caterpillar, *Mahasena corbetti* Tams (Lepidoptera: Psychidae) from India. *Phytoparasitica* **2018**, *46*, 355–364. [CrossRef]
57. Batugal, P.V.; Rao, R.; Oliver, J. (Eds.) *Coconut Genetic Resources*; International Plant Resources Genetic Institute-Regional Office for Asia; The Pacific and Oceania (IPGRI-APO): Sardang, Selangor DE, Malaysia, 2005.
58. Rahman, M.A.; Jahan, H.; Talukdar, S.; Kazi1, R. First Record of the Bagworm Moth, *Mahasena corbetti* Tams (Lepidoptera: Psychidae) in Bangladesh. *Int. J. Innov. Res.* **2019**, *4*, 22–26.
59. Yew Cheong, L.; Chin Chong, T. Understanding pest biology and behaviour for effective control of oil palm bagworm. *Planter* **2012**, *88*, 669–715.
60. Basri, W.M.; Ramlah, A.A.S.; Norman, K. Status report on the use of *Bacillus thuringiensis* in the control of some oil palm pests. *Elaeis* **1994**, *6*, 82–101.
61. Priwiratama, H.; Rozziansha, T.A.P.; Susanto, A.; Prasetyo, A.E. Effect of bagworm *Pteroma pendula* Joannis attack on the decrease in oil palm productivity. *J. Hama Penyakit Tumbuh. Trop.* **2019**, *19*, 101–108. [CrossRef]

62. Mazuan, S.; Mohamed, S.; Ishak, I.; Omar, D.; Asib, N. Optimization of motorized backpack mistblower for efficient application of insecticides against the bagworm. *Pak. J. Agric. Sci.* **2001**, *34*, 479–485. [CrossRef]
63. Aldana de la Torre, R.C.; Aldana, J.; Calvache, H.; Franco, P. *Manual de Plagas de la Palma de Aceite en Colombia*, 4th ed.; Cenipalma: Bogota, Colombia, 2010.
64. Barrios, C.; Aldana-De La Torre, R.C.; Bustillo-Pardey, A. Biología del defoliador de la palma de aceite, *Stenoma cecropia* Meyrick (Lepidoptera: Elachistidae). *Palmas* **2013**, *34*, 13–19.
65. de Sousa Brandão, A.D.; Farias, P.R.S.; Dionisio, L.F.S.; Tinôco, R.S.; da Silva, A.G.; da Silva, T.A.F. Spatial and temporal distribution of *Opsiphanes invirae* (Lepidoptera: Nymphalidae) in oil palm, Pará State, Brazil. *Rev. Bras. Cienc. Agrar.* **2017**, *12*, 464–469. [CrossRef]
66. Morais, W.D.C.; Plata-Rueda, A.; Martínez, L.C.; Zanuncio, A.J.V.; Fernandes, F.L.; Wilcken, C.F.; Zanuncio, J.C.; Serrão, J.E. Potential of Diaphania hyalinata and Tenebrio molitor as alternative host for mass rearing of Palmistichus elaeisis (Hymenoptera: Eulophidae). *Entomol. Gen.* **2019**, *39*, 285–294. [CrossRef]
67. Flower, R.W. Leaf beetles (Coleoptera: Chrysomelidae). In *Encyclopedia of Entomology*; Springer: Dordrecht, The Netherlands, 2004. [CrossRef]
68. Castillo Carrillo, C.I. Biodiversity in Ecuador and its immense potential for agricultural pest control. In *Agricultural, Forestry and Bioindustry Biotechnology and Biodiscovery*; Springer: Cham, Switzerland, 2020; pp. 143–161.
69. Kathirithamby, J.; Solulu, T.; Caudwell, R. Descriptions of female Myrmecolacidae (Strepsiptera) parasitic in Orthoptera (Tettigoniidae) in Papua New Guinea. *Tijdschr. Entomol.* **2001**, *144*, 187–196. [CrossRef]
70. Martínez, L.C.; Plata-Rueda, A.; Zanuncio, J.C.; Serrão, J.E. Bioactivity of six plant extracts on adults of *Demotispa neivai* (Coleoptera: Chrysomelidae). *J. Insect Sci.* **2015**, *15*, 34. [CrossRef]
71. Martínez, L.C.; Plata-Rueda, A.; Ramírez, A.; Serrão, J.E. Susceptibility of *Demotispa neivai* (Coleoptera: Chrysomelidae) to *Beauveria bassiana* and *Metarhizium anisopliae* entomopathogenic fungal isolates. *Pest Manag. Sci.* **2022**, *78*, 123–133. [CrossRef]
72. Kantharaju, N.C.; Venkatesh, H.; Yalavar, S. Biology of arecanut spindle bug, *Carvalhoia arecae* Miller and China (Heteroptera: Miridae). *J. Ecol. Environ.* **2011**, *29*, 148–151.
73. Kantharaju, N.; Thippeswamy, C.; Venkatesh, H. Efficacy of certain insecticides against arecanut spindle bug, *Carvalhoia arecae* Miller and China (Heteroptera: Miridae) under field conditions. *Int. J. Plant Prot.* **2009**, *2*, 237–239.
74. Poorani, J.; Padmanaban, B.; Thanigairaj, R. Natural enemies of banana lacewing bug, *Stephanitis typica* (Distant) in India, including first report of *Anagrus* sp. (Hymenoptera: Mymaridae) as its egg parasitoid. *Mun. Ent. Zool.* **2019**, *14*, 83–87.
75. Zenner de Polanía, I.; Posada Flórez, F.J. *Manejo de Insectos, Plagas y Benéficos, de la Palma Africana*; Manuel de Asistencia Técnica No. 54; Instituto Colombiano Agropecuario: Santa Fé de Bogotá, Colombia, 1992.
76. Aldana de la Torre, J.; Calvache Guerrero, H.; Méndez, A. Distribución de hormigas y su efecto sobre *Leptopharsa gibbicarina* en una plantación de palma de aceite. *Palmas* **1995**, *16*, 19–23.
77. Ramos, Y.P.; Ibagué, D.F.; Arias, N.A.A.; Alzate, O. Relación entre el anaranjamiento foliar y la presencia del ácaro de fronde (*Retracrus elaeis*) y su manejo con aspersiones de azufre en el cultivo de palma de aceite (*Elaeis guineensis* Jacq.). *Palmas* **2019**, *40*, 161–169.
78. Matsumura, Y.; Jafarpour, M.; Reut, M.; Shams Moattar, B.; Darvizeh, A.; Gorb, S.N.; Rajabi, H. Excavation mechanics of the elongated female rostrum of the acorn weevil *Curculio glandium* (Coleoptera; Curculionidae). *Appl. Phys. A* **2021**, *127*, 348. [CrossRef]
79. Fiaboe, K.K.M.; Peterson, A.T.; Kairo, M.T.K.; Roda, A.L. Predicting the potential worldwide distribution of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) using ecological niche modeling. *Fla. Entomol.* **2012**, *95*, 659–673. [CrossRef]
80. Baguma, J.; Otema, M.; Ddamulira, G.; Naluyimba, R.; Egonyu, J.P. Distribution and incidence of the oil palm weevil *Rhynchophorus phoenicis* (Fabricius, 1801) (Coleoptera: Curculionidae) in selected agro-ecological zones of Uganda. *Afr. Entomol.* **2019**, *27*, 477–487. [CrossRef]
81. Egonyu, J.P.; Gitonga, K.J.; Khamis, F.M.; Copeland, R.S.; Finyange, P.; Odhiambo, R.; Ddamulira, G. Trapping, identification and rearing of edible palm weevils in Kenya and Uganda. *J. Insects Food Feed* **2021**, *7*, 1243–1253. [CrossRef]
82. Faleiro, R.J.; Al-Dandan, A.M.; Raikar, S.P.; Abdallah, A.B.; Al-Abdullah, A.L.; Gadi, I. Attract and kill technology to control Red palm weevil: Experiences on date palm in Saudi Arabia and oil palm in India. In Proceedings of the 2nd Date's Festival, Siwa Oasis, Egypt, 27–29 October 2016.
83. Cabello, T. Biology and population dynamics of the Red palm weevil, *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Dryophthoridae) in Spain. In *I Jornada Internacional sobre el Picudo Rojo de las Palmeras*; Fundación Agrolimed, Generalitat Valenciana: Valencia, Spain, 2007; pp. 12–13.
84. Abraham, V.A.; Al-Shuaib, M.A.; Falleiro, J.R.; Abozuhairah, R.A.; Vidyasagar, P.S.P.V. An integrated management approach for the red palm weevil *Rhynchophorus ferrugineus* Oliv. A key pest of date palm in the Middle East. *J. Sci. Res. Agric. Sci.* **1998**, *3*, 77–84. [CrossRef]
85. El-Sabea, A.M.R.; Faleiro, J.R.; Abo-El-Saad, M.M. The threat of red palm weevil *Rhynchophorus ferrugineus* to date plantations of the Gulf region in the Middle-East: An economic perspective. *Outlooks Pest Manag.* **2009**, *20*, 131. [CrossRef]

86. Abozuhairah, R.A.; Vidyasagar, P.S.P.V.; Abraham, V. Integrated management of red palm weevil *Rhynchophorus ferrugineus* in date palm plantations of the Kingdom of Saudi Arabia. In Proceedings of the International Congress of Entomology, Florence, Italy, 25–31 August 1996; pp. 25–36.
87. Aldryhim, Y.; Al-Bukiri, S. Effect of irrigation on within-grove distribution of red palm weevil *Rhynchophorus ferrugineus*. *J. Agric. Mar. Sci.* **2003**, *8*, 47–49. [CrossRef]
88. Vidyasagar, P.S.P.V.; Al-Saihati, A.A.; Al-Mohanna, O.E.; Subbei, A.I.; Abdul Mohsin, A.M. Management of red palm weevil *Rhynchophorus ferrugineus* Olivier. A serious pest of date palm in Al-Qatif, Kingdom of Saudi Arabia. *Plant. Crops* **2000**, *28*, 35–43.
89. Asante, S.K.; Kumar, R.A.D. Distribution and abundance of *Temnoschoita quadrimaculata* Gly (Coleoptera: Curculionidae) on oil palm, Elaeis guineensis Jacq. in Ghana. *Insect Sci. Appl.* **1987**, *8*, 115–120. [CrossRef]
90. Alouw, J.C.; Hosang, M.L.; Nguyen, Q. Biotechnology contributing to integrated pest management: The example of two major coconut pests, *Oryctes rhinoceros* and *Brontispa longissima*. In *Coconut Biotechnology: Towards the Sustainability of the 'Tree of Life'*; Adkins, S., Foale, M., Bourdeix, R., Nguyen, Q., Biddle, J., Eds.; Springe: Cham, Switzerland, 2020; pp. 151–168.
91. Manjeri, G.; Muhamad, R.; Tan, S.G. *Oryctes rhinoceros* beetles, an oil palm pest in Malaysia. *Annu. Res. Rev. Biol.* **2014**, *4*, 3429–3439. [CrossRef]
92. Hallett, R.H.; Perez, A.L.; Gries, G.; Gries, R.; Pierce, H.D.; Yue, J.; Oehlschlager, A.C.; Gonzalez, L.M.; Borden, J.H. Aggregation pheromone of coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae). *J. Chem. Ecol.* **1995**, *95*, 1549–1570. [CrossRef] [PubMed]
93. Chakravarthy, A.K.; Chandrashekharaiah, M.; Kandakoor, S.B.; Nagaraj, D.N. Efficacy of aggregation pheromone in trapping red palm weevil (*Rhynchophorus ferrugineus* Olivier) and rhinoceros beetle (*Oryctes rhinoceros* Linn.) from infested coconut palms. *J. Environ. Biol.* **2014**, *35*, 479–484.
94. Nordin, A.B.A.; Simeh, M.A.; Amiruddin, M.N.; Weng, C.K.; Salam, B.A. Economic feasibility of organic palm oil production in Malaysia. *OPIEJ* **2004**, *4*, 29–38.
95. Paudel, S.; Mansfield, S.; Villamizar, L.F.; Jackson, T.A.; Marshall, S.D. Can biological control overcome the threat from newly invasive coconut rhinoceros beetle populations (Coleoptera: Scarabaeidae)? A review. *Ann. Entomol. Soc. Am.* **2021**, *114*, 247–256. [CrossRef]
96. Martínez, L.C.; Plata-Rueda, A.; Zanuncio, J.C.; Serrão, J.E. Comparative toxicity of six insecticides on the rhinoceros beetle (Coleoptera: Scarabaeidae). *Fla. Entomol.* **2014**, *97*, 1056–1062. [CrossRef]
97. Peña, E.A.; Jiménez, O.D. Distribución del daño del insecto *Sagalassa valida* Walker en el sistema radical de la palma de aceite (*Elaeis guineensis* Jacquin) en la zona de Tumaco. *Palmas* **1994**, *15*, 19–23.
98. El-Shafie, H.A.F.; Faleiro, J.R. Semiochemicals and Their Potential Use in Pest Management. In *Biological Control of Pest and Vector Insects*; Shields, V.D.C., Ed.; IntechOpen: London, UK, 2017; pp. 1–21. [CrossRef]
99. Oehlschlager, A.C.; Chinchilla, C.; Castillo, G.; Gonzalez, L. Control of red ring disease by mass trapping of *Rhynchophorus palmarum* (Coleoptera: Curculionidae). *Fla. Entomol.* **2002**, *85*, 507–513. [CrossRef]
100. Guarino, S.; Bue, P.L.; Peri, E.; Colazza, S. Responses of *Rhynchophorus ferrugineus* adults to selected synthetic palm esters: Electroantennographic studies and trap catches in an urban environment. *Pest Manag. Sci.* **2011**, *67*, 77–81. [CrossRef]
101. Oehlschlager, C. *Current Status of Trapping Palm Weevils and Beetles*; Chem Tica Internacional: San Jose, Costa Rica, 2004.
102. Oehlschlager, C. *Optimizing Trapping of Palm Weevils and Beetles Optimizing Trapping of Palm Weevils and Beetles*; ChemTica Internacional: San Jose, Costa Rica, 2007. [CrossRef]
103. Sasaerila, Y.; Gries, R.; Gries, G.; Khaskin, G.; King, S.; Boo, T. Decadienoates: Sex pheromone components of nettle caterpillars *Darna trima* and *D. bradleyi*. *J. Chem. Ecol.* **2000**, *26*, 1969–1981. [CrossRef]
104. Sharma, A.; Sandhi, R.K.; Reddy, G.V.P. A review of interactions between insect biological control agents and semiochemicals. *INMUEX* **2019**, *10*, 439. [CrossRef]
105. Nangai, V.L.; Martin, B. Interpreting the acoustic characteristics of Red Palm Weevil towards its detection—A review. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *225*, 012178. [CrossRef]
106. Hetzroni, A.; Soroker, V.; Cohen, Y. Toward practical acoustic red palm weevil detection. *Comput. Electron. Agric.* **2016**, *124*, 100–106. [CrossRef]
107. Siriwardena, K.A.P.; Fernando, L.C.P.; Nanayakkara, N.; Perera, K.F.G.; Kumara, A.D.N.T.; Nanayakkara, T. Portable acoustic device for detection of coconut palms infested by *Rynchophorus ferrugineus* (Coleoptera: Curculionidae). *J. Crop Prot.* **2010**, *29*, 25–29. [CrossRef]
108. Herrick, N.J.; Mankin, R.W. Acoustical detection of early instar *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in Canary Island date palm, *Phoenix canariensis* (Arecales: Arecacae). *Fla. Entomol.* **2012**, *95*, 983–990. [CrossRef]
109. Ashry, I.; Mao, Y.; Al-fehaid, Y.; Al-shawaf, A. Early detection of red palm weevil using distributed optical sensor. *Sci. Rep.* **2020**, *10*, 31–55. [CrossRef]
110. Wang, B.; Mao, Y.; Ashry, I.; Al-fehaid, Y.; Al-shawaf, A. Towards detecting red palm weevil using machine learning and fiber optic distributed acoustic sensing. *Sensors* **2001**, *21*, 1592. [CrossRef]
111. Rach, M.M.; Gomis, H.M.; Granado, O.L.; Malumbres, M.P.; Campoy, A.M.J.J.; Serrano Martín, A. On the design of a bioacoustic sensor for the early detection of the Ped palm weevil. *Sensors* **2013**, *13*, 1706–1729. [CrossRef]
112. Karakaya, D.; Ulucan, O.; Turkan, M. Electronic nose and its applications: A survey. *Int. J. Autom. Comput.* **2020**, *17*, 179–209. [CrossRef]

113. Anankware, P.J.; Fening, K.; Osekre, E.; Obeng-Ofori, D. Insects as food and feed: A review. *Int. J. Agric. Res. Rev.* **2015**, *3*, 143–151.
114. Anankware, J.P.; Roberts, B.J.; Cheseto, X.; Osuga, I.; Savolainen, V.; Collins, C.M. The nutritional profiles of five important edible insect species from West Africa—An analytical and literature synthesis. *Front. Nutr.* **2021**, *8*, 29–41. [CrossRef]
115. Okia, C.; Odongo, W.; Nzabamwita, P.; Ndimubandi, J.; Nalika, N.; Nyeko, P. Local knowledge and practices on use and management of edible insects in Lake Victoria basin, East Africa. *J. Insects Food Feed* **2017**, *3*, 83–93. [CrossRef]
116. Hanboonsong, Y. Edible insects and associated food habits in Thailand. In *Forest Insects as food: Humans Bite Back, Proceedings of the Workshop on Asia-Pacific Resources and Their Potential for Development, Bangkok, Thailand, 19–21 February, 2008*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2010; pp. 173–182.
117. Ukoroije, R.; Bobmanuel, R. The acceptability of *Oryctes owariensis* Beauvois (Coleoptera: Scarabaeidae) larva as food in Bayelsa State, Nigeria. *East Afr. Sch. J. Agric. Life Sci.* **2019**, *2*, 509–515. [CrossRef]
118. Manno, N.; Estraver, W.Z.; Tafur, C.M.; Torres, C.L.; Schwarzinger, C.; List, M.; Schoefberger, W.; Coico, F.R.M.; Leon, J.M.; Battisti, A.; et al. Edible insects and other chitin-bearing foods in ethnic Peru: Accessibility, nutritional acceptance, and food-security implications. *J. Ethnobiol.* **2018**, *38*, 424–447. [CrossRef]
119. Stout, M.J. Host-plant resistance in pest management. In *Integrated Pest Management*; Abrol, D.P., Ed.; Academic Press: Cambridge, MA, USA, 2014; pp. 1–21. [CrossRef]
120. Martin, J.J.J.; Yarra, R.; Wei, L.; Cao, X. Oil palm breeding in the modern era: Challenges and opportunities. *Plants* **2022**, *11*, 1395. [CrossRef] [PubMed]
121. Joshi, H.; Choudhary, P.; Mundra, S.L. Future prospects of nanotechnology in agriculture. *Int. J. Chem. Stud.* **2019**, *7*, 957–963.
122. Maluin, F.N.; Hussein, M.Z.; Idris, A.S. An Overview of the oil palm industry: Challenges and some emerging opportunities for nanotechnology development. *Agronomy* **2020**, *10*, 356. [CrossRef]
123. Elizabath, A.; Babychan, M.; Mathew, A.M.; Syriac, G.M. Application of nanotechnology in agriculture. *Int. J. Pure Appl. Biosci.* **2019**, *7*, 131–139. [CrossRef]
124. Bhan, S.; Mohan, L.; Srivastava, C.N. Nanopesticides: A recent novel ecofriendly approach in insect pest management. *J. Entomol. Res.* **2018**, *42*, 263–270. [CrossRef]
125. Agarwal, M.; Verma, A. Modern Technologies for Pest Control: A Review. In *Heavy Metals—Their Environmental Impacts and Mitigation*; Nazal, M.K., Zhao, H., Eds.; IntechOpen: London, UK, 2020. [CrossRef]
126. Tunaz, H. Insect Growth Regulators for Insect Pest Control. *Turk. J. Agric. For.* **2004**, *28*, 377–387.
127. Anwer, A.; Singh, G. Geo-spatial technology for plant disease and insect pest management. *Bull. Environ. Pharmacol. Life* **2019**, *8*, 1–12.
128. Balijepalli, S.B.; Faleiro, J.R. Is policy analysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil *Rynchophorus ferrugineus*? *Arab. J. Plant Prot.* **2019**, *37*, 89–100. [CrossRef]
129. Orden de 18 de Noviembre de 1996 por la que se Establecen Medidas Provisionales de Protección Contra el Curculiónido Ferruginoso de las Palmeras [*Rhynchophorus ferrugineus* (Olivier)]. Available online: www.boe.es/diarioboe/txt.php?id=BOE-A-1996-26385 (accessed on 14 June 2022).
130. Ministry of Agriculture, Fisheries and Food 2000. Order of February 28, 2000, Establishing Provisional Protection Measures against the Ferruginous Curculionid of Palm Trees ["*Rhynchophorus ferrugineus*" ("Olivier")]. Available online: https://noticias.juridicas.com/base_datos/Admin/o280200-mapa.html (accessed on 10 November 2022).
131. OJEU. *Commission Decision 2007/365/EC on Emergency Measures against the Introduction and Spread within the EU of R. ferrugineus (Olivier) [Notified under Document Number C (2007) 2161]*; Official Journal of the European Union L 139; OJEU: Luxembourg, 2007; pp. 24–27.
132. OJEU. *Commission Decision of 6 October 2008 amending Decision 2007/365/EC on Emergency Measures to Prevent the Introduction into and the Spread within the Community of R. ferrugineus (Olivier) [Notified under Document Number C (2008) 5550]. Official Journal of the European Union L 266*; OJEU: Luxembourg, 2008; pp. 51–54.
133. OJEU. *Commission Decision of 17 August 2010 amending Decision 2007/365/EC on Emergency Measures to Prevent the Introduction into and the Spread within the Community of R. ferrugineus (Olivier) [Notified under Document Number C (2010) 5640]. Official Journal of the European Union L 226*; OJEU: Luxembourg, 2010; pp. 42–44.