SpecialReports

AgbioInvestor

THE QUEEN'S AWARDS FOR ENTERPRISE: INTERNATIONAL TRADE 2022

The Crop Protection Market:

Insects, Weeds & Diseases

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Scope of Report

This report intends to establish market values for crop protection products (conventional and/or biological) based on target pest classifications. We utilised data from our AgbioCrop and AgbioSelect products in combination with information gathered from desk research to quantify the extent to which a crop protection product is used to control target pests within a classification.

Contents

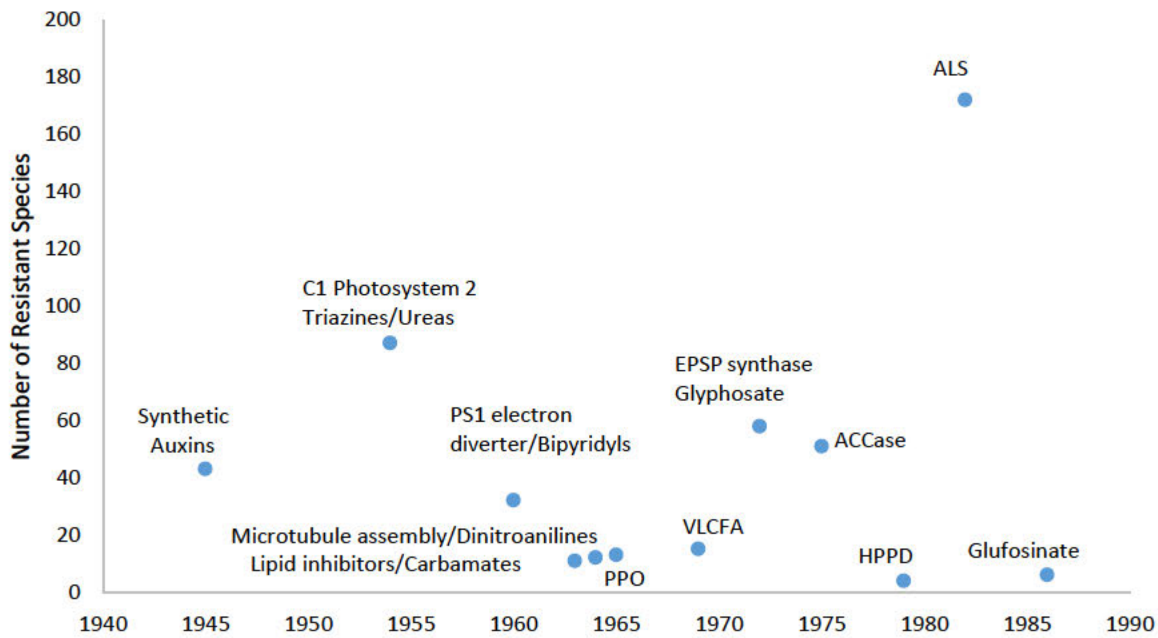
Weeds

The weed section of this report refers to plant organisms that compete with commercially significant arable crops for fundamental plant development resources, including light, nutrients and water. The weed-control sector recognises two broad categories of weeds: grasses and broadleaf weeds. Grass weeds include any monocotyledonous weed type possessing one initial leaf, whereas broadleaf weeds include any dicotyledonous weed type possessing two initial leaves.

Resistance Management/Spectrum of Activity

Weeds, pests and diseases developing resistance to herbicides, insecticides and fungicides is an issue that has grown in significance over the last 60 years. Many introductions in the 1950s and 1960s were based on broad-spectrum contact active agrochemicals; however, many of these are no longer approved in some markets. Replacements from R&D have generally been systemic single-site active products, which are more prone to resistance development. Resistance-avoidance strategies have included the use of co-formulations of active ingredients with different modes of action, particularly incorporating contact active products; however, many of these are no longer available in the EU.

Weed Resistance Management



Source: Weedscience.com

The graph above shows the number of weed species that have developed resistance to the various classes of herbicide chemistry/modes of action, plotted against the year of first introduction of a member of each class. For example, more than 170 weed species have developed resistance to ALS herbicides, the first of which was introduced in 1982. Weed resistance to herbicides is a growing issue, necessitating the development of new modes of action to sustain the ability to control problem weeds. There is a perception that resistance development is greater for single-site active herbicides, notably ALS and ACCase herbicides and glyphosate. However, other single-site active classes – notably 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors and protoporphyrinogen oxidase (PPO) inhibitors – have suffered only limited resistance, whilst significant resistance has developed to less specific herbicide classes, notably the triazines and ureas.

Section 1: Introduction

In the Americas, the repeated usage of glyphosate on Roundup Ready crops has resulted in some weed species developing resistance to the herbicide. This has led to the usage of co-formulations of other herbicides offering multiple different modes of action, which are applied early in the season to provide a more comprehensive weed control strategy.

It has also led to the development of genetic solutions to glyphosate resistance, including the introduction of 2,4-D and dicamba tolerance traits, to be used alongside glyphosate or glufosinate tolerance for the control of glyphosate-resistant weeds. Herbicide resistance is defined as being either target site or non-target site. Target-site resistance involves mutations of genes encoding the protein-binding sites in weeds, whereas non-target resistance involves altering one or more physiological processes within the weed, including herbicide absorption, translocation, sequestration or metabolism.

Weed Species That Have Developed the Most Resistance			
Species	**Common Name**	**Type**	**No. Sites of Action***
Lolium rigidum	Rigid Ryegrass	Grass	12
Poa annua	Annual Bluegrass	Grass	12
Amaranthus palmeri	Palmer Amaranth	Broadleaf	10
Echinochloa crus-galli	Barnyard Grass	Grass	9
Eleusine indica	Goosegrass	Grass	8
Lolium perenne	Perennial Ryegrass	Grass	8
Amaranthus tuberculatus	Waterhemp	Broadleaf	7
Avena fatua	Wild Oat	Grass	7
Amaranthus hybridus	Pigweed	Broadleaf	6
Amaranthus retroflexus	Redroot Pigweed	Broadleaf	6
Conyza sumatrensis	Sumatran Fleabane	Broadleaf	6
Echinochloa colona	Jungle Rice	Grass	6
Raphanus raphanistrum	Wild Radish	Broadleaf	6
Alopecurus myosuroides	Black Grass	Grass	5
Ambrosia artemisiifolia	Ragweed	Broadleaf	5

**A site of action is a mode of herbicide action*

Of the top 15 weeds that have developed resistance to herbicides at the greatest number of sites of activity (modes of herbicide action), grass weeds dominate, comprising 8 of the top 15 but 6 of the top 8.

Herbicide Resistance by Weed Species				
Rank	**Weed Family**	**Common Name**	**Type**	**% Resistant Species**
1	Poaceae	Grasses	Grass	33
2	Asteraceae	Daisies	Broadleaf	16
3	Brassicaceae	Crucifers	Broadleaf	8
4	Amaranthaceae	Pigweeds	Broadleaf	4
5	Cyperaceae	Sedges	Grass	4
6	Polygonaceae	Knotweeds	Broadleaf	3
7	Scrophulariaceae	Figworts/Flowering Plants	Broadleaf	3
8	Alismataceae	Water Plantains	Broadleaf	2
9	Chenopodiaceae	Goosefoots	Broadleaf	2
10	Caryophyllaceae	Pinks/Carnations	Broadleaf	2
	TOTAL			**77**

Of the weed families identified, grass weeds account for 37% of the total, and broadleaf weeds 40%.

Chewing Pests

Chewing pests are mandibulate organisms that cause mechanical damage to host crops by chewing and biting plant material. Damage caused by these pests includes holes in the foliage and stem, and can result in plant discolouration, severed stems, stunting and wilting. The major chewing pests include Lepidoptera, such as moths and caterpillars, and Coleoptera, the true beetles.

Lepidoptera

Lepidoptera is a large order of insects that includes moths and butterflies. Lepidopterans are significant agricultural pests in many crops worldwide. Consequently, they are a significant focus of crop protection companies.

The life cycle of lepidopteran pests consists of 4 distinct stages – egg, larval, pupal and mature – with the larval stage being the primary feeding stage of the life cycle and, consequently, the most damaging to agriculture. However, it is worth noting that mature Lepidoptera are anthophilous, equipped with probosci or haustella that allow them to feed on floral liquid substances, much like sucking pests.

Lepidopteran PPPs are classified by the Insecticide Resistance Action Committee (IRAC) according to modes of action, which are themselves classified according to target. **Nerve & Muscle** targets, **Growth & Development** targets, **Respiration** targets, **Midgut** targets and an unknown/non-specific product class are described in further detail in the table below.

Insecticide Resistance Action Committee (IRAC) Classification of PPPs by Mode of Action		
Target	**IRAC Group**	**Mode of Action**
Nerve & Muscle Targets	Group 1	Acetylcholinesterase (AChE) inhibitors
	Group 2	GABA-gated chloride channel blockers
	Group 3	Sodium channel modulators
	Group 4	Nicotinic acetylcholine receptor (nAChR) competitive modulators
	Group 5	Nicotinic acetylcholine receptor (nAChR) allosteric modulators – Site I
	Group 6	Glutamate-gated chloride channel (GluCl) allosteric modulators
	Group 14	Nicotinic acetylcholine receptor (nAChR) blockers
	Group 22	Voltage-dependent sodium channel blockers
	Group 28	Ryanodine receptor modulators
	Group 30	GABA-gated chloride channel allosteric modulators
	Group 32	Nicotinic acetylcholine receptor (nAChR) allosteric modulators – Site II
Respiration Targets	Group 13	Uncouplers of oxidative phosphorylation via disruption of the proton gradient
	Group 21	Mitochondrial complex I electron transport inhibitors
Midgut Targets	Group 11	Microbial disruptors of insect midgut membranes
	Group 31	Baculoviruses
Growth & Development Targets	Group 7	Juvenile hormone mimics
	Group 15	Inhibitors of chitin biosynthesis, Type 0
	Group 18	Ecdysone receptor agonists

Pest Control by Genetic Manipulation of Crops

Lepidoptera and Coleoptera control is also achieved through the insertion of insect resistance genes into crops, commonly sourced from the bacterium *Bacillus thuringiensis* (B.t). A range of delta endotoxin proteins are expressed by B.t and its subspecies, and isolated genes produce delta endotoxins with activity against different target pests. B.t genes used in agriculture are of 2 types: *Cry* and *Vip*. *Cry* genes have been identified with target specificity to many insect groups, and genes producing Cry1, Cry2 and Cry3 class delta endotoxins. *Vip* genes also produce proteins active against lepidopteran (Vip3) and coleopteran (Vip1 and Vip2) pests; however, in commercial agriculture, only those controlling lepidopteran pests are currently used.

In nature, B.t bacteria express Cry proteins during sporulation in an effort to lyse the midgut epithelial cells of their insect hosts when seeking another location in which to establish a new population. Agricultural biotechnology has isolated this ability and utilised it to protect crops from insect attack.

Vip proteins are also expressed in B.t bacteria, although at a different stage in the bacterial population life cycle – the vegetative growth (log) phase – giving them the name of vegetative insecticidal proteins (Vips).

Coleoptera

Coleoptera is considered the largest of the insect orders, comprising an estimated 400,000 species and a quarter of all known invertebrate species. Considered true beetles, coleopterans are mandibulate, go through a holometabolous life cycle – egg, larval, pupal and mature stages – and possess forewings encased in hardened exteriors, or elytra. A major coleopteran group comprises the weevils; adult weevils have a very hard outer shell, are usually flightless and have a prominent snout on their head. The majority of non-weevil beetles are also ‘hard shelled’ but are more active flyers and do not possess a snout.

Coleopteran adults can possess heavily sclerotised forewings (elytra) that lack veins and cover the membranous hind wings. The entire body is generally hardened, with three pairs of segmented legs.

As with Lepidoptera, many species of Coleoptera – including weevils, Colorado potato beetle (CPB), pollen beetle and cabbage stem flea beetle (CSFB) – are significant agricultural pests that cause crop damage by feeding on plant material. However, it should be noted that some coleopterans – for example, Coccinellidae – feed on plant-sucking insects that cause crop damage, such as aphids, thrips and mites.

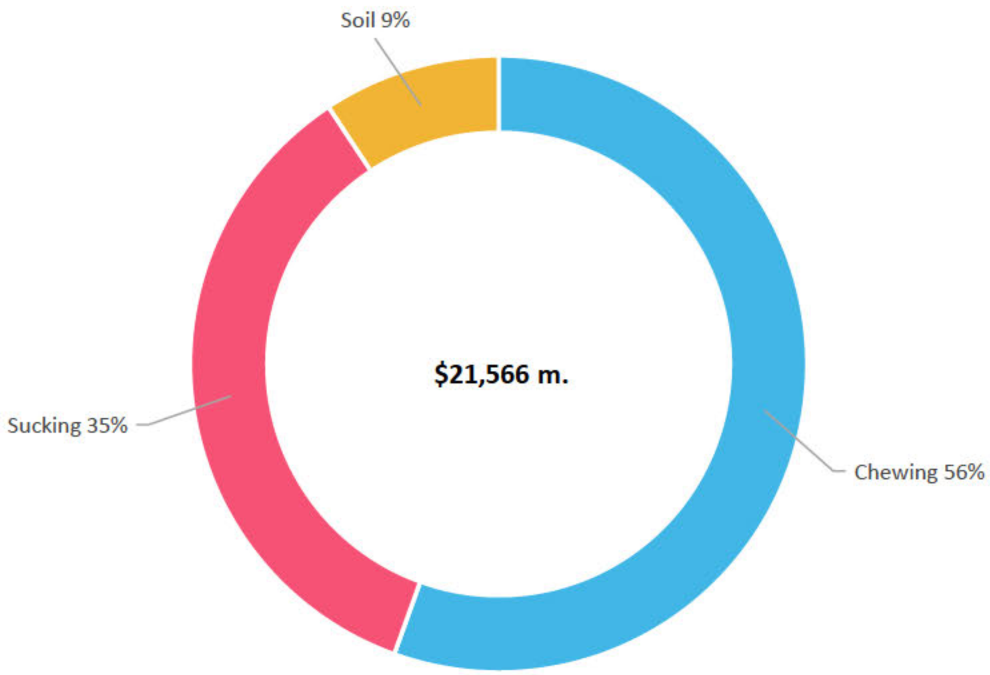
Other Chewing Pests

The ‘other’ chewing pest classification is intended to cover all agricultural chewing pests not contained within the Lepidoptera or Coleoptera groupings. It is difficult to precisely define this category as it covers a spectrum of insects, including orthopteran species such as ants, locusts and grasshoppers.

Market Values

Insects

Insecticide Market by Pest Type ($ m.)

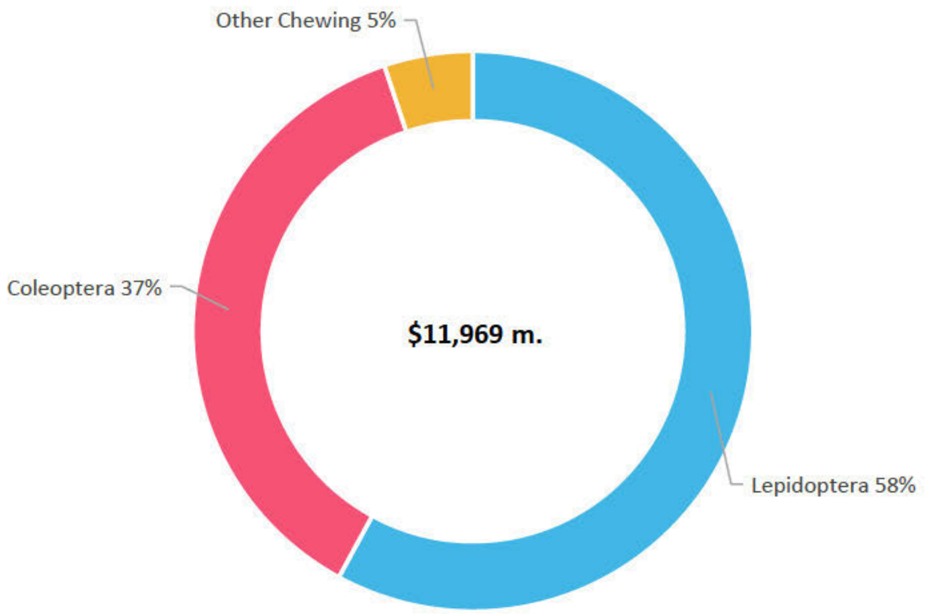


Insecticide Market by Crop 2022 ($m.)

Crop	Insecticides
Soybean	3,781
Rice	2,302
Cotton	2,196
Maize	1,926
Pome/Stone Fruit	1,171
Cereals	902
Sugarcane	749
Potato	506
Oilseed Rape	429
Vine	396
Sunflower	88
Sugar Beet	81
Other Fruits & Vegetables	5,640
Other Crops	1,399
Total	**21,566**

Chewing Insects

Chewing Insecticide Market by Class



Chewing Pests - Lepidoptera

Leading Lepidoptera-Control Insecticides

Rank	Active Ingredient	Sales for Lepidoptera Control ($m.)
1	chlorantraniliprole	[redacted]
2	acephate	
3	lambda-cyhalothrin	
4	emamectin benzoate	
5	flubendiamide	
6	abamectin	
7	spinetoram	
8	cypermethrin	
9	bifenthrin	
10	indoxacarb	
11	chlorfenapyr	
12	methomyl	
13	clothianidin	
14	methoxyfenozide	
15	chlorpyrifos	
16	*Bacillus thuringiensis*	
17	cyantraniliprole	
18	lufenuron	
19	spinosad	
20	alpha-cypermethrin	
	Others	
	Total	

Section 2: Market values - Insects

The following table lists the major lepidopteran pests by key crops for which the pests are of commercial significance. Each pest may infest other crops as well, but not with the same degree of impact.

Key Lepidopteran Pests by Crop		
Crop	**Common Name**	**Latin Name**
Maize	Cutworm	*Agrotis ipsilon*
Soybean	Cutworm	*Agrotis ipsilon*
Soybean	Velvet Bean Caterpillar	*Anticarsia gemmatalis*
Pome/Stone Fruit	Fruit-tree Leafroller Moth	*Archips argyrospila*
Soybean	Soybean Looper	*Chrysodeixis includens*
Rice	Leafroller	*Cnaphalocrocis medinalis*
Maize	Lesser Cornstalk Borer	*Elasmopalpus lignosellus*
Soybean	Lesser Cornstalk Borer	*Elasmopalpus lignosellus*
Pome/Stone Fruit	Oriental Fruit Moth	*Grapholita molesta*
Cotton	Bollworm Complex	*Helicoverpa armigera*
Maize	Corn Earworm	*Helicoverpa zea*
Soybean	Corn Earworm/Soybean Pod Worm	*Helicoverpa zea*
Soybean	Green Clover Worm	*Hypena scabra*
Pome/Stone Fruit	Codling Moth	*Laspeyresia pomonella*
Pome/Stone Fruit	Apple Leaf Miner	*Lyonetia clerkella*
Maize	European Corn Borer	*Ostrinia nubilalis*
Rice	Yellow Rice Borer	*Scirpophaga incertulas*
Maize	Fall Armyworm	*Spodoptera frugiperda*
Soybean	Fall Armyworm	*Spodoptera frugiperda*
Maize	Western Bean Cutworm	*Striacosta albicosta*
Vine	Leafrollers	Tortricidae spp.
Vine	Leafroller	*Sparganothis pilleriana*
Pome/Stone Fruit	Moths	*Orthosia hibisci, Lithophane antennata, Amphipyra pyramidoides*

Key Lepidopteran Pests

Cutworm (*Agrotis ipsilon*) is chiefly a pest of seedling plants. It may produce several generations a year, but the spring generation is usually the most damaging because of the vulnerable young plants available at this time. Female black cutworm moths usually deposit eggs (between 1 and 30) on densely growing plants relatively low to the ground, on the petioles, lower leaf surface or stem. Damp, low-lying areas within untilled fields are particularly favourable for egg deposition and larval survival. Eggs hatch in 3–6 days and the larvae move into the soil, where they remain during the day, moving to the surface at night to feed on young plants. The moth stage carries the pest into adjoining areas. Cutworms are a pest worldwide and can affect many crops, including maize, many vegetables, cotton, tobacco and turf grasses.

Velvet bean caterpillar (*Anticarsia gemmatalis*) is native to tropical and subtropical areas of the western hemisphere. It is a foliage-feeding pest of soybean; infestation occurs in the late summer months and can cause great damage to soybean and other legumes, including peanut, kudzu, velvet bean, horse bean, cotton, cowpea, coffeeweed, black locust, hairy indigo, lespedeza, sesbania and white sweetclover. The caterpillar has a life cycle of around 4 weeks, with the larval stage able to strip fields of soybean foliage in 5–7 days.

Fruit-tree leafroller moth (*Archips argyrospila*) is a pest of apple and pear trees. The species produces only 1 generation a year, with eggs laid on the twigs of host plants in June and July and hatching the following year. Young larvae feed on buds, blossoms, young fruit and unfolding leaves, which are webbed together to form a nest in which pupation occurs.

Soybean looper (*Chrysodeixis includens*) is predominantly a pest of soybean, but also feeds on peanut, cotton, and maize, as well as vegetable (pea, crucifers, sweet potato, tomato, capsicum, bush bean, cucumber and watermelon) and floriculture crops (African daisy, begonia, carnation, chrysanthemum, geranium, lantana and sunflower). Larvae consume large amounts of foliage and occasionally feed on pods and fruit, while moths feed solely on flower nectar. Caterpillars generally feed for 2–3 weeks before pupating. The pest is abundant in the Americas.

Rice leafroller (*Cnaphalocrocis medinalis*) is endemic to Asia and Australia. It can also affect maize and sorghum. Eggs are laid on the upper side of leaves, and the pest has a life cycle of 25–35 days. The larvae produce thread-like silk that fastens to leaf margins to form a shelter, in which they live and feed on green tissues. In feeding, they tear both ends of the leaves, leading to leaf wilt, reduced photosynthesis and lower rice yields. Each larva can damage 3–5 leaves.

Cornstalk borer (*Elasmopalpus lignosellus*) is found throughout the western hemisphere, particularly in sandy soils. The pest produces up to 4 generations a year; eggs are mostly deposited below the soil surface, adjacent to plants. Larvae live in the soil, constructing tunnels from soil and excrement tightly woven together with silk. They leave the tunnel to feed in the basal stalk area or just beneath the soil surface. Larvae feed on a range of crops, including soybean, peanut, maize and grain sorghum, as well as small-grain cereals, rice, sugarcane and a range of vegetable crops.

Oriental fruit moth (*Grapholita molesta*) is a pest throughout the world. It causes damage to peach, plum, nectarine and apricot, as well as almond, cherry, apple, pear and quince. It can produce up to 6 generations per year. The larvae attack tree buds, shoots and terminal twigs of young trees, as well as entering green fruits. Their fruit damage also attracts secondary pests, such as nepticulid beetles (*Carpophilus* spp.), which act as vectors for brown rot (*Monilinia* spp.) infection.

Bollworm complex (Old World bollworm) (*Helicoverpa armigera*) is a pest throughout the world. Its major host plants are cotton, pigeon pea, chickpea, tomato, sorghum and cowpea; other hosts include groundnut, okra, pea, field bean, soybean, lucerne, other legumes, tobacco, potato, maize, flax, a number of fruits (plum and citrus), forestry trees and a range of vegetable crops. It can typically produce 2–5 generations per year. On cotton, larvae bore into maturing green bolls, which subsequently fall from the plant. On maize, eggs are laid on the silks, then larvae invade the cobs and consume the developing grain. Attack results in the fall of affected fruit crops, while on chickpea and pigeon pea the larvae bore into pods and consume the developing seed. Secondary infection of affected crops is common.

Corn earworm/Soybean pod worm (*Helicoverpa zea*) is a major pest in North America, but also throughout Central and South America, Australia and parts of Asia. Eggs are deposited singly, usually on leaf hairs and corn silk. After hatching, larvae seek a suitable feeding site – normally the reproductive structure of the plant. Corn earworm also attacks soybean, artichoke, asparagus, cabbage, cantaloupe, collard, cowpea, cucumber, eggplant, lettuce, lima bean, melon, okra, pea, pepper, potato, pumpkin, snap bean, spinach, squash, sweet potato and watermelon. Other crops injured by corn earworm include alfalfa, clover, cotton, flax, oat, millet, rice, sorghum, sugarcane, sunflower, tobacco, vetch and wheat. The number of generations produced per year varies between 1 and 7, depending on climate and temperature. Moths of the second generation emerge from corn fields from mid-July to mid-August, and seek soybean, cotton, peanut, sorghum, and other crop and wild host plants; at this time, soybean is flowering and attractive to the pest. Eggs are laid individually on soybean terminals, flowers and leaves, and larvae feed on foliage, flowers and fruit.

Diamondback moth (*Plutella xylostella*), sometimes referred to as the cabbage moth, is present worldwide wherever its *Brassica* host plants – most notably oilseed rape/canola – grow. It has a rapid lifecycle of up to 15 generations per annum, resulting in a year-round presence in the mid- and subtropical regions and contributing to resistance-development issues. IRAC has reported several biochemical mechanisms conferring insecticide resistance in diamondback moths, such as an enhanced metabolic detoxification mechanism, insensitive acetylcholinesterase, reduced Cry1C binding to target sites in the midgut membrane, reduced conversion of Cry1C protein to toxin, reduced penetration, and target site resistance.

Fall armyworm (*Spodoptera frugiperda*) is native to the Americas but is now also found in Africa, Asia and Oceania. It is capable of colonising many crops; however, the most frequently injured are alfalfa, barley, bermudagrass, buckwheat, cotton, clover, maize, oat, millet, peanut, rice, ryegrass, sorghum, sugar beet, sudangrass, soybean, sugarcane, timothy, tobacco, and wheat. It has a life cycle of about 30 days during the summer, 60 days in the spring and autumn, and 80–90 days during the winter. Larvae damage plants by consuming foliage. Young larvae initially consume leaf tissue from one side, leaving the opposite epidermal layer intact. By the second or third instar, larvae begin to make holes in leaves and eat from the edge of the leaves inwards. In maize, they sometimes burrow into the ear, feeding on kernels and burrowing through the husk on the side of the ear.

Green clover worm (*Hypena scabra*) overwinter as pupae in leaf litter and crop debris. As temperatures warm in the spring, adults emerge and mate. Eggs are laid on the underside of leaves and hatch in 4 days. Larvae develop through 6 instars (stages) and consume most of their food during stages 4–6; they feed on alfalfa, bean, clover, cowpea, soybean, strawberry, vetch, as well as many common weeds and other legumes. Young larvae feed throughout the soybean plant, but older larvae feed primarily in the upper third of the canopy, generally in the middle of leaves rather than at the margins. Mature larvae burrow into the soil or among crop debris to pupate. They usually produce 2 generations per year.

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