Chapter 13
Botanical Pesticides as Biocontrol Products

Myriam Siegwart and Anne-Violette Lavoir

13.1 Introduction

Our historical knowledge of plant extracts being used as pesticides is fragmented. We do know that in Europe people relied on this practice over 3000 years ago to fight ectoparasites and to protect stored foods (Pavela 2016). *Chrysanthemum* flowers and aromatic plants were the main sources of such extracts. Later, with the development of agriculture, a greater variety of botanical pesticides were used to control crop pests. The first commercial botanical product was nicotine, which was used against plum beetles from the seventeenth century. Rotenone, a substance extracted from many Fabaceae species, was also widely used as an insecticide in agriculture from 1850 onwards. However, these practices became anecdotal by the Second World War with the discovery of synthetic chemical pesticides. Since then, side effects of this generation of pesticides have led us to take a fresh look at ancestral practices and draw inspiration from them to develop new methods and products.

Botanical biopesticides can be divided into two categories:

- those that are not commercially available, i.e. extracts made directly by farmers from local plants. It is difficult to evaluate their frequency of use, but some ethnobotanical studies have mapped cultural practices using local flora for protection against insects (Belmain and Stevenson 2001).

M. Siegwart
PSH. INRAE, Avignon, France

A.-V. Lavoir (✉)
ISA. INRAE, CNRS, UCA, Sophia Antipolis, France
e-mail: anne-violette.lavoir@unice.fr

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- industrially produced extracts sold as biopesticides. There are many different products, but most are produced by combining plant-based active ingredients with co-formulants.

At the beginning of the twenty-first century, despite the proven undesirable effects of synthetic pesticides and strong research interest in botanical biopesticides, these products represented only 5% of the biopesticide market, which itself accounted for only 8% of the global pesticide market in 2014 (GeoData.gouv 2021). Although many predicted a renaissance of this type of pesticides, it has not yet materialized, despite slightly higher sales in recent years. This modest growth can be explained by a change in strategy by agrochemical companies following the withdrawal from the market of the old families of synthetic pesticides (organochlorine, organophosphate and carbamate compounds) with unacceptable toxicological and ecotoxicological profiles. These companies replaced them with a new generation of synthetic pesticides (neonicotinoid, spinozine, oxadiazine, diamide compounds) that are considered less persistent and more specific, and thus as having a lesser impact on human health and the environment. This also explains why, on a global scale, the use of chemical pesticides has not fallen.

In Europe, the inertia regarding botanical pesticides can also be attributed to very strict regulations on placing plant protection products on the market. Botanical products must follow the same cumbersome and costly registration process as synthetic compounds. Only recently has a more streamlined evaluation procedure been approved for "low-risk active substances" in Europe (Regulation (EC) No 1107/2009). In France, biocontrol products benefit from accelerated evaluation procedures to obtain marketing authorization as well as reduced fees for these procedures.

Other difficulties specific to botanical biopesticides also limit their market growth, such as the supply of plant matter, the extraction process and yield, and the development of very specific and complex formulations. These conceptual and technical obstacles must be overcome to optimize and ensure environmentally friendly use of botanical biopesticides (see Chap. 14). In this chapter, we will look at France as a case study along with French and European regulations on botanical pesticides before going into more detail on these active substances.

13.2 Botanical Biopesticides and Organic Agriculture

Botanical biopesticides are based on plant extracts, which means they are natural products. But simply being natural products does not mean they can be systematically used in organic agriculture. Nicotine, for example, was banned as an insecticide because of its toxic side effects, despite its natural plant origin.

The regulatory framework for biopesticides varies considerably between countries and is often poorly understood. The basic concept is simple: non-synthetic (natural) substances can be used in organic agriculture, as long as they are not specifically prohibited and catalogued. Synthetic substances are automatically prohibited unless explicitly authorized on a national or EU-level list. The terms "synthetic" and "non-synthetic" are not clearly defined and have been subject to debate. However, the general principle is more or less followed by most countries. For example, in Japan, synthetic products may be used in organic agriculture if there is an imminent or serious threat to the crop or when alternative measures are ineffective. In Europe, biopesticides must have a marketing authorization, and conditions of use are specific to each EU country. Botanical products are considered plant protection products and are therefore subject to the same regulations, with a few exceptions.

The International Federation of Organic Agriculture Movements (IFOAM) is an international non-governmental organization that centralizes discussions between organic farming organizations from more than 172 countries. It has developed a common system of standards, verification and commercial identity. In Europe, active substances are evaluated at the EU level based on toxicity for humans (proven or presumed effects, including endocrine-disrupting effects) and environmental pollution (persistent, bioaccumulative and toxic pollutants). The initial marketing approval of an active substance is valid for 10 years. Commercial products composed of active substances to which various adjuvants are added may only be used or placed on the market if they have been authorized in and by the relevant Member State.

In the following paragraphs, we will take a closer look at French regulations as a case study to illustrate these points. In France, the Rural and Maritime Fisheries Code defines biocontrol products as agents and products using natural mechanisms within the scope of integrated pest management. It differentiates among macroorganisms and microorganisms, semiochemicals and natural substances of plant, animal, microbial or mineral origin. Aside from macroorganisms, the other three categories are subject to the same regulations as plant protection products.

These products may then be added to the list of biocontrol products drawn up and published by the French Ministry of Agriculture in its official bulletin. This list is updated regularly (French Ministry of Agriculture 2021). The products on the list benefit from several advantages, including authorization for commercial advertising, fewer use restrictions, authorization for sale and use in home gardens, parks, forests, roads and walking areas accessible or open to the public, and a reduction in the sales tax rate earmarked for the phytopharmacovigilance scheme.

Extended biocontrol products must meet several criteria to be included on the list. First, they must have a valid marketing authorization. The "active substances" are then classified according to the following categories: insect traps, microorganisms, semiochemicals, or natural substances of plant, animal, microbial or mineral origin. A natural substance is defined as any compound, molecule or mixture of the two existing in nature. These substances can come directly from a natural source (plants, microorganisms) or be chemically synthesized if the molecule produced is strictly identical to its natural counterpart. Finally, the last criterion for inclusion on this list is based on the assessment of the risk to human health and the environment. While the active substance of these products must be of natural origin, the various added adjuvants are not held to this standard. However, the entire formulated product is evaluated based on toxicity and ecotoxicity criteria.

Not all biocontrol products can be used in organic farming; to be authorized for such use, a product must be included in Annex 2 of European Commission Regulation (EC) No 889/2008 (amended by Regulation (EU) 2016/673). This additional, more restrictive step is nevertheless necessary. This verifies the absence of genetically modified organisms in the production chain of these substances, as well as the use of pheromones, which must be limited to traps and diffusers, thereby excluding kairomones and allomones (Acta Biocontrole 2018).

13.3 Description of Botanical Biopesticides Currently Used as Biocontrol Products in France

The number of active substances (or mixtures of active substances) of plant origin authorized for extended biocontrol in agriculture is low compared to other biopesticide categories in the world, as the French case study illustrates (Table 13.1). Certain substances such as azadirachtin (Text Box 13.1) have only provisional authorizations for sale in some countries (including France). Others, such as certain pyrethrum-based formulations, have been removed from the list of biocontrol products because one of the adjuvants has an ecotoxicological profile that does not meet the necessary criteria.

13.3.1 Pyrethrins

The active substances known as pyrethrins that are used as insecticides are synthesized from flowers of the Asteraceae family, with the main species belonging to the *Tanacetum* genus (synonym *Chrysanthemum*). *Tanacetum cinerariifolium* (also known as Dalmatian pellitory and pyrethrum), *T. coccineum* and *T. pinnatum* have been specifically described as having high levels of these compounds (Dajoz 1969). The term pyrethrum refers to a mixture of six esters (Table 13.2) produced by esterification of two acids and three alcohols with similar structures.

These compounds are neurotoxins. They act on the sodium channel, a protein in the cytoplasmic membrane of the axon in neurons involved in action potential propagation along these cells, and thus nerve signal transmission (see Chap. 16). Pyrethrins settle on these canals and slow down their closure. At the individual scale,

Table 13.1 List of various biocontrol plant protection products based on botanical substances authorized on the French market in 2021

	Active ingredient	Use	Date placed on the market	Formulated product (commercial)	Company
Insecticide	Pyrethrins (+ abamectin[a])	**Ornamental trees and shrubs and flower crops**: mites, whiteflies, scale insects, caterpillars, aphids, thrips	2009	Fazilo	Compo France SAS
	Rapeseed oil	**Vegetable, fruit and ornamental crops:** whiteflies, mites, aphids, scale insects, psyllids, true bugs	2017 2011	Nativert Naturen	Compo France SAS Scotts France SAS
	Rapeseed oil + pyrethrins	**Ornamental crops:** mites, aphids, leafhoppers	2009	Spruzit	Neudorff GMBH KG/Compo France SAS
	Sweet orange essential oil	**Field crops; vegetable, fruit, ornamental, tropical and grapevine crops:** whiteflies, thrips, mites, froghoppers, scale insects, psyllids, leafhoppers, true bugs	2017 2009	Prev-Am Plus Essen'ciel, Limocide, Prev-Am	Oro Agri/ Nufarm SAS Vivagro
	Maltodextrin	**All vegetable and ornamental crops:** aphids, mites, whiteflies	2016 2016	Eradicoat Blanmoscate	Certis Europe M. Cazorla, S.L.
	Terpenoid mixture	**Vegetable, fruit and ornamental crops:** whiteflies, mites, aphids, scale insects, psyllids, true bugs	2019	Requiem prime	Bayer SAS
Fungicide	Eugenol + geraniol + thymol	**Grapevine:** grey rot	2017 2017	Cagenoleta Mevalone	M. Cazorla, S.L. Sumi Agro France SAS
	Sweet orange essential oil	**Field crops, vegetable and fruit crops, grapevine:** powdery mildew, blight, rust, blister mites	2017 2009	Prev-Am Plus Essen'ciel, Limocide, Prev-Am	Oro Agri/ Nufarm SAS Vivagro
	Clove essential oil	**Fruit crops:** conservation diseases	2011	Bioxeda	Xeda International SA
Nematicide	Garlic extract	**Vegetable crops**: nematodes	2016 2017	Nemguard Namoteli	

(continued)

Table 13.1 (continued)

	Active ingredient	Use	Date placed on the market	Formulated product (commercial)	Company
					Certis M. Cazorla, S.L.
Herbicide	Pelargonic acid	**General treatments; vegetable, fruit, ornamental, tropical crops; viticulture; non-agricultural areas; fragrant, aromatic and medicinal plants:** mosses, dicotyledons and grasses	2014 2017 2017	Natur'net, Herbistop Kalipe Beloukha, Herbatak, Bromory, Starnet, Devatol, Finalsan	Compo France SAS Bayer Belchim/ Compo France SAS Protecta, SBM, Scotts, Start
	Acetic acid	**General treatments, ornamental crops, non-agricultural areas**	2013	Naturen Express, Cito fast, Cito max	Evergreen garden care SAS Aroma SAS Aedes protecta SAS
	Caprylic acid	**General treatments, ornamental crops, non-agricultural areas**	2018	Desherb'nat	SBM development
Other	Spearmint essential oil	**Potato:** inhibition or suppression of germs	2010	BioX-M	Xeda International SA

Source: Acta Biocontrole (2018) and French Ministry of Agriculture (2021). This list is updated regularly

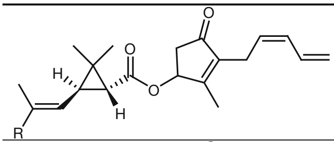
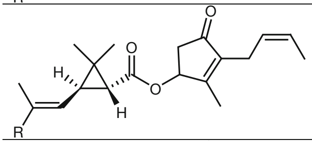
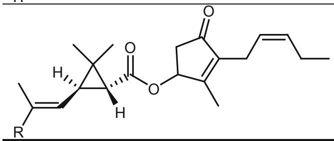
[a]Abamectin is an avermectin, i.e. a macrocyclic organic compound of bacterial origin

poisoning with these active ingredients results in hyperactivity followed by convulsion. Because these products are broken down in the gut, they act through direct contact and inhalation rather than ingestion.

These products are not only biologically effective, but they also have low environmental persistence: the molecules are unstable in light, air and water. They have a broad spectrum of action within the arthropoda phylum. They will kill not only all species of pests but all arthropods that come into contact with the product, including natural enemies. However, they are not very toxic to mammals (lethal dose estimated at 50–100 g for humans; Lauwerys 1990).

People have used the insecticidal properties of these flower extracts since the nineteenth century (Ware 1991). In the 1920s, their use was limited because of their high cost and fleeting effect. During the 1930s, the massive production of these extracts in Japan caused prices to fall, resulting in increased use (Regnault-Roger et al. 2008). However, because the active ingredients are so unstable, researchers sought out more persistent derivatives, which gave rise to a large family of synthetic

Table 13.2 List of the six major components of pyrethrum and their proportion in *T. cinerariifolium*

Structure	Common name	Proportion in an extract of *T. cinerariifolium*	Relative toxicity
	Pyrethrin I	35%	100%
	Pyrethrin II	32%	23%
	Cinerin I	10%	71%
	Cinerin II	14%	18%
	Jasmolin I	5%	Unknown
	Jasmolin II	4%	Unknown

R = CH_3 (pyrethric acid): series I
R = CO_2CH_3 (chrysanthemic acid): series II

insecticides (pyrethroids), the first of which began being used in the 1960s. Pyrethrins then fell into disuse. After 40 years of using synthetic pyrethroids, growing awareness of their side effects meant a return to the natural substances in the 2000s. Today, using natural pyrethrins is controversial. For example, in France, they are authorized as a biocontrol product, when combined with abamectin or rapeseed oil, on ornamental trees and shrubs, flower crops and house plants to control mites, whiteflies, herbivorous caterpillars, scale insects, aphids and thrips (Table 13.1). However, when added to mixtures with piperonyl butoxide, they are not considered biocontrol products. Pyrethrins can be used in conventional agriculture to control pests of cereals and tobacco, as well as to disinfect premises used for food storage (Acta Phytosanitary 2019). In 2016, 1774 kg of natural pyrethrins were sold, accounting for 17% of microbiological and botanical insecticides (Agreste 2021).

13.3.2 Vegetable Oils: The Example of Rapeseed Oil

Non-volatile vegetable oils are fatty and viscous extracts from plants, composed of fatty acid esters with a high molecular weight (Regnault-Roger et al. 2008), unlike essential oils, which are mainly composed of volatile molecules (described below). Vegetable oils are used as contact insecticides or as adjuvants for fat-soluble active ingredients. They work by forming an impermeable film that cuts off the air supply of the insect (or its eggs), causing asphyxiation, and by deeply penetrating the cuticle due to the amphibolic nature of some of their compounds. They are therefore only effective if the arthropods are present at the time of treatment. They may also affect insect pest behaviour by limiting oviposition; the application of vegetable oils is thought to limit the emission of volatile molecules pests use to recognize their host plant (demonstrated by Mensah et al. 2005 with mineral oils; suggested by Nicetic et al. 2011). Because their mode of action is more related to physical rather than chemical properties (Nicetic et al. 2011), vegetable oils are essentially non-selective and will have this insecticidal effect on both pests and non-target beneficial organisms (see Chap. 14).

Rapeseed oil is marketed worldwide as an insecticide to control pests in maize, orchards, vegetable crops, and ornamental or indoor plants. It is also sold as an adjuvant in the manufacture of fungicidal, herbicidal or insecticidal mixtures. There is little data in the scientific literature on its effectiveness as an insecticide or fungicide. In one review, Sams and Deyton (2002) reported three studies describing the fungicidal effects of rapeseed oil on powdery mildew, including an anti-sporulation effect. Cloyd et al. (2009) compared different botanical biopesticides and showed that rapeseed oil-based products varied in their effectiveness depending on the amount of oil used and the target pest. Although this biopesticide has a very broad spectrum of action, the quantity used must be adapted to the pest and the crop. Finally, Nicetic et al. (2011) compared the insecticidal effect of rapeseed oil versus mineral oils. The findings showed that rapeseed oil does increase pest mortality and limit oviposition compared to the control plot, but less effectively than the mineral oils tested.

Text Box 13.1: Azadirachtin and Neem Oil: To Be Or Not to Be a Biocontrol Product, That Is the Question

The insecticidal activity of neem oil, derived from the seeds of an Indian tree called *Azadirachta indica* A. Juss. (Meliaceae), is mainly due to limonoid compounds, which are modified triterpenoids. Neem oil also contains salanin and nimbin, antifeedant substances. Andiroba oil is also extracted from the seeds of another Meliaceae species, *Carapa guianensis*, for its limonoid content and insecticidal bioactivity.

The main limonoid in neem oil is azadirachtin, which inhibits feeding and imaginal moulting, and is a chemical sterilizing agent (Veitch et al. 2008). It is especially effective on young larval stages as its main mechanism of action alters the release of a growth hormone from the insect, causing morphological abnormalities at moulting (Dwivedi 2008). This active substance is absorbed by crop plant tissue, which ensures systemic action. It can therefore be used in many ways: classic sprinkling and by root absorption in hydroponic conditions or by injection in the stems.

(continued)

Text Box 13.1 (continued)

This substance is probably the most emblematic product among insecticidal compounds based on plant extracts. Its effectiveness has been demonstrated on over 400 species of arthropods (Flamini 2003; Ntalli and Menkissoglu-Spiroudi 2011), which has led to the plant from which it originates being called "the tree for solving global problems" (National Research Council 1992).

Azadirachtin is the only botanical pesticide authorized on the US market in the last 20 years[1] (Miresmailli and Isman 2014). NeemAzal®-T/S sold by Trifolio-M® is the most widely sold product in some European countries and has a declared azadirachtin A content of 10,000 ppm (Pavela et al. 2009). In France, two products that use azadirachtin A – NeemAzal®-T/S and Azatin® – have been authorized for sale and used since 2018, but only for crops grown under cover. NeemAzal®-T/S has also received provisional marketing authorization for 3 months each year since 2015 to control aphids in apple and pear crops. This restriction is in place because the active ingredient is a suspected endocrine disruptor (French National Assembly 2014). Its low toxicity to mammals and the environment is relative. For example, compared to glyphosate, it is more harmful to the environment and has a higher acute toxicity (Agritox 2021).

13.3.3 Essential Oils from Aromatic Plants

Essential oils are considered a very promising option for the development and production of botanical biopesticides (Isman 2000; Tripathi et al. 2009; Isman et al. 2011; Regnault-Roger et al. 2012; Pavela and Benelli 2016). They are produced using an extraction method set out in the AFNOR T-75-006 standard, which specifies how they must be obtained via steam distillation, dry distillation or mechanical processes. They are a complex mixture of secondary metabolites; they have a low molecular weight and are therefore volatile. Their bioactivity is due to several compounds, mainly terpenoids, including monoterpenes and sesquiterpenes, and to a lesser extent phenylpropanoids. Some compounds present in lower amounts may also impact their effectiveness or cause synergistic effects between compounds.

More than 3000 species of aromatic plants are known to date and about 10% are already sold commercially as raw materials in food, cosmetics, perfume, aromatherapy and alternative medicine (Bakkali et al. 2008). Aromatic plants yield around 0.5–2% essential oils, making them highly concentrated plant extracts compared to other plant sources (Isman 2017). Such yield levels are considered relatively good. Extraction and analysis methods are not very complex and their low costs are

[1] Products formulated with essential oils are subject to other regulations.

positive arguments for their use as biopesticides. Another major interest of essential oils is also their low persistence in the environment due to their high instability: they are rapidly degraded by light or high temperatures (Turek and Stintzing 2013). All these arguments explain why essential oil-based biopesticides are exempt from regulation by the United States Environmental Protection Agency.

Several botanical insecticides using essential oils (rosemary, mint, cinnamon, thyme, black pepper, clove) are available on the North American market and have uses ranging from farming to stored food protection, park management and disease vector control (Cloyd et al. 2009; Isman et al. 2011; Pavela 2016). Sweet orange essential oil is sold commercially around the world as an insecticide, especially against whiteflies, and as a fungicide, mainly against powdery mildew (Table 13.1). As insecticides, essential oils can affect pest behaviour (attraction, repulsion, inhibition of feeding and reproduction), metabolism (via deregulation of the endocrine balance), or nervous system activity (Regnault-Roger 1997; Isman 2006; Rattan 2010; Mossa 2016; Jankowska et al. 2017). Treatment is based on contact or fumigation; both types of application work by inhalation (Ikbal and Pavela 2019). Not all pests are sensitive to all essential oils and their relative specificity of action could guarantee an ecotoxicological profile that is considered safer for the environment. However, developing effective control strategies requires many tests to identify functional pest-essential oil pairs while assessing plant toxicity risks on crops (Cloyd et al. 2009; Ikbal and Pavela 2019).

13.3.4 Fatty Acids: The Example of Pelargonic Acid

The herbicidal activity of fatty acids has been known for many years (Poignant 1954). Fatty acids with medium aliphatic chains, such as caprylic acid (C8, octanoic acid) and pelargonic acid (C9), are the most effective (Coleman and Penner 2006). Pelargonic acid is one biological herbicide that is available in a range of formulations. For example, there are 24 commercial products containing pelargonic acid in France, ten of which are authorized for extended biocontrol and marketed as non-selective herbicides (Table 13.1). Commercial products are formulated with aliphatic fatty acids of different lengths that are mixed with vinegar or acetic acid and emulsifiers. These herbicidal oil solutions act very quickly by destabilizing plant cell membranes, leading to a rapid loss of cell functions. They have no selectivity and will kill all vegetation. However, sufficiently developed weeds or species with particularly developed underground organs (thistle, weed grasses, etc.) tend to grow back due to the lack of residual activity after the initial burning effect of the application.

Pelargonic acid is therefore a broad-spectrum commercial herbicide that is non-selective on crops (except for perennial crops) that works on contact and mainly acts against annual plants and mosses. It is considered an herbicide with low toxicity for humans with a transient environmental impact because it has no residual activity. Adding organic acids, such as succinic, lactic or glycolic acids, makes pelargonic acid formulations more effective (Coleman and Penner 2008). Oleic acid is usually a major component of these mixtures, although the exact compositions of these commercial products are trade secrets.

13.3.5 Sulphur Compounds in the Brassicaceae Family and **Allium** *Genus*

Some plants in the genus *Allium* (including garlic) or in the Brassicaceae family are rich in sulphur compounds and can be used directly to control the proliferation of soil organisms harmful to crops (insects, mites, weeds, nematodes, fungi and pathogenic bacteria). The sulphur compounds in these plants are the active ingredients of interest and can be classified into two groups: non-protein sulphur amino acids in *Allium* and glucosinolates in Brassicaceae. Non-protein sulphur amino acids are all cysteine derivatives and are precursors of volatile substances with biocidal activity. Similarly, glucosinolates can be degraded into unstable compounds that will produce different volatile compounds depending on the environmental conditions: thiocyanates, nitriles and isothiocyanates. The latter are the most abundant and widely studied.

These two plant families have proved useful in controlling Diptera species thanks to the repulsive action of their sulphur compounds: the smell of onion repels cabbage flies (*Delia radium*) while garlic extract repels mammalian parasites (*Simulium indicum* and *Culex quinquefasciatus*). These compounds may also inhibit feeding, which has been described, for example in the green peach aphid *Myzus persicae*. Finally, the toxic effect of these compounds has been demonstrated in many species of coleopterans, lepidopterans, hymenopterans, hemipterans, orthopterans and dipterans (Auger et al. 2002). *Allium* sulphur compounds have been shown to be effective against the nematode *Meloidogyne incognita* and Brassicaceae are often recommended for control of root-knot or cyst nematodes by biofumigation (Potter et al. 1998). These compounds have only a marginal acaricide effect, but their herbicidal effect is well known: farmers must wait to replant crops after biofumigation so the germination of the seeds planted is not inhibited. Finally, bactericidal and fungicidal effects are mainly known in human pathogens, although a few cases seem promising for possible application in agriculture. For example, *Pectobacterium carotovorum* and *Rhizobium radiobacter* are sensitive to three *Allium* extracts (Grainge and Ahmed 1988) and *Botrytis allii* is sensitive to thiols and sulphides (Kadota and Ishida 1972).

Biofumigation is the most widespread process for using these natural substances. This involves crushing and burying a brassicaceous plant (mustard, radish) or an *Allium* in the soil, which then generates biocidal gases. One limitation of this method is its lesser effectiveness on insect pests that have adapted to these compounds through co-evolution (case of *Acrolepiopsis assectella* larvae).

13.3.6 Maltodextrin

Maltodextrin is a substance of plant origin (more precisely, from maize *Zea mays*) composed of glucose polymers and obtained by hydrolysing starch. It is widely used in food processing, cosmetics and pharmacology, but its use as a biopesticide is relatively recent (European Food Safety Authority 2013) and very few scientific studies have been published on the subject. Cahenzli et al. (2018) showed that maltodextrin was toxic to *Drosophila suzukii*, albeit with lower efficacy compared to other botanical pesticides tested.

The insecticidal mode of action is quite similar to that of vegetable oils, i.e. it acts via suffocation by sealing the respiratory openings and limiting movement by causing the legs and wings to stick. The cross-linking of glucose polymers by rapid drying becomes impermeable to air. Maltodextrin-based products sold as biopesticides mainly target small pests such as aphids, mites and whiteflies on all vegetable and ornamental crops grown in greenhouses. Products are currently under development for future use in the field, particularly in arboriculture. Maltodextrin is also often used as a formulant in preparing essential oils for pesticide purposes (Luiz de Oliveira et al. 2018). Perhaps there could be a dual benefit to using this component itself as an insecticide formulant.

13.4 Conclusion

Botanical biopesticides contain an array of active substances with biological activity that varies in terms of specificity against a target. Currently, the use of such products is limited and few are authorized for sale. However, public and private research actors around the globe are now working to develop new solutions to meet the environmental challenges of modern agriculture and better support human health and the environment. Several challenges must be tackled, including identifying new botanical substances, understanding their mode of action and specificity, optimizing their production and assessing the risks generated by their use. These challenges are outlined in Chap. 14.