Hort4EUGreen

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CHEMICAL PESTICIDE-FREE HORTICULTURE

Biological control of crop pests, pathogens and weeds

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"Enhancing practical skills of horticulture specialists to better address the demands of the European Green Deal"

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Table of Content

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Biological control of crop pests, pathogens and weeds

Rumen Tomov, Roxana Ciceoi

Introduction

Biological control of crop pests, pathogens, and weeds is an integral aspect of sustainable agriculture within the European Union (EU), aligning with its broader environmental and agricultural policies.

The importance of this approach can be understood from several scientific and ecological perspectives, as biological crop protection brings several benefits, among which the ecological, environmental, agricultural, and economic, are the most important. The module makes on overview of definitions of biological control, which is one of the most complicated issues that ever was in plant protection. Biological control, often referred to as biocontrol, is a method of controlling pests (including insects, mites, weeds, and plant diseases) using other living organisms. Besides this, the use of the terminology encompass so many related aspects, that debates can go forever. Biocontrol relies on predation, parasitism, herbivory, or other natural mechanisms, and typically involves an active human management role.

Although it depends on the authors and its perspective, generally there are acknowledged three main categories of biological control, in the form of

(1) classical biocontrol, based on introducing natural enemies from a pest's native habitat;

(2) augmentative biocontrol, based on supplemental release of natural enemies;

(3) conservation biocontrol, based on modifying the environment to enhance the action of specific natural enemies or the general natural enemy community.

The history of biological control can be traced back over centuries, although its scientific basis and widespread application primarily developed in the late 19th and 20th centuries. Although was not the intentions here, there is a short overview of the key milestones and developments in the history of biological control, for a deeper understanding of the developments of this particularly important field of plant protection, and also as a basis for its multifaced definitions and proposed or adopted methods. There was a true journey, from empirical observations to a scientifically grounded practice integrated into modern agriculture and ecological management, an evolution that mirrors the ecological awareness of practitioners, but also of the society, and the pursuit of sustainable solutions to agricultural production.

The module has a very practical approach, for farmer and other practitioners, presenting the commercially available auxiliary products, macrobials and microbials, and the pests that can be managed by them. Other chapters are referring directly to the use of semiochemicals – pheromones, parapheromones, antifeedants, kairomones, etc., and also of natural substances - botanicals and minerals, for control and management of crop pests. There are also special references to the biological control of crop pests and pathogens in vegetable growing and fruit growing, two of the major areas of interest of horticultural production.

The biological control is a cornerstone of environmentally sustainable pest management strategies, offering a natural alternative to chemical pesticides and aligning with the principles of ecological balance and conservation.

Biological control of crop pests, pathogens and weeds

Summary

In this module, are presented aspects related to biological control, including the ways of protecting and enhancing the biological control agents, the use of macrobials, microbials, semiochemicals and natural substances, with explanations on each category.

For the practical works and for the readers involved in horticultural production, lists about commercially available auxiliary products, from all these categories and the pest that can be managed by these products are included.

Learning outcome descriptors

By the end of the module, the students are expected to know, understand, and be able to:

- describe the principles of biological control;
- understand the role of biological control inside the Integrated Pest Management concept;
- recognize and describe various predators, parasitoids, pathogens, and competitors used in biological control;
- understand the environmental benefits and potential risks associated with biological control, including non-target effects and ecological balance;
- recognize the ethical implications and responsibilities involved in biological control, especially regarding invasive species and biodiversity conservation.

General and transferable skills

1	ability to analyze pest management problems, evaluate different control strategies, and develop effective solutions
2	skills in conducting thorough literature reviews and staying updated with the latest scientific findings and advancements in the field
3	the ability to present information, ideas, and strategies about biological control effectively
4	ability to adapt to new challenges, changing conditions, and evolving pest management scenarios, particularly in the context of climate change.

Learning outcome descriptors

Knowledge, understanding and professional skills

1	understanding of the basic principles and mechanisms underlying biological control, including the types and methods of biological control
2	familiarity with various natural enemies, including predators, parasitoids, pathogens, and competitors used in biological control,
3	comprehensive knowledge of IPM strategies, where biological control is integrated with other pest management practices
4	awareness of the risks associated with biological control, including non-target effects and the introduction of exotic species
5	skills in identifying pests, pathogens, weeds, and biological control agents, and diagnosing pest-related problems in crops
6	ability to provide expert advice and consultation to growers, industry, and other stakeholders on biological control and pest management

Unit 3.1 What is biological control?

Rumen Tomov

3.1.1 Definitions

The use of predators, parasitoids and pathogens as a form of natural pest control has a long history detailed by Van Driesche & Bellows (1996), van Lenteren, (2012). The last 100 years has seen a dramatic increase in their use as well as our understanding of how they can better be manipulated as part of effective, safe, pest management systems (Orr, 2009).

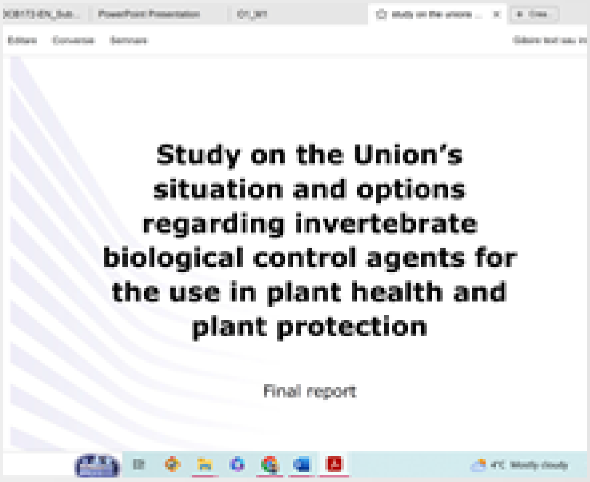
A significant role in the development of the concept of biological control was played by the establishment of the International Organisation for Biological Control (IOBC) in 1955 as a global organization affiliated to the International Council of Scientific Unions (ICSU) aimed at the promotion of environmentally safe methods of pest and disease control (https://www.iobc-global.org/). In addition, several stakeholders are actively involved in the development and promotion of biocontrol practices, as - International Plant

Protection Convention, European and Mediterranean Plant Protection Organization, European Food Safety Authority of the European Union, International Biocontrol Manufacturers Association.

Pests' natural control play important role is several ecologically based production systems including organic farming (Brumfield & Ogier, 2000), total-habitat management (Prokopy, 1994; Kogan and Bajwa, 2001), integrated fruit and crop production (Sansavini, 1997) etc. Biological control can be a safe alternative to chemical pesticides and is expected to contribute to achieving the objectives of the Farm to Fork Strategy, of the European Green Deal.

Several analytical reports related to biocontrol in Europe were published recently, underlining the growing interest to the biological control. Hulot & Hiller (2021) made a comprehensive literature review on biocontrol in light of the European Green Deal and detected 129 projects related to biocontrol over the past twenty years. The increasing number of projects financed by the EU over time shows a growing interest in biocontrol both from the research community and from the European policymakers.

To pinpoint key issues and aid in the groundwork for conceiving a new potential initiative, the EU Council, through Decision (EU) 2021/1102, commissioned a study focusing on the current state and potential strategies pertaining to the introduction, production, assessment, marketing, and application of invertebrate biocontrol agents (IBCAs) within the European Union's territory. The conclusive report of this study was released at the end of 2022.



A must read. Source here

The crop protection in the European Union is analysed by Buckwell et al. (2020). The International Organisation for Biological Control (IOBC) initiative brought together practitioners and researchers from widely diverse fields to identify the main limitations to biocontrol uptake and to recommend means of mitigation (Barratt et al. 2018).

Despite the increasing interest to the biological control during last decade, no formal EU definition of biocontrol or bio protection currently exists (Hulot & Hiller, 2021). On the other hand, more than 30 definitions of biological control could be found in the literature (van Lenteren, 2012). Integrating a single EU wide accepted definition in upcoming regulations and guidance would be beneficial for a common understanding of the functions of biocontrol, and its value to the EU Green Deal.

A clear legal definition of biocontrol and its relationship to IPM and organic agriculture, would remove potential misunderstandings (Hulot & Hiller, 2021).

Definition and scope

Typically, biological control aims to control pests to below economic damage thresholds and does not strive for complete eradication. By allowing a small tolerable population of e.g. pest or non-damaging insects within the crop, it is possible to ensure prey for natural enemies throughout the growing season and thereby decrease the risk of natural enemies migrating from the field (Nilsson et al., 2016).

Biological control depends on different mechanisms outlined by Stenberg et al. (2021) - Predation, parasitism, pathogenicity, and herbivory; risk avoidance behaviour of pests; antibiosis; competition; mobilization of plant intrinsic defences and semiochemicals released by living agents.

There are three basic terms describing organisms involved in the biological control (van Lenteren, 2012).

- Natural enemy: an organism which lives at the expense of another organism, and which may help to limit the population of this other organism. The term 'natural enemy' in this context includes parasitoids, parasites, predators and pathogens.

- Biological control agent (bioagent): a natural enemy, antagonist or competitor, and other self-replicating biotic entity used for pest management.
- Beneficial organism: any organism directly or indirectly advantageous to plants or plant products, including biological control agents.

Eilenberg et al. (2001) proposed standardizing the terminology used in biological control across various research fields, including the biological control of arthropods, weeds, and plant pathogens. They offered the following definition:

> ”Biological control (or biocontrol) is the use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be.”

According to Nilsson et al. (2016) pests’ natural enemies can be exploited in order to protect agricultural and horticultural crops, natural ecosystems and forest plantations. This is called biological control and differs from other pest management methods by the fact that living organisms are used for pest control.

Till recently, it was widely recognized that the most important element of a biological control definition should be that a living organism is reducing the population density of another living organism (Eilenberg et al., 2001; van Lenteren, 2012; Stenberg et al., 2021).

Biological control is a field which has grown rapidly in the last two decades involving different biocontrol technologies. In parallel developments, there have been increasing references to biological control in industrial contexts and legislation, resulting in conceptual and terminological disintegration Stenberg et al. (2021).

Twenty years after paper of Eilenberg et al. (2001), Stenberg et al. (2021) reviewed use of previously suggested terms in key felds (e.g., phytopathology, entomology, and weed science), eliminated redundant terminology, and proposed that biological control should be based on three key principles.

(1) only living agents can mediate biological control,
(2) biological control always targets a pest, directly or indirectly,
(3) all biocontrol methods can be classified in four main categories:

- Natural biological control (if there is no deliberate human intervention),

- Conservation biological control (involving human stimulation of resident agents of biological control),
- Augmentative biological control (human addition of biocontrol agents, temporarily augmenting the population of biocontrol agents), and
- Classical biological control (adding new biocontrol agents for proliferation and permanent establishment)

Wider definition of biological control

In parallel with growing environmental awareness among farmers and consumers, various new products with bio-prefixes have been introduced for crop protection. Some of these contain living organisms, while others contain nature-based, non-living, or active ingredients (Stenberg et al., 2021).

The International Biocontrol Manufacturers' Association (IBMA) advocates for the use of the term 'bioprotection', a broad concept that includes all biological-origin tools used in managing pests, pathogens, and weeds (IBMA, 2018). Bioprotection refers to both biocontrol methods and technologies, highlighting their natural aspect, which implies negligible or temporary environmental impact, safety for humans and non-target animals, and no significant health risks (IBMA, 2020).

Products used in biological control are commonly referred to as '*bioprotectants*', '*biopesticides*', '*biological control agents*', or simply '*biologicals*'.

Bioprotectants are derived from natural sources and are designed to be safe for human use while exerting minimal environmental impact. Specifically, they encompass macro-organisms, also known as Invertebrate Biocontrol Agents, as well as plant protection products that contain micro-organisms. Additionally, they include Semiochemicals, which are chemical mediators like pheromones and kairomones, and natural substances originating from plant, animal, or mineral sources (IBMA, 2022).

> According to van Lenteren, (2012) the Biological pesticide (biopesticide) is 'a generic term, not specifically definable, but generally applied to a microbial control agent, usually a pathogen, formulated and applied in a manner similar to a chemical pesticide, and normally used for the rapid reduction of a pest population for short-term pest management'.

Biopesticides do not have any residue problem, which is a matter of substantial concern for consumers, specifically for edible fruits and vegetables.

Biopesticides, including entomopathogenic viruses, bacteria, fungi, nematodes, and plant secondary metabolites, are gaining increasing importance as they are alternatives to chemical pesticides and are a major component of many pest control programs (Senthil-Nathan, 2015).

Just a simple comparison of biopesticides eight different approaches is presented in table 1.

Table 1. Categorization of biopesticides

FAO and WHO (2017)	Senthil-Nathan (2015) Samada & Tambunan (2020)	Khater (2012)	OECD (2023)
Biopesticide	Bioopesticides	ecosmart biorational insecticides	Biological Pesticides (BioPesticides)
A generic term generally applied to a substance derived from nature, such as a microorganism or botanical or semiochemical, that may be formulated and applied in a manner similar to a conventional chemical pesticide and that is normally used for short-term pest control [adapted from ISPM Pub. No. 3, 1996 (IPPC, 2005)].	Microbial pesticides – products that come from microorganisms such as bacteria, fungi, viruses, protozoa and algae; Plant-incorporated protectants - pesticidal substances in plants that result from plant genetic modification; Biochemical pesticides (biochemical) - plant growth regulators that interrupt the growth, mating, or attractive pheromones in pests	Biological insecticides - natural enemies such as parasitoids, predators, nematodes, and pathogens as virus, bacteria, fungi, or protozoa; Biochemicals insecticides - botanicals, insect growth regulators, insect pheromones, photoinsecticides, and inorganics; Transgenic insecticides-genetically modified plants or organisms	Microbials- bacteria, algae, protozoa viruses, fungi pheromones and semiochemicals Macrobials/invertebrates- insects and nematodes Plant extracts/botanicals

EU	European Environment Agency (EEA, 2023)	Health and Safety Executive (HSE, 2023)	croplifeeurope.eu
Biopesticide	Biopesticide	Biopesticide	Biopesticide
In the EU, biopesticides are defined as ‘a form of pesticide based on microorganisms or natural products’. They originate from nature, don’t cause harm to humans and have minimal impact on the environment, but they are classified as active substances under EU regulations.	A pesticide in which the active ingredient is a virus, fungus, or bacteria, or a natural product derived from a plant source. A biopesticide's mechanism of action is based on specific biological effects and not on chemical poisons	Products based on pheromone and other semiochemical; Products containing a microbial (for example bacterium, fungus, protozoa, virus, viroid); Pproducts based on plant extracts; Other novel alternative products	Biopesticides are derived from nature, they regroup four main categories: Semiochemicals (e.g., pheromones), Natural substances (e.g., botanicals, biochemicals), Macrobials (e.g., beneficial insects) Microbials such as bacteria or viruses.

Samada & Tambunan (2020) reviewed the status, future prospect and challenges associated with the use of biopesticides in pest control and suggest the following definition ‘Biopesticides are living organisms or natural products that control agricultural pests including bacteria, fungi, weeds, viruses and insects.

According to another opinions biopesticides include natural enemies such as parasitoids, predators, nematodes as well (Khater, 2012; OECD, 2023). Khater, 2012, reviewed the mode of actions, uses, commercial products, and safety concerns of ecosmart biorational insecticides (derived from two words, “*biological*” and “*rational*”) and refer to pesticides that have limited or no adverse effects on the environment, non- target organisms including humans.

Despite of numerous definitions concerning biopesticides, at EU level Micro-organisms, semiochemicals and natural substances are considered as Plant Protection Products and are regulated by Legislation on Plant Protection Products and must follow the EU pesticide regulation process. In the EU, the approval for use of microbials, semiochemicals and natural substances falls under the same process and regulation as for synthetic substances and products, that is Regulation (EC) 1107/2009. https://food.ec.europa.eu/plants/pesticides_en

Invertebrates, such as insects, mites or nematodes, feeding or antagonizing on harmful organism can be used as one form of natural pest control. In order to better distinguish them from other categories of biological pest control, they are usually referred to as invertebrate biological control agents (IBCAs). https://food.ec.europa.eu/plants/plant-health-and-biosecurity/invertebrate-biological-control-agents-ibcas-against-plant-pests_en

Biopesticides are a crucial component of integrated pest management programs for pest control, which lead to more natural alternatives to chemical pesticides that are eco-friendly and safer. Most biopesticides work because of chemical reactions with the pests. Since the emergence of biopesticides for potential pest management, numerous products have been released and some of them dominate the market (Samada & Tambunan, 2020).

The described development of terminology related to biopesticides led to the emergence of a more wide definition of biological control.

For conceptual and regulatory reasons, there is a need to maintain a clear distinction between products containing living organism and containing non-living gradients, but for commercial reasons there is a clear tendency to blur them Stenberg et al. (2021).

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Inclusion of semiochemicals in the biocontrol definition

The "living component" is present in the Answer given by Mr Andriukaitis on behalf of the European Commission Question reference: E-003275/2018, but in addition the use of semiochemicals is considered as element of biological control as well "***Biocontrol** is one of several types of pest control, in which pests are controlled **using other living organisms**. These biological control agents can be either **macro-organisms** (e.g. insects, mites) or **micro-organisms** (e.g.bacteria, fungi). **Semiochemicals** (like pheromones) are in general also considered as part of biocontrol*"

Inclusion of natural substances in the biocontrol definition

The practice of biocontrol is described in the dictionary of agroecology and plant pathology as comprising the use of living organisms or **natural substances** to prevent or reduce damage and diseases caused by harmful organisms such as animal pests, weeds and pathogens (Busson, 2019, Prajapati et. al., 2020).

According to Buckwell et al. (2020) biological control or bioprotection refers to the control of pests, diseases and weeds based on naturally occurring compounds or organisms. They suggest the following definition:

> ‘Biocontrol (or bioprotection): refers to a range of tools used to control pests, diseases and weeds based on naturally occurring compounds or organisms. These include: macrobials (invertebrate control agents), microbials (e.g. bacteria), semiochemicals (e.g. pheromones) and natural substances (e.g. garlic extract). PPPs used in biocontrol must be sourced from nature or can be synthetized as long as they’re nature identical and are sometimes called biopesticides’ (Buckwell et al., 2020).

Macro-organisms are referred to as Invertebrate Biocontrol Agents may be regulated under differing national legislation of the 27 EU members. Registration for invertebrate biocontrol agents is currently done at Member State level, following national law Buckwell et al. (2020).

According to Stenberg et al. (2021) bio protection can be used as an excellent umbrella term that encompasses protection provided by either living agents or non-living substances of biological origin. However, to preserve scientifc clarity and integrity of biological control. Stenberg et al. (2021) suggest keeping the boundary between the living agents within biological control and the non-living substances in other forms of bioprotection.

Based on the wider definition of biological control According to Hulot & Hiller (2021) Depending on the types of living organisms or natural substances used, four categories of technological approaches/categories to biological control are widely agreed:

- Macro-organisms: invertebrates, such as insects and nematodes used for biocontrol purpose - referred to as Invertebrate Biocontrol Agents
- Micro-organisms: viruses, bacteria and fungi
- Semio-chemicals or chemical mediators: pheromones
- Natural substances of mineral, plant or animal origin

Semiochemicals, and **natural substances** are considered as bioagents by some authorities (Buckwell et al., 2020).

EU wide definition

In order to achieve the Union-wide reduction targets ('Union 2030 reduction targets') as well as national 2030 reduction targets the EU is currently discussing a new regulation to reduce pesticides. It was proposed by the EU Commission in July 2022 as part of the Green Deal. The following EU definition of Biological control is proposed.

'Biological control' means the control of organisms harmful to plants or plant products using natural means of biological origin or substances identical to them, such as micro-organisms, semiochemicals, extracts from plant products as defined in Article 3(6) of Regulation (EC) No 1107/2009, or invertebrate macro-organisms. COM (2022) 305

https://food.ec.europa.eu/plants/pesticides/sustainable-use-pesticides_en

IBMA is pleased to see this EU definition that encompasses the four established categories of biocontrol. This provides flexibility to include the natural substances identical to those of biological origin in addition to the plant extracts listed in Reg.1107/2009 thus enabling future innovation.

On the other hand some recommendations for improving the definition have been published as well.

'Whereas organic farming uses natural substances which are considered as biocontrol according to the SUR definition, other natural substances allowed in organic farming would not be part of biocontrol according to the definition proposed by the Commission. Indeed, the SUR proposal establishes a definition of biological control in the Article 3(23))7 , which includes all natural substances allowed in organic farming according to the EU legislation, except inorganic compounds (mineral compounds such as copper, sulphur, potassium bicarbonate). The definition of biocontrol in the SUR should be aligned with the EU Regulation on organic farming and should include inorganic compounds of mineral origin. This would also be in line with national definitions

of biocontrol. For example, the French legislation defines biocontrol as four categories: microbials, invertebrate biocontrol agents, semiochemicals and natural substances' IFOAM (2023).

According Stenberg et al., (2023) the new Regulation on the sustainable use of plant protection products has good intentions, but also unsatisfactory definitions which unfortunately will impede the transition to sustainable plant production. Terminological confusion will arise between academia, industry and policy makers due to the longstanding, strong tradition within the scientific community to use the term biological control exclusively for the use of living agents, including viruses. The European Commission should seize this opportunity to provide a clear framework on the use of biological control. This should be done by adopting the established scientific definition of biological control, i.e., the use of living agents to combat pests and pathogens. Non-living substances derived from nature can instead be termed nature-based substances. Together with the biocontrol agents, they can be classified under the bioprotection umbrella.

In conclusion, it is noteworthy that despite the extensive discussions among researchers, businesses, and policymakers, there is still no EU definition of biological control.

3.1.2 The evolution of biological control

Rumen Tomov

The history of biological starts some centuries aog, but the major developments happened in the late 19th and 20th centuries. The key milestones and developments in the history of biological control could be categorized in:

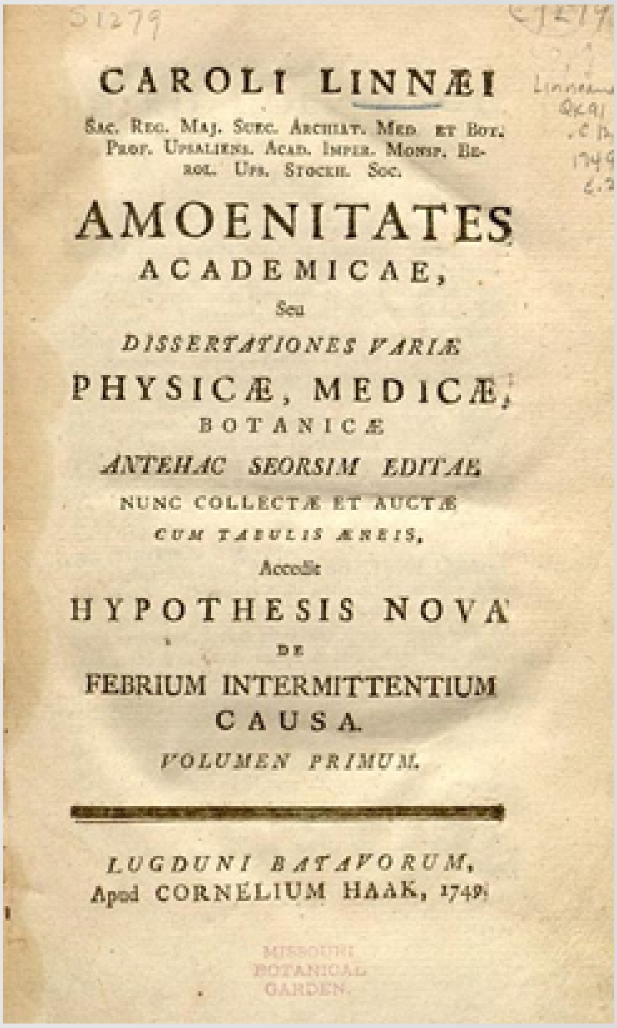
Ancient and early use

are referenced in different sources, e.g. 324 B.C. the Chinese introduce ants (*Oecophylla smaragdina*) in citrus trees to manage caterpillars and large boring insects while in 1000-1300 B.C. date growers in Arabia seasonally transport predatory ants from nearby mountains to oases to control phytophagous ants that attack date palms (Cornell University, 2010). Most likely, the early people practicing agriculture observed natural predation and parasitism, but they might not have understood these interactions in scientific terms and only mentioned them briefly.

Source here

Development in The Age of Enlightenment are more often mentioned. In 1763 Linnaeus published a prize-winning essay in his multi-volume zoological and botanical publication *Amoenitates Academicae*, where he suggests using mechanical and biological control to manage orchard caterpillars.

Development in The Age of Enlightenment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Sac. Reg. Maj. Suec. Archiatr. Med. et Bot. Prof. Upsaliens. Acad. Imper. Monsp. Berol. Ups. Stockh. Soc.

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HYPOTHESIS NOVA DE FEBRIUM INTERMITTENTIUM CAUSA.

VOLUMEN PRIMUM.

LUGDUNI BATAVORUM,

Apud CORNELIUM HAAK, 1749.

Development in the 19th Century

is marked by many observations and documentation of predation of agricultural pests by certain beetle species. For example, in 1888 the *Novius* (Rodolia) *cardinalis Muls*. was introduced from Australia to California, to control cottony cushion scale in citrus crops. As the vedalia beetle's impact was dramatic and immediate, this lead to a widespread recognition of biological control as a practical pest management strategy and later the bioagent was introduced into other 32 countries to control *Icerya purchase*.

Novius (Rodolia) cardinalis Muls.
Source here

Expansion and evolution in the 20th Century

happened after the success of the vedalia beetle, especially in managing invasive species in colonized territories. In the same period the development of theoretical frameworks and methodologies for biological control began. This period was marked by increased understanding of ecological interactions and the role of specific natural enemies in pest control. Research institutions and governmental agencies specializing in biological control were established in various countries, fostering research, development, and implementation of biocontrol programs.

Post-World War II Developments

marked by the growth and extensive adoption of synthetic chemical pesticides, overshadowed earlier methods of biological control. However, this trend shifted in the 1960s, spurred by increased awareness of the detrimental environmental and health effects of excessive pesticide usage, notably highlighted in Rachel Carson's "Silent Spring." This shift in perspective rekindled interest in biological control within integrated pest management (IPM) strategies.

Recent Advances and Current Trends

are marked by the molecular biology and biotechnology: advances, as they provided new tools for understanding and improving biological control agents. In this period there has been increasing collaboration at the international level to address issues related to the introduction of biocontrol agents, including risk assessment and regulatory frameworks.

Today, there is a focus on ecosystem services, biological control being acknowledged as one of the main preserving biodiversity and providing ecosystem services factors.

3.1.3 Biocontrol classifications

Rumen Tomov, Roxana Ciceoi

According to Van Driesche & Bellows (1996), van Lenteren (2000), Nilsson et al. (2016) the main types of biological control are classical, augmentation and conservation biological control. Gurr and Wratten (1999) proposed the concept of **integrated biological control**, which uses conservation biological control techniques to support classical, inoculation and inundation biological control. Stenberg et al. (2021) suggest new category 'Natural biological control. Eilenberg et al. (2001) suggest the term 'augmentation' to be avoided and Inoculation and Inundation biological control to be considered as different types of biocontrol. Hajek & Eilenberg (2018) maintains the separation of inundative and inoculative biological control, while retaining augmentative as an aggregate term. Stenberg et al. (2021 advocate use of the broader term augmentative biological control for all cases of non-permanent pest control, whether the released organisms reproduce or not.

Good definitions of different types of biological control are presented by Eilenberg et al. (2001), van Lenteren, (2012) and Stenberg et al. (2021).

Having in mind that the wider approach which considers semiochemicals and natural substances as elements of biocontrol, the above mentioned and widely agreed types of biocontrol are relevant for natural enemies only. In this respect two more types of biocontrol should be added: (1) Use of semiochemicals and (2) Use of natural substances.

The different types of biocontrol are described as follows:

Classical biological control

”Use of natural enemies in inoculative releases; usually, both the pest and the natural enemy are of exotic origin’ (van Lenteren, 2012).
”The intentional introduction of an exotic, usually co-evolved, biological control agent for permanent establishment and long-term pest control’ (Eilenberg et al., 2001).

The goal of classical biological control, permanent establishment of a biological control agent for self-sustained long term control, distinguishes clearly this strategy from inundation and inoculation biological control, thus requiring a distinct name for this practice. The introduced bioagent could control exotic or native pest Eilenberg et al. (2001). The general procedures included in CBC against an exotic pests are detailed in many publications and general books reviewed by Kenis et el. 2017. A database (BIOCAT) is documenting all deliberate introductions of insects for the biological control of other insects since the 1890s. The database has been updated to include information from publications to the end of 2010, some fields have been restructured, and the nomenclature checked, especially for BCAs (Cock et al. 2016). An overview of all documented releases of exotic invertebrate biological control agents (IBCAs) into Europe is presented by Gerber & Schaffner (2016).

Augmentative biological control

"Use of natural enemies in inundative and seasonal inoculative releases' (van Lenteren, 2012).
'Augmentation biological control includes activities in which natural enemy populations are increased through mass culture, periodic release (either inoculative or inundative) and colonization, for suppression of native or non-native pests' (Orr, 2009).

According to van Lenteren (2012) the augmentative biological control utilizes one to several releases of a natural enemy to suppress a pest during the course of a season or a crop's production cycle. Permanent establishment with consistent pest suppression in the absence of augmentation is not its aim. Augmentative releases are meant to supplement an established complex of endemic and/or exotic natural enemy populations during critical periods when the natural enemy complex is incapable of suppressing the pest consistently on its own. Two types of augmentation are defined:
a) Inoculation biological control
The intentional release of a living organism as a biological control agent with the expectation that it will multiply and control

the pest for an extended period, but not permanently' In glasshouses, the early release of parasitoids and predators, often with alternative food sources, is inoculation biological control. Examples of this are the releases of Encarsia formosa Gahan (Hymenoptera: Aphelinidae) and other natural enemies, now commonly practised in glasshouses (Eilenberg et al., 2000; van Lenteren, 2000). The number of insects released is insufficient to control the pest insects, and success depends on the ability of the released organisms to multiply and reduce the target population.

b) Inundation biological control
'The use of living organisms to control pests when control is achieved exclusively by the released organisms themselves' Inundatively released biological control agents must normally contact and kill a sufficiently high proportion of the pest population or by other means reduce the damage level to give economic control before dispersing or being inactivated Eilenberg et al. (2001). An important feature of this definition is that although we apply the biological control agent without the expectation that it will reproduce, it must be a living organism capable of reproduction. Agents used for inundative releases, especially micro-organisms, are also commonly called 'biopesticides'. However, this term has been used by Copping (1998) and Hall & Menn (1999) to include botanical pesticides and pheromones. Any mass-release with the expectation of immediate effects by the individuals released should be termed inundation biological control, irrespective of the mode of action Eilenberg et al. (2001).

Augmentative biological control is applied worldwide, and more than 150 species of natural enemies are now commercially available for augmentative biological control van Lenteren 2012. An analysis of the place of crop protection in the EU food system is made by Buckwell et al. 2020.

Additional information about augmentative biological control could be found in **Unit 3.3 and 3.4.**

Conservation biological control

'Actions that preserve or protect natural enemies' (Ehler, 1998)
'Modification of the environment or existing practices to protect and enhance specific natural enemies or other organisms to reduce the effect of pests' Eilenberg et al. (2001).

This approach is a combination of protecting biological control agents and providing resources so that they can be more effective. Therefore, conservation practices include limited and selective use of pesticides but also active processes such as providing refuges adjacent to crops or within crops, facilitating transfer of natural enemies between crops or even directly provisioning food or shelter for natural enemies (van Driesche & Bellows, 1996). Habitat manipulation is a sub-discipline within conservation biological control that aims to actively improve habitats for natural enemies in order to establish them in sufficient numbers to suppress crop pests below the economic threshold (Nilsson et al. 2016).

According to Eilenberg et al. (2001) it can be hard to distinguish clearly between conservation biological control, ‘cultural control’ and ‘good farming practice’. The authors consider that conservation biological control is being practised when specified natural enemies are protected and enhanced in order to obtain control of specified pests. Cultural control will tend to target the pest population directly and not the biological control agent, and good farming practice may extend to new situations, practices which have been shown to reduce pest incidence in other, similar situations.

Additional information about conservation biological control could be found in **Unit 3.2.**

Natural biological control

This type of biocontrol was suggested by Stenberg et al. (2021). It refers to cases when with no deliberate human intervention, resident organisms exert a background level of pest control, through various processes that meet all of the conceptual criteria for biological control and thus can be regarded as natural biological control mechanisms. Examples of natural biocontrol are soil suppressiveness, natural biological control of weeds.

Use of semiochemicals

Semiochemicals are substances or mixtures of substances emitted by plants, animals, and other organisms that evoke a behavioural or physiological response in individuals of the same or other species (SANTE/12815/2014). In recent years, semiochemicals have been increasingly used in plant protection strategies as attractants and repelents.

Additional information about use of semiochemicals could be found in **Unit 3.5.**

Use of natural substances

Natural Substances are a diverse group of substances. This diversity is also reflected in the different definitions that are used. Watt (2022) showed that the EU is the only region without clear data requirements specifically for registration of Natural Substances. Natural Substances are currently being assessed under the regulatory framework developed for conventional plant protection products in the EU. Key literature sources related to regulatory systems and the outcome are presented.

There are globally different definitions for natural substances. Some definitions are based on mode of action, some on origin, some on risk, some on a mixture of parameters. The IBMA's definition of Natural Substances is: *"Substances that consist of one or more components that originate from nature, including but not limited to: plants, algae/micro algae, animals, minerals, bacteria, fungi, protozoans, viruses, viroids and mycoplasmas. They can either be sourced from nature or are nature identical if synthetized. This definition excludes Semiochemical and microbials."* IBMA (2023).

Additional information about Use of natural substances (botanicals and minerals) could be found in **Unit 3.6.**

3.1.4 Safe use of biocontrol agents

Rumen Tomov

Is there any risk in the use of bioagents?

Use of biological control agents may, nevertheless, present some risks, in particular for the environment if non-indigenous agents are introduced from other continents, and for the user if agents are formulated as plant protection products. EPPO PM 6/3 2020. According to Loomans & van Lenteren, (2005) the deliberate or accidental introduction of species from their native ranges to new environments is a major threat to biological diversity. Biological control is both an important management tool for controlling threats to agriculture an the environment as well as-in rare cases-a potential threat to the environment itself.

Barratt (2011) reviewed direct and indirect effects that have been identified for biological control introductions recognized by different authors as:

- Direct effects - impacts that a biological control agent might have on organisms other than the target in the new environment
- Indirect effects - impacts on species in the same trophic level as the biological control agent, such as other parasitoids, e.g. hybridization, competition or displacement, or impacts on other organisms in other trophic levels and ultimately on food webs

While biological control agents (bioagents) offer a more environmentally friendly alternative to chemical pesticides in horticulture, their use is not always without risks. The main risks associated with the use of bioagents for biocontrol in horticulture include:

1. Non-target effects risks: some biocontrol agents might adversely affect non-target organisms, including beneficial insects, wildlife, and even plants. This can occur if the bioagent is not specific enough to the target pest.
2. Ecological risks, mainly invasive potential: introduced biocontrol agents could become invasive, especially if they are non-native species, and this can disrupt local ecosystems and lead to unintended ecological consequences. In the same time bioagents might interact with the ecosystem in unforeseen ways, potentially altering food webs or habitat structures.
3. Resistance development risks might also happen, if biocontrol agents are used repeatedly or improperly.
4. Alteration of human and animal health risks, especially by their allergenic potential or, although improbable, by their potential pathogenic effect to humans, livestock, or other non-target animals.
5. Regulatory and compliance risks may have a direct economic impact, as the strict regulations governing the use of biocontrol agents may lead to failure to comply with, which can lead to legal and financial consequences.
6. Trade restrictions risks derive from the fact that the use of certain biocontrol agents is different from country to country,

and importing horticultural products may have restrictions because of specific biocontrol organisms used to protect the commodity.

7. Effectiveness variability risks may happen because biocontrol agents may have different effect, depending on environmental conditions, application methods, and pest behaviors. This implies through applied research, to have scientific evidence for recommendations in specific utilization conditions.

8. Challenges in mass production often occur, being difficult to consistently producing and distributing biocontrol agents at a large scale, all around the world. Trade, which implies longer period of time and unstable climatic parameters, can affect biocontrol agents availability and quality.

To mitigate all above mentioned risks, it is essential to conduct thorough risk assessments and engage in rigorous research and development, adhere to regulatory guidelines, and implement careful monitoring and management practices. Educating farmers and practitioners about the correct use of biocontrol agents and promoting integrated pest management strategies that combine biological control with other sustainable practices are also key to minimizing risks.

The risk of application of biological control agents is recognized by the main stakeholders and several documents were published

Guidance to the Environmental Safety Evaluation of Microbial Biocontrol Agents, has been published by the Organisation for Economic Co-operation and Development (OECD) Environment Directorate, OECD (2014).

Working Document to the Environmental Safety Evaluationof Microbial Biocontrol Agents has been published by the Organisation for Economic Co-operation and Development (OECD) under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology. (SANCO/12117/2012 –rev. 0)

The EPPO PM 6 Standards on the safe use of biological control provide the NPPOs with guidelines for assessing and reducing the risks associated with various aspects of the introduction and use of biological control agents and, as appropriate, for comparing them with the benefits in terms of efficacy.

https://www.eppo.int/RESOURCES/eppo_standards/pm6_biocontrol

EFSA Plant Health Panel published a statement with Panel observations and recommendations on the process for risk assessment prior to release of BCA to control invasive alien plants (EFSA PLH Panel, 2015).

More information about legal framework for use of biological control could be found in Module 1, subunit 1.1.6. These risks need to be carefully managed to ensure the safety and effectiveness of biocontrol methods.

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According to Hulot & Hiller (2021) the biocontrol can obtain sufficient efficacy levels for a satisfactory level of crop protection. Such levels are met in horticulture, especially under glass in a protected environment, where biocontrol has become a mainstream and popular choice of pest control in Europe. EU research has shown that such efficacy levels could also be reached in orchards and vineyards. The Horizon 2020 project POnTE delivered interesting findings for fighting Xylella fastidiosa ravaging olive trees in Southern Italy with the help of a biocontrol inundation strategy reducing pathogen incidence below 10% (Liccardo et.al, 2020). The FP7 project BCA GRAPE showed the potential effect of particular Ampelomyces fungi strains, where efficacy levels meant a significant reduction of the powdery mildew disease, both in incidence and severity (BCA-grape, 2007). Hulot & Hiller (2021) provides a comprehensive picture to policymakers, stakeholders and the public on the current status of biocontrol in the strategy towards sustainable agriculture. Growing evidence for the efficacy of biocontrol products, in the EU and around the world, resulted both in a higher EU approval rate and an expected market growth for products of around 15% a year over the next five years (Mordor Intelligence, 2021). The biocontrol can be regarded as a key enabler for achieving the objectives of the European Green Deal and the EU Farm to Fork strategy (Hulot & Hiller, 2021).

REFERENCES

Barratt, B. (2011). Assessing safety of biological control introductions. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 6(42).

Barratt, B. I. P., Moran, V. C., Bigler, F., & van Lenteren, J. C. (2018). The status of biological control and recommendations for improving uptake for the future. BioControl, 63(1), 155-167. https://doi.org/10.1007/s10526-017-9831-y

BCA-grape. (2007). New biocontrol agents for powdery mildew on grapevine. Seventh Framework Programme. Retrieved from http://www.bcagrape.eu/UserFiles/File/Conference_proceeding

Brumfield, R. G., & Ogier, J. P. (2000). A review of organic horticulture and agriculture in the US. In Proceedings of the XIVth International Symposium on Horticultural Economics (Acta Horticulturae, No. 536, pp. 21–28). St Peter Port, Guernsey, UK.

Buckwell, A., De Wachter, E., Nadeu, E., & Williams, A. (2020). Crop Protection & the EU Food System. Where are they going? RISE Foundation, Brussels.

Busson, M., Chetty, J., Robin, M., & Aubertot, J. (2019). Biocontrol: Definition. [Online] Dictionnaire d'Agroecologie. Retrieved from https://dicoagroecologie.fr/en/encyclopedia/biocontrol/

COM (2022) 305 final 2022/0196 (COD) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the sustainable use of plant protection products and amending Regulation (EU) 2021/2115.

Cornell University (2010). Integrated pest management CSS 4440/Entom 4440. Lecture Notes, 1.2. A brief history of IPM, Historical Chart. Available at https://courses.cit.cornell.edu/ipm444/lec-notes/extra/ipm-history.html

Copping, G. (1998). The BioPesticide Manual. British Crop Protection Council.

EFSA PLH Panel (EFSA Panel on Plant Health). (2015). Statement on the assessment of the risk posed to plant health in the EU territory by the intentional release of biological control agents of invasive alien plant species. EFSA Journal, 13(6), 4134. doi:10.2903/j.efsa.2015.4134

Ehler, L. E. (1998). Conservation biological control: past, present and future. In P. Barbosa (Ed.), Conservation Biological Control (pp. 1-8). Academic Press.

Eilenberg, J., Enkegaard, A., Vestergaard, S., & Jensen, B. (2000). Biocontrol of pests on plant crops in Denmark: present status and future potential. Biocontrol Science and Technology, 10, 703–716.

Eilenberg, J., Hajek, A., & Lomer, C. (2001). Suggestions for unifying the terminology in biological control. BioControl, 46, 387–400.

European Commission. (2022). Study on the Union's situation and options regarding invertebrate biological control agents for the use in Plant Health and Plant Protection. Publications Office of the European Union. https://data.europa.eu/doi/10.2875/990274

FAO and WHO. (2017). International Code of Conduct on Pesticide Management Guidelines for the registration of microbial, botanical and semiochemical pest control agents for plant protection and public health uses. ISBN 978-92-5-130015-2.

Gerber, E., & Schaffner, U. (2016). Review of invertebrate biological control agents introduced into Europe. CABI Books.

Gurr, G. M., & Wratten, S. D. (1999). 'Integrated biological control': a proposal for enhancing success in biological control. International Journal of Pest Management, 45(2), 81–84.

Hajek, A., & Eilenberg, J. (2018). Natural enemies—an introduction to biological control. Cambridge University Press. https://doi.org/10.1017/CBO9780511811838

Hall, F. R., & Menn, J. J. (Eds.). (1999). Biopesticides, Use and Delivery. Humana Press.

HSE. (2023). Health and Safety Executive. Retrieved from https://www.hse.gov.uk/pesticides/pesticides-registration/active-substances/biopesticides.htm

IBMA. (2018). IBMA International Biocontrol Manufacturers Association white paper: New EU regulatory framework for bioprotection agents. Retrieved from https://www.ibma-global.org/upload/attach-document/ibma-white-paper-web-fnal-a5-spreads.pdf

IBMA. (2020). International Biocontrol Manufacturers Association, Definition – Bioprotection as the global term for all biocontrol technologies [Online]. Available at: https://ibma-global.org/wp-content/uploads/2020/12/ibmadefinitionleafletweb.pdf (Accessed: 2023, August 30).

IBMA (2022). Natural substances as plant protection products: Europe is lagging behind. IBMA natural substances regulatory group. Available athttps://ibma-global.org/wp-content/uploads/2022/06/IBMA-Natural-Substances-Green-Paper-web-single-page.pdf.

IFOAM. (2023). IFOAM Organics Europe's recommendations on the Sustainable Use of Pesticides Regulation (SUR) January 2023. Retrieved from https://www.organicseurope.bio/content/uploads/2023/01/IFOAMEU_Policy_SUR_position-paper_202301.pdf (Accessed: 2023, August 30).

Kenis, M., Hurley, B., Hajek, A., & Cock, M. (2017). Classical biological control of insect pests of trees: facts and figures. Biological Invasions, DOI 10.1007/s10530-017-1414-4.

Khater, H. F. (2012). Ecosmart Biorational Insecticides: Alternative Insect Control Strategies. In F. Perveen (Ed.), Insecticides - Advances in Integrated Pest Management. InTech. doi: 10.5772/2447.

Kogan, M., & Bajwa, W. I. (2001). IPM in the next century: how might things change? Proceedings of Oregon Horticultural Society, 92, 51–70.

Liccardo, A., Fierro, A., Garganese, F., Picciotti, U., & Porcelli, F. (2020). A biological control model to manage the vector and the infection of Xylella fastidiosa on olive trees. PLoS ONE, 15(4), e0232363. https://doi.org/10.1371/journal.pone.0232363.

Loomans, A. J. M., & van Lenteren, J. C. (2005). Tools for environmental risk assessment of invertebrate biological control agents: A full and quick scan method. In Proceedings Second International Symposium on Biological Control of Arthropods, Davos, Switzerland, 12-16 September 2005 (pp. 611-619).

Mordor Intelligence Review. (2021). Biological Control Market, Growth, Trends, Covid-19 impact, and forecasts 2021-2026 [Online]. Available at: https://www.mordorintelligence.com/industry-reports/biological-control-market (Accessed: 2023, August 30).

INilsson, U., Porcel, M., Świergiel, W., & Wivstad, M. (2016). Habitat manipulation – as a pest management tool in vegetable and fruit cropping systems, with the focus on insects and mites. SLU, EPOK – Centre for Organic Food & Farming, Upsala, ISBN 978-91-576-9402-7.
OECD. (2014). OECD Guidance to the Environmental Safety Evaluation of Microbial Biocontrol Agents, Series on Pesticides and Biocides, No. 67. OECD Publishing, Paris. https://doi.org/10.1787/9789264221659-en.
OECD. (2023). Biological Pesticides. Retrieved from https://www.oecd.org/chemicalsafety/pesticides-biocides/biological-pesticides.htm
Prajapati, S., Kumar, N., Kumar, S., Lakharan, L., & Maurya, S. (2020). Biological control, a sustainable approach for plant diseases management: a review. Journal of Pharmacognosy and Phytochemistry, 9(2), 1514-1523.
Prokopy, R. (1994). Integration in orchard pest and habitat management: a review. Agriculture, Ecosystems and Environment, 50, 1–10.
Samada, L. H., & Tambunan, U. S. F. (2020). Biopesticides as Promising Alternatives to Chemical Pesticides: A Review of Their Current and Future Status. OnLine Journal of Biological Sciences, 20(2), 66-76. DOI: 10.3844/ojbsci.2020.66.76
SANCO/12117/2012 – rev. 0) Working Document to the Environmental Safety Evaluation of Microbial Biocontrol Agents.
Sansavini, S. (1997). Integrated fruit production in Europe: research and strategies for a sustainable industry. Scientia Horticulturae, 68, 25–36.
SANTE/12815/2014. Guidance document on semiochemical active substances and plant protection products. European Commission Health & Food Safety Directorate-General.
Senthil-Nathan, S. (2015). A Review of Biopesticides and Their Mode of Action Against Insect Pests. In P. Thangavel & G. Sridevi (Eds.), Environmental Sustainability (pp. 49). Springer India. DOI: 10.1007/978-81-322-2056-5_3

Stenberg, J., Sundh, I., Becher, P., Björkman, C., Dubey, M., Egan, P., ... Vetukuri, R. (2021). When is it biological control? A framework of definitions, mechanisms, and classifications. Journal of Pest Science, 94, 665–676.
Stenberg, J., Becher, P., Jonsson, M., Karlsson, M., Sundh, I., & Viketoft, M. (2023). Political deafness may impede transition to biological control. Trends in Plant Science, 28(5), 498-500. DOI: https://doi.org/10.1016/j.tplants.2023.02.005
van Driesche, R. G., & Bellows, T. R. Jr. (1996). Biological Control. Chapman Hall.
van Lenteren, J. (2012). IOBC Internet Book of Biological Control, version 6.
van Lenteren, J. C. (2000). Success in biological control of arthropods by augmentation of natural enemies. In G. Gurr & S. Wratten (Eds.), Biological Control, Measures of Success (pp. 77–103). Kluwer Academic Publishers.
Watt, I. (2022). Natural substances as plant protection products: Europe is lagging behind, IBMA natural substances regulatory group. The BCPC Congress, 9 November 2022, UK.
IBMA (2022). Natural substances as plant protection products: Europe is lagging behind. IBMA natural substances regulatory group. Available athttps://ibma-global.org/wp-content/uploads/2022/06/IBMA-Natural-Substances-Green-Paper-web-single-page.pdf.

Unit 3.2 Conservation biological control

Rumen Tomov

Modern agricultural ecosystems usually have low biodiversity and are frequently disrupted by farming methods, creating unwelcoming surroundings for numerous natural predators. Biodiversity decline has accelerated in the last century and has taken place at various levels. In agricultural plots, a limited number of crops and varieties are commonly cultivated as monocultures. These fields are often treated with chemical herbicides to manage weeds, resulting in a scarcity of flowering plants that produce nectar and pollen for natural predators. Traditional agricultural practices, such as mechanical soil disturbance through ploughing and harrowing, can interfere with the growth of natural predators within the field. The expansion of larger, more manageable fields has contributed to the disappearance of complex structural elements like herbs, shrubs, trees along field borders etc.

These elements are crucial as sites for hibernation and nesting for many natural enemies and other beneficial organisms that benefit the growing process.

According to Gurr & Wratten (1999) the poor availability of key ecological resources such as nectar, pollen, moderated microclimate, or alternative hosts may constrain the ability of enemies to regulate host populations following their release. A major limiting factor in the life cycle of many natural enemies, particularly parasitoids, is the availability of food for adults. They depend on external food resources for not only sustaining host searching but also for the development of eggs (Vinson, 1998; Wäckers et al., 2008). The availability of these adult food sources may be an important limiting factor on the effectiveness of parasitoids in pest management (Heimpel & Jervis, 2005).

Natural enemies, like many other arthropods, visit flowers for the food resources found in **nectar** and **pollen** (Heimpel & Jervis, 2005). Another important food resource for beneficials is **honeydew**, which may be more widespread in agricultural landscapes and more readily available than nectar (Wäckers et al., 2008). Some natural enemies use green corridors, which connect complex and species-rich habitats such as forests with low diversity arable fields, as highways along which they can move more rapidly into arable fields and colonise crop plants attacked by pests (Nilsson et al., 2016).

NBy securing the presence of beneficial organisms in the fields by providing suitable living conditions, plants are better protected against pests and diseases (IPM Toolbox, 2023).

During last decades, there is a move towards controlling pests through Conservation Biological Control (CBC) (McCravy, 2008).

Conservation biological control (CBC) has been defined as '**modification of the environment or existing practices to protect and enhance specific natural enemies of other organisms to reduce the effect of pests'** (Eilenberg et al., 2001). CBC is a complex strategy that involves a range of ecological and behavioural processes that operate at different spatial and temporal scales and depend on many other factors such as the target pest organism, natural enemy species, and actions taken (Landis et al., 2000; Tscharntke et al., 2016; Wan et al., 2022). In practice, CBC is effected by either (1) reducing the pesticide-induced mortality of natural enemies through better targeting in time and space, reducing rates of application or using compounds with a narrower spectrum efficacy, or (2) by habitat manipulation to improve natural enemy fitness and effectiveness (Gurr et al., 2004).

Many review papers documented the positive effect of CBC measures applied in annual cropping systems. In perennial systems, such as apple orchards, practices focus on providing specific resources for natural enemies such as suitable food (e.g., nectar, pollen, alternative prey), and shelter (e.g., alternative habitat, nest boxes) (Gurr et al., 2017). A global meta-analysis of Judt et al. (2023) summarized the effects of local CBC measures on pest insect abundance, their natural enemies, biological control, and fruit quality in apple orchards.

Several hypotheses try to explain the increased abundance of natural enemies and/or decreased herbivore abundance as a result of CBC measures:

The natural enemy hypothesis

fewer herbivores are available in complex environments because of more diverse and abundant natural enemies (Wan et al., 2014).

The repellent chemicals hypothesis

(i.e., the non-host plants emit odours that repel the herbivore (Uvah & Coaker, 1984).

The resource concentration hypothesis

(i.e., herbivores have more difficulties in finding crop plants in diversified cropping systems compared to monocultures (O'Rourke & Petersen, 2017).

The associational resistance hypothesis

(i.e., the release of “odour masking” substances that make the crop “invisible” to the herbivores (Tahvanainen & Root, 1972).

The “enemies hypothesis”
states that more natural enemies should be found in diverse plantings because of greater availability of alternative food, shelter, and habitat Root (1973).

Effect of vegetation diversity on natural enemies, herbivores and crop damage and production is reviewed by Poveda et al. (2008).

The recent policies like the European Green Deal, have directed their attention towards advocating for greener approaches, including the adoption of conservation biological control (CBC). This approach aims to counterbalance the negative effects of habitat reduction and disruption caused by intensive farming. It does so by introducing diversity to habitats on both local and broader landscape levels or by decreasing the intensity of crop cultivation.

The protection and enhancement of important beneficial organisms, e.g., through adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites is among the tools and techniques to prevent and/or suppress harmful organisms (IPM Toolbox, 2023).

3.2.1 Ways of protecting biological control agents

Agronomic techniques, physical and mechanical methods for crop pests management

Impact of different IPM practices on natural enemies are reviewed by Orr (2009). Possible negative impact or crop rotation, trap cropping, fertilization, tillage, traps and barriers UV blocking films is discussed. When implementing these practices, their impact on natural enemies must be considered.

Biological agent-friendly use of pesticides

Pesticide use has negative direct and indirect effects on populations of beneficial insects. Synthetic pesticides can be deadly to beneficial insects, with direct death being the most common. Predators and parasitoids are more vulnerable to pesticides than plant-feeding insects because plant-feeding insects may have detoxifying systems. Pesticides destroy natural enemies, both those that are resistant at the time of treatment and those that migrate into the sprayed region. There is also the possibility of pesticide build up to fatal levels if the pesticides do not kill the exposed natural enemies immediately after application. If the pesticide kills the host, the parasite larva that dwells within it will not develop (Samanta et al., 2023).

Indirect negative effects depend on concentration, natural enemy species, pesticide exposure time, developmental life stage(s) evaluated, and the influence of residues and repellency (McClanahan, 1967). any indirect effects may inhibit the ability of natural enemies to establish populations; suppress the capacity of natural enemies to utilize prey; impact parasitism (for parasitoids) or consumption (for predators) rates; decrease female reproduction; reduce prey Indirect Effects of Pesticides on Natural Enemies availability; inhibit ability of natural enemies to recognize prey; influence the sex ratio (females: males); and reduce mobility, which could impact prey-finding (Cloyd, 2012). Natural enemies could be indirectly affected by feeding on contaminated honeydew excreted by phloem-feeding insect prey. Certain pesticides may also exhibit repellent activity or alter host plant physiology indirectly affecting the ability of natural enemies to regulate existing arthropod pest populations (Abdel-Raheem, 2022). Abdel-Raheem (2022) summarized the indirect effects of Systemic insecticides, Insect growth regulators, Selective feeding blockers, Microbials, Miticides and Fungicides on natural enemies.

Use of pesticides in Conservation biological control

Some agricultural crops are attacked by multiple species of pest organism, for some of which there are no commercialized biological agents. In some cases the pest infestation level is very high and released biocontrol agents are not able to suppress the pest for short period.

In these cases, chemical pesticides should be applied by producers for successful pest control integrating pesticides with biological control agents. This is often referred to as 'compatibility,' which is the ability to integrate or combine natural enemies with pesticides so as to regulate arthropod pest populations without directly or indirectly affecting the life history parameters or population dynamics of natural enemies (Cloyd, 2005)

Cloyd (2012) demonstrates that compatibility of natural enemies with pesticides depends on a range of factors including class of pesticide applied, natural enemy type (parasitoid or predator), natural enemy species, pesticide formulation, concentration in which natural enemies are exposed to, exposure time, timing of application (spatially and temporally), and developmental life stage (early vs. later instars) exposed to pesticide. In addition, more than one physiological or behavioral parameter (longevity, reproduction, fecundity, and/or searching efficiency) of a given natural enemy may be indirectly affected by pesticides.

Comprehensive review of studies on compatibility of biological control and pesticides is presented by (Banks & Laubmeier, 2023). Abdel-Raheem (2022) has demonstrated the feasibility of combining or integrating natural enemies with certain pesticides including systemic insecticides, insect growth regulators, selective feeding blockers, microbials, miticides, and fungicides.

According to Lacey et al. (1977) There are three primary means by which natural enemies could be integrated with pesticides:

- **pesticide selection**, (sing non-nerve toxin or “selective” pesticides;
- **spatial separation of natural enemies and pesticides**, applying pesticides to localized areas of infestation;
- **temporal discontinuity between natural enemies and pesticides** (applying pesticides when natural enemies are absent or when tolerable life stages are present),

Review of possibility for using selective insecticides in Conservation biological control is presented by Torres & Bueno (2018).

Selectivity

The selectivity is a combination of insecticide toxicity and the probability of contact (Brown, 1989), and thus can vary significantly between natural enemies and the targeted pest. In addition to being species-specific, insecticide selectivity may vary within species (Torres & Bueno, 2018). Bartlett (1964) defined pesticide ‘selectivity’ as the capacity of a pesticide treatment to spare natural enemies while destroying the target pest. ‘Selectivity’ differs from ‘specificity’, which is the capacity of a compound to cause high mortality in a particular species (Fisher et al., 1999).

According to (Torres & Bueno, 2018) CBC using selective insecticides may be achieved by two types of selectivity:
(1) Physiological selectivity (insecticide specificity) and
(2) Ecological selectivity(selective application)

Physiological selectivity (insecticide specificity)

Physiological selectivity results from ‘physiological differences in the susceptibilities of pest and natural enemies to a pesticide’ (Fisher et al., 1999). A ratio of calculated LC50s between pest and natural enemy may show differential susceptibility favoring the natural enemy, as an example of physiological selectivity (Brown, 1989). Based on physiological selectivity and other characteristics, insecticides have been variously tagged as soft, ecofriendly, green, reduced-risk, or IPM friendly. These designations are freely used in the literature, but are of limited value because of their imprecision. (Torres & Bueno, 2018)

Ecological selectivity (selective application)

Ecological selectivity results from ‘differential exposure of pests and natural enemies to a pesticide’ (Fisher et al., 1999). Some nonselective insecticides can be made selective to the target pest through the delivery approach. Such insecticides themselves do not fit the category of soft, ecofriendly, or green insecticides, but can be functionally made to work in this manner. For example, by creating preferential contact with the target pest (systemically inside plants for sucking-sap pests, in lures for fruit flies, spot application for species of limited distribution, etc.). If such application approaches result in low mortality of natural enemy populations and good suppression of the target pest, they may promote ecological selectivity. Therefore, ecological selectivity can be achieved through careful application to differentially access the target pest. (Torres & Bueno, 2018).

Ecological selectivity seeks to reduce contact of a nonselective insecticide with natural enemies by adjusting the way it is delivered in the environment. (Collier et al., 2016) discusses approaches to increase the ecological selectivity of pesticides and pesticide application methods as minimisation of the dose applied, controlled release and dropleg technologies and the impacts of seed treatments on non-target species. Changes in the way pesticides are used offer many options for ecological selectivity. Here are some examples:

a) Selective treatment

Treatment of a portion of a field or tree has been utilized against mobile adult insect pests, which can be pulled and arrested to baited or treated areas using feeding and/or mating attractants. Attraction may be achieved through using semiochemicals such as sex pheromone and plant green volatiles to selectively draw adult pests to the treated area (Gregg et al., 2018). This method has gained popularity as SPLAT, which signifies “specialized pheromone and lure application technology”. It has been used with Mediterranean fruit fly pheromone and various insecticides, especially with spinosad (Vargas et al., 2008). An attractive bouquet of green volatiles is now available in a commercial product for adult Helicoverpa spp., which are attracted to treated areas (Gregg et al., 2016). This shows the potential of using spot application with a nonselective insecticide (Torres & Bueno, 2018).

Controlled-release technology

pesticides are chemically contained within a polymer or some other carrier they should become less toxic, since all the active ingredient will be released gradually over time. (Collier et al., 2016). Placing insecticides on limited areas also reduces the risk of contact with immature natural enemies and those with limited dispersal ability (e.g., predatory spiders and mites) (Torres & Bueno, 2018).

Dropleg technology

technology for spraying the lower surfaces of foliage of vegetable and field crops.The application of pesticides to the lower surfaces of foliage has several advantages, such as reduced spray drift, as well as increased efficacy of nonsystemic pesticides, especially against plant pests such as aphids or cabbage whitefly larvae which are 'hidden' amongst the foliage (Rueegg et al., 2006).

Spatiotemporally selective application

has been adopted in orchards. Adult stages of the major groups of fruit pests do not damage fruit (e.g. fruit flies and moths), but the adults are the major target for control due to their endophytic larval stages. Further, the critical pest management window is typically concentrated into the window of fruiting phenology. Therefore, application on alternate rows/plants or with spot treatments including feeding attractants occur only during the period of fruit susceptibility. This significantly reduces insecticide delivered into the environment, and helps preserve natural enemies to suppress less-mobile pests such as scales, mealybugs, and aphids (Torres & Bueno, 2018).

Combined physiological and ecological selectivity

of the protection gained by immature endoparasitoids within their hosts. Reduced mortality results from reduced exposure to a diminished rate of toxic compound conveyed through the host (Torres & Bueno, 2018).

b) Pesticide application in context of European Green Deel

The Regulation (EC) 1107/2009) introduced the concept of low-risk plant protection products (PPPs.) To be authorised as low-risk, a PPP can only contain active substances approved as low-risk and may not contain any 'substances of concern'. In order to help farmers access low-risk PPPs and to promote IPM, the Council in 2016 endorsed an "Implementation Plan on increasing low-risk plant protection product availability and accelerating integrated pest management implementation in Member States. (Special Report 05/2020)

An active substance can be approved as a low-risk substance if it meets the regular approval criteria and in addition meets the low-risk criteria as specified in Annex II, point 5 of Regulation (EC) 1107/2009. There are specific criteria for chemical substances and for micro-organisms. Products that contain only low-risk substances can then be authorised as a low-risk plant protection product. Because of their favourable properties low-risk products should be preferred by farmers and other users in their approach to manage pests.

The EU Pesticides Database contains information on active substances (including those that are low-risk or candidates for substitution) and basic substances, either approved or non-approved in the EU. Some safeners and synergists are also listed but these have not yet been assessed at EU level.

https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en

Geiger et al. (2010) concluded that despite decades of European policy to ban harmful pesticides, the negative effects of pesticides on wild plant and animal species persist, at the same time reducing the opportunities for biological pest control. If biodiversity is to be restored in Europe and opportunities are to be created for crop production utilizing biodiversitybased ecosystem services such as biological pest control, there must be a Europe-wide shift towards farming with minimal use of pesticides over large areas.

Several Pesticide Side Effect Database are available and should be referred before planning of pesticide application and integrating pesticides with biological control agents.

A database **(SELCTV)** of the literature on pesticide side-effects on arthropod natural enemies has been developed for characterization, analysis and use in decision-making for pest control and environmental impact assessment (Theiling & Croft, 1988).

Some biocontrol agent manufacturers recommend usage of pesticides named ‘correctives’ to increase the effect of released natural enemies.

Useful tips for protection of biological control agent

Protecting natural enemies from pesticides is essential for maintaining a balanced and healthy ecosystem. Here are some strategies to achieve this:

Selective Pesticide Use

- Apply pesticides after exerting all other control tactics before the pest-species reaches densities or causes damage equivalent to the economic threshold as the last option
- Choose low risk pesticides that have minimal impact on non-target organisms, such as narrow-spectrum (are more specific in the types of invertebrates they kill). These products target specific pests while sparing beneficial insects and natural enemies.
- Whenever possible, priority should be given to bio-pesticides

Localized Application

- Apply psicides in a selective manner. Treat only heavily infested areas with “spot” applications instead of entire plants.
- Use precision application methods to target pesticides only to areas with pest infestations rather than blanket spraying. This minimizes the exposure of natural enemies to pesticides.
- In case where fostering of biocontrol is needed recommended by bioagent producers pesticides as correctives.

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Timing

Apply pesticides during periods when natural enemies are less active, such as early morning or late evening. This can reduce the direct exposure of these beneficial organisms.

3.2.2 Ways of enhancing the biological control agents

> Conservation biological control approaches/practices have gained popularity in pest control due to their ability to fulfil essential criteria like efficacy, predictability and cost (Heinz et al., 2004; Gurr et al., 2017; Hatt et al. 2018). Several approaches for enhancing the biological control agents have been studied during last decades. Different tools for habitat manipulation have been developed. In addition, concepts such as farmscaping and permaculture have attempted to integrate analogous concepts with the aim of boosting ecological benefits, like implementing natural regulatory mechanisms, within agricultural or residential environments.

CONCEPTS FOR ENHANCING THE BIOLOGICAL CONTROL AGENTS

Habitat manipulation

Habitat manipulation is a sub-discipline within conservation biological control that aims to actively improve habitats for natural enemies in order to establish them in sufficient numbers to suppress crop pests below the economic threshold (Nilsson et al., 2016).

Thus habitat manipulation, though it makes a major contribution to CBC, includes a wider series of approaches that may operate independently of natural enemies and,

Hort4EUGreen

constitute a form of ecological engineering. Ecological engineering is a human activity that modifies the environment according to ecological principles. Accordingly, it is a useful conceptual framework for considering the practice of habitat manipulation for arthropod pest management. This form of ecological engineering presents an attractive option for the design of sustainable agroecosystems.

The habitat manipulation often involves increasing the species diversity and structural complexity of agroecosystems (Gurr et al., 2004).

Key elements of habitat manipulation based on vegetative diversity are:
Floral supplement – provide natural enemies with nectar or pollen as additional food for parasitoids and predators
Shelter habitats - provide natural enemies with a safe haven from man-made disturbances such as ploughing and harvesting. Space for breeding and rest during hot days. overwintering sites
Alternative prey and host - key resource to maintain natural enemies within a production area at times when pest populations are low in the field.

The wide array of habitat manipulations currently includes **agroforestry, biological control, crop rotations, crop diversity, flower strips, natural enemy refuges, trap crops and other technologies**.

Each of these technologies, and combinations of these pest suppression technologies, offers opportunities to reduce crop losses to pests while at the same time reducing the use of pesticides (Gurr et al., 2004)

A comprehensive analysis of the habitat manipulation literature is presented by Landis et al. (2000), Gurr et al. (2004), Griffiths et al. (2008), Hopwood (2008), Gurr et al. (2017).

Farmscaping

The Farmscaping is a holistic (whole-farm) ecological approach to pest management—particularly for insects. An entomologist, Dr. Robert Bugg coined the term „**farmscaping**„ - defining it as the "deliberate use of specific plants and landscaping techniques to attract and conserve 'beneficials'." It refers to the arrangement of plants used for economic purposes (cash crops) and insectary plants used for food and habitat for beneficial insects (Dufour, 2023).

The term farmscaping is more commonly referred to as "conservation biological control or ecological engineering" and has been broadened to incorporate other types of companion plantings such as:

1) living mulches or trap crops;

2) fence rows or borders;

3) island patches within rows or occupying entire rows spaced at regular intervals within the field; or
4) herb or flower cash crops intercropped with vegetable or fruit crops (Gurr et al. 2004; Sitaramaiah et al. 2005).

In the practice of farmscaping, the use of water reservoirs and other strategies to attract and support beneficial organisms such as bats and predatory birds is included. Farmscaping involves different elements (table 2) the use of insectary plants, hedgerows, cover crops, and water reservoirs to create a habitat that supports beneficial species, that, in turn, help control pest populations in a natural way. Farmscaping emphasizes the importance of selecting appropriate strategies and plants for effective biological control (Zehnder, 2009).

Table 2. The elements of farmscaping according to different sources

Philips et al., 2014	Gurr et al., 2004	Meena et al., 2017	eOrganic.org
intercropping, trap crops, companion plantings, living mulches. insectary plantings, beetle banks, hedgerows.	herb or flower cash crops intercropped with vegetable or fruit crops living mulches or trap crops fence rows or borders island patches within rows or occupying entire rows spaced at regular intervals within the field.	intercropping trap crops companion planting mixed cropping - Push Pull System cover crops banker plants tailored flower strips	hedgerows, insectary plants, cover crops water reservoirs

According to Philips et al. (2014) there are **two basic approaches** to farmscaping in relation to pest management: those that work from the bottom up and those that work from the top down.

Bottom – up approaches include intercropping, trap crops, companion plantings, and living mulches. These techniques are designed to "mask" or "disguise" the cash crop, or repel pest insects, thereby protecting the crop. These practices may also provide additional ecosystem services by fixing nitrogen, preventing erosion, suppressing weeds, or providing nectar or pollen to beneficial arthropods.

Top – down approaches are designed to enhance populations of natural enemies that, in turn, should provide improved pest suppression. Techniques commonly used to enhance natural enemy populations include insectary plantings, beetle banks, and hedgerows.

Farmscaping is a potential approach to enhance on-farm biodiversity that will result in long lasting stability of agroecosystem (Meena et al., 2017).

Permaculture

With regard to the conservation of biodiversity in productive landscapes, Fischer et al. (2006) proposed pattern- and process-oriented strategies for the design and management of agricultural landscapes. The concept of permaculture arose from the combination of the words “permanent” and “agriculture”, and describes a design system as well as a best practices framework for the creation and management of sustainable and resilient agroecosystems. The co-founder, David Holmgren, defines permaculture as ‘consciously designed landscapes, which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre, and energy for provision of local needs’ (Holmgren, 2002). The concept of permaculture and the main principles are presented by Krebs & Bach (2018).

Plant-based pest control strategies

The following Plant-based pest control strategies are defined by different authors:

Banker plant systems (Huang et al.,2011)

Trap crops (Shelton & Badenes-Perez, 2006)

Push-Pull – Behavioral manipulation of pests by making crop-plants unattractive/unsuitable (push) combined with luring pests towards attractive non-crop sources (pull) where they are subsecquently removed (sometimes through biological control) (Cook et al. 2007)

Vegetation management – restoration of natural control in agroecosystemn by designing and constructing vegetational architectures, e.g. flower strips (Altieri & Letourneau, 1982)

Habitat management – A subset of conservation biological control methods, alternation of habitats to improve performance/survival of natural enemies (Landis et al. 2000)

Hopwood et al. (2016) suggest 4 steps for implementing conservation biological control:
(1) Recognize existing beneficial insects and their habitat,
(2) Conserve existing beneficial insect habitat,
(3) Provide new beneficial insect habitat,
(4) Manage habitat and cropland to minimize harm to beneficial insects.

Management practices for enhancing the biological control agents

Numerous management practices have been used to conserve natural enemies and promote their activity in horticultural crops.
Hopwood et al. (2016) have described the following CBC practices:
(1) Native plant field borders,
(2) Temporary insectary strips,
(3) Hedgerows and windbreaks,
(4) Cover crops,
(5) Conservation cover,
(6) Herbaceous buffer practices,
(7) Tunnel nests, beetle banks, Brush piles.

Acording to Judt et al. (2023) options for plant diversification strategies are numerous and comprise flowering strips, beetle banks, intercropping with annual or perennial crops, trap crops, push-pull system, ground covers, agroforestry, hedgerows, and many more.

There are two general plant-based approaches for enhancement of natural enemies:

- **Use of wild flora;**
- **Use of secondary plants**

According to Parolin et al. (2012) plants that are added to a crop system with the aim of increasing the efficiency of biological control systems are called **secondary plants**. They are a basic component which influences the interactions between crops, pests and natural enemies. The secondary plants fall into several categories: companion, repellent, barrier, indicator, trap, insectary, and banker. The biggest constraint upon progress of using these plants, has been confusion over definitions and terminology. Parolin et al. (2012) review the knowledge of the currently employed plant categories (direct and/or indirect effects on crop plants and pest regulating functions) and provide clear definitions.

Plant-based agronomic techniques as **Crop rotation, Mixed cropping (Intercropping, Companion cropping, Trap cropping, Barrier plants) and Cover crops** contribute to vegetation diversification. They have different importance for the Conservation biological control despite the fact that their primary role is pest suppression. Additional information for these techniques could be found in Module 2

Some examples of management practices that could be used to enhance natural enemies and promote their activity in horticultural crops are presented here:

Trap crops

Trap cropping is a means of promising conservation biological control that involves growing another non-crop species in a selected area to attract pests from target crop, preventing pests from reaching the crop and finally to control that pest in order to reduce damage to the main crop (Hokkanen, 1991; Shelton & Badenes-Perez, 2006).

Biological control is one especially promising way to increase pest mortality on the trap crop, without having to spray the trap crop with pesticides. Fortunately, trap crops can potentially attract natural enemies of insect pests (Parolin, et al. 2012; Parker et al. 2013; Naranjo et al. 2015), and through predation and parasitism, these natural enemies reduce the ability of trap crops to act as pest breeding grounds to disperse back into the main crop Sarkar et al. (2018)

Trap cropping system in respect of Natural Enemy Attraction is described by Sarkar et al. (2018). An advantage of trap cropping over an artificially released natural enemy-based biological control could be an attractive remedy for natural enemies in cropping systems. Besides, many trap crop species can conserve natural enemies. Sarkar et al. (2018) have provided information based on different trap crops as companion plant, their functions and an updated list of trap cropping applications to attract insect pests and natural enemies that should be proven as helpful in future trap cropping endeavors. According to Parolin et al. (2012) the role of trap plants in respect to natural enemies is feeding, and those of companion plants is attracting.

Cover crops/Ground covers

An orchard ground cover, if properly maintained, promotes the build-up of natural enemies of certain pests Bajwa & Kogan 2004. Cover crops affect the ecology of orchards and vineyards by improving soil biology and fertility and by increasing biological control of insect pests by harbouring predators and parasitoids (Altieri and Nicholls, 2000). Cover crops attract and provide a nectar source for beneficial insects, spiders and mites. A global meta-analysis of Judt et al. (2023) showed that local CBC measures significantly increased the abundance of natural enemies in apple orchards but did not increase pest insects or decrease apple fruit quality. Flowers and ground cover, in particular, had favourable effects on beneficial organisms. Ground covers also have the potential to reduce herbivore numbers directly or indirectly, for example, by emitting volatile compounds

(Dicke, 2015; Turlings et al., 1990). Aromatic plants can exert a chemical repellent effect on pest insects (Song and Han, 2020; Zhang et al., 2017) or attract natural enemies, thereby reducing the number of herbivores (Song et al., 2017)

Native plant field borders/Wildflower Interventions

Impacts of Wildflower Interventions on Beneficial Insects in Fruit Crops are review by Fountain (2022). This review focuses on the benefits that additional floral resources, in the vicinity of fruit crops, provide to pest regulation and pollination services through the provision of natural enemies (predators and parasitoids) and pollinating insects. More recently, fruit growers have begun to sow areas of wildflowers, which reportedly offer environmental and ecosystem service (goods and services that humans gain from the natural world) benefits (Losey &Vaughan, 2006; Lautenbach et al., 2011). Mateos-Fierro et al. (2021) found twice the abundance of natural enemies in wildflower strips in cherry orchards, 15 % more natural antagonists in the cherry trees and a 25 % increase in aphid predation. Alvarez ´ et al. (2021) found higher egg predation of olive moth (Prays oleae) by natural antagonists in olive orchards with ground covers.

Insectary plants

The insectary plant is a flowering plant which attracts and possibly maintains, with its nectar and pollen resources, a population of natural enemies which contribute to biological pest management on crops. Parolin et al. (2012). Insectary plants are introduced into agricultural or horticultural systems to increase the amounts of nectar and pollen resources required by some natural enemies of pests (Bugg 1990, 1994; Colley & Luna 2000). They attract beneficial insects, such as parasitoid wasps and predatory flies, with extrafloral nectaries or flowers with readily accessible pollen and nectar which are not otherwise available in a monoculture (Landis et al. 2000; Vattala et al. 2006; Nafziger & Fadamiro 2011). Insectary planting can be individual clump or container plantings, perennial hedgerows, and/or annual strips in the field. (Temporary insectary strips)

In cherry orchards in Italy, planting of flowering strips increased the abundance and diversity of natural enemies, and reduced the need for insecticides (Polidori et al., 2017). Hedgerows planted with a diverse mix of flowering plants increased the abundance and diversity of natural enemies such as predatory insects, which in turn reduced pest populations in nearby crops. Marshall & Moonen, (2002).

Banker plants

A banker plant is the plant component of the “banker plant” system, which, together with alternative food and beneficial organisms, is “a rearing and release system purposefully added to or established in a crop for control of pests in greenhouse or open field” (Huang et al. 2011). Parolin et al. (2012).The authors present different definitions as well. The goal of banker plant systems is to sustain a reproducing population of natural enemies within a crop that will provide long-term pest suppression (Frank, 2010). Biological control agents are released onto the banker plants and as they reproduce and increase in numbers, they spread out into the rest of the greenhouse. This represents a mini-rearing system for the natural enemies. Continuous release of parasitoid adults has a stabilizing effect on population fluctuations in the glasshouse aphid–predator system (Yano, 2006). This way, banker plants retain a specific natural enemy or potentially the “right diversity” of predators and parasitoids with precise alternative resources (Frank, 2010). Two extensive reviews of the banker plant method have recently been published, giving all details and definitions of the components of a banker plant system, with long lists of examples for different pest categories (Frank, 2010; Huang et al. 2011).

An advantage of the banker plant system over augmentative biological control is preventive control without repeated releases of natural enemies (Frank, 2010). This has a clear advantage over the handrelease method (Pickett et al., 2004). Osborne et al. (2005) describe the difference between two types of banker plant systems. One uses the same pest species or crop pest as the one that is to be managed, but this entails a significant risk. The second uses a factitious/surrogate, or natural alternative host or prey. This host is reared on plants which have not been grown as a crop in the greenhouse where they will be used (Parolin et al., 2012).

Miller & Rebek (2018) made review of the history of biological control in enclosed environments, pesticides compatible with natural enemies, the use of various species of banker plants, and specifically the *Aphidius colemani* (Viereck) (Hymenoptera: Braconidae)–*Rhopalosiphum padi* (L.) (Hemiptera: Aphididae) system to manage aphid pests. The banker plan herbivore interacts indirectly with target pest via a shared natural enemy. Such indirect prey interactions have been referred to as "apparent competition" (Holt, 1997)

Banker plant systems containing the following beneficial species – *Aphidius ervi, Aphidius colemani, Aphidius matricariae, Aphidius gifuensis, Aphelinus abdominalis, Praon volucre, Aphidoletes aphidimyza, Lysiphlebus testaceipes, Ephedrus cerasicola, Dieretiella rapae, Chrysopa carnea* and *Episyrphus* sp. against aphids are presented by Huang et al. (2011)

The commercial systems are primary banker plants aimed at supporting the action of aphid parasitoids *Aphidius ervi*, *Aphidius colemani*, *Aphelinus abdominalis*.

Field margins

The field margin is the whole of the crop edge, any margin strip present and the semi-natural habitat associated with the boundary (Marshall & Moonen, 2002). Field margins are a key feature of agricultural landscapes, present in some form at the edges of all agricultural fields (Marshall, 1988). Complex interactions between cropped and non-crop areas are important for many taxa. Clear understanding of these interactions may allow the design of field and margin arrangements that utilize biodiversity within the crop and conserve farmland wildlife at the landscape scale.

The role of field margins and their interactions with adjacent agriculture are reviewed with the objective of assessing their relative benefits for agriculture and the environment by Marshall & Moonen (2002). Hegarty & Cooper (1994) showed in Ireland that hedges with a boundary strip or uncultivated and unsprayed headland often have higher species richness than other hedges.

Under arable farming, when soils are regularly cultivated, the field margin may be regarded as an ecotone. The ecotone is a region of marked ecological change, often between different environments, reflecting a transition zone between two different habitats and disjunct species distributions (Forman, 1995)

Hedgerows and windbreaks

Hedgerows are common linear semi-natural features in lowland agricultural landscapes across the world (Hannon & Sisk, 2009; Morandin & Kremen, 2013; Dainese et al., 2016; Dondina et al., 2016; Lacoeuilhe et al., 2016; Ponisio et al., 2016). Comprehensive review of hedgerows related studies is presented by (Garratt et al. 2017).

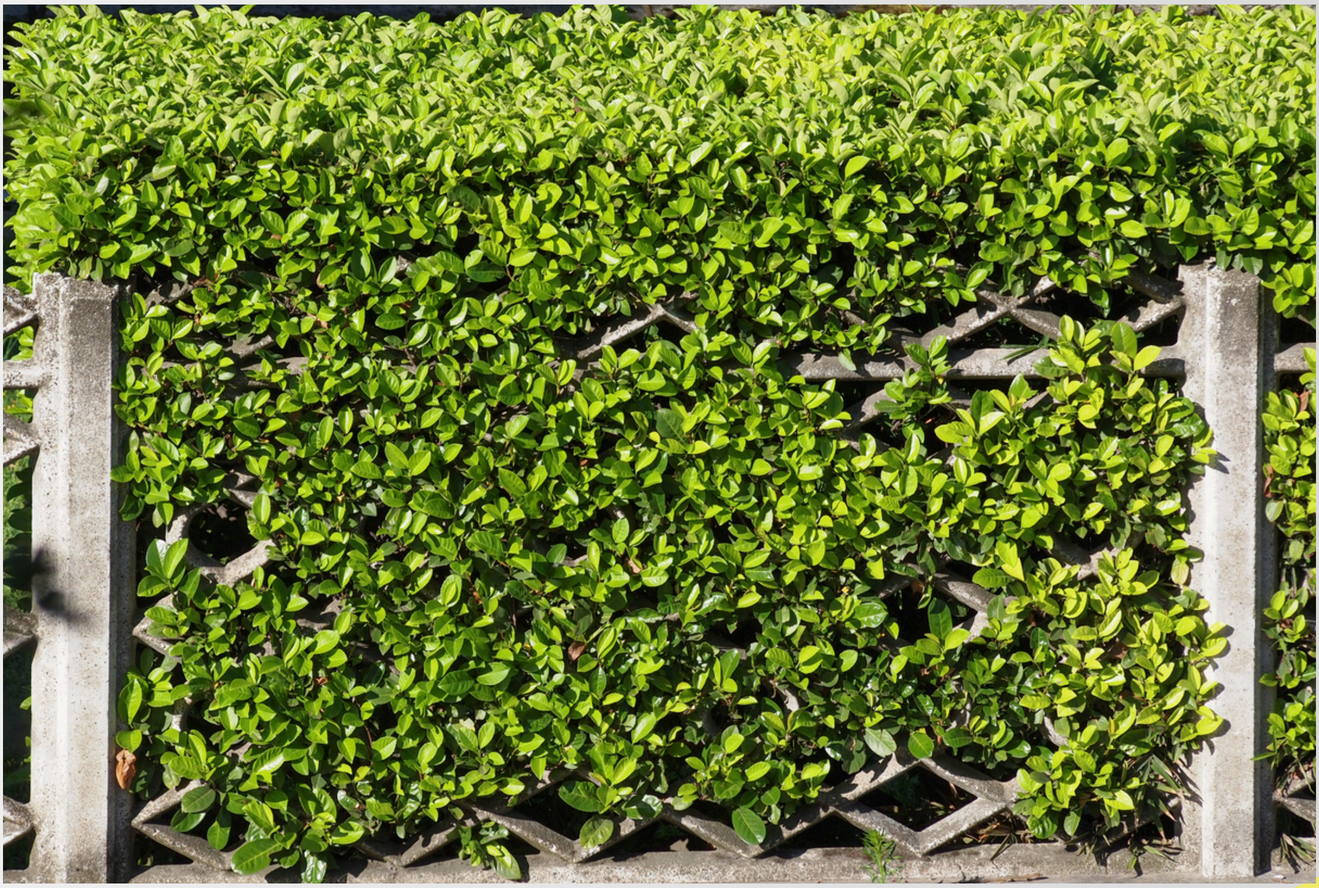
Hedgerows play a significant role in the scenery of various agricultural systems globally. The way these hedgerows are cared for can offer a means to improve ecological enhancement. The advantages derived from hedgerows depend on their quality, and undisturbed, diverse hedgerows containing a variety of tree and shrub species are particularly beneficial for promoting the presence of bumblebees and spiders. In addition to the actual hedgerow plants, the availability of floral resources is crucial for hoverflies' sustenance.

Garratt et al. (2017) show the potential benefits of hedgerows for pollinators and natural enemies in agricultural landscapes. They demonstrate that continuous, unbroken hedgerows with diverse woody species and a florally rich understorey within a landscape containing a high proportion of local semi-natural habitat could maximise the provision of ecosystem services provided by pollinators and natural enemies.

Letourneau et al. (2011) have shown that hedgerows can reduce pest infestations in nearby crops by providing habitat and food resources for natural enemies, which can help control pest populations.

Westphal et al. (2003) hedgerows can increase biodiversity by providing habitat for a variety of beneficial insects, birds, and mammals, which can help to balance ecosystems and reduce reliance on pesticides.

Hedgerows are a priority habitat across Europe and support for their management is provided to land managers through agri-environment schemes (Natural England, 2013).



Beetle banks

Beetle banks are simply grassy ridges in the center of the field that provide proximal overwintering habitat and more rapid colonization by predators (Collins et al. 2002, MacLeod et al. 2004; Gurr et al. 2004). Beetle banks are designed to provide shelter and habitat, but also to "mask" the presence of the host crop (Philips et al., 2014).

Additional information about the beetle banks could be found at:
https://agricology.co.uk/resource/beetle-banks/
https://www.rspb.org.uk/our-work/conservation/conservation-and-sustainability/farming/advice/managing-habitats/beetle-banks/
https://xerces.org/sites/default/files/publications/20-040.pdf

Enhancement of birds and bats

More than 50% of bird species are predominantly insectivorous, with nearly 75% of bird species occasionally consuming invertebrates (Wenny et al., 2011). A recent study by Nyffeler et al. (2018) estimated that insectivorous birds consume 400–500 million tons of arthropod prey globally per year, with approximately 28 million tons (~7%) coming from agricultural areas. Insectivorous birds have been shown to be important pest predators and reduce pest abundance and fruit damage (Garcia et al., 2021; Martinez-Sastre et al., 2020.

Additionally, predatory birds such as falcons and owls have been shown to provide critical vertebrate pest suppression services, significantly reducing the abundance or activity of pest birds (Shave et al., 2018) and rodents (Whelan et al. 2015) in agroecosystems. The presence of wild birds in agroecosystems is often perceived as an economically important threat to crops, often disproportionate to the levels of damage actually incurred (Dolbeer et al., 1994; Groepper et al., 2013).

Garcia et al. (2020) reviewed the literature on birds in agricultural systems, discuss examples of how birds can provide services and disservices to crops, examine factors that influence the net effects of birds, and discuss emerging tools that will help fill key knowledge gaps surrounding the complex roles of birds in agricultural systems

Some farm management strategies that have garnered attention include the construction of nest boxes and perches for insectivorous and predatory birds as well as managing seminatural habitat within farms, and in landscapes surrounding farms (Lindell et al., 2018). Additionally, constructing nest boxes for the predatory bird species in sweet cherry orchards resulted in a significantly lower abundances of fruit-eating birds (Shave et al., 2018).

García et al. (2021) demonstrated the usefulness of nest boxes for insectivorous birds in enhancing biological control of apple pests at a regional scale, identifying tit species as complementary predators of apple pests and herbivores.

Tuneu-Corral et al. (2023) have assessed the state of knowledge of the ecosystem services provided by bats as pest consumers at a global level and provides recommendations that may favor the efficiency of pest predation by bats. The literature analysis showed that well-managed artificial water sources in agricultural areas contributed to the availability of insect prey, attracting bats and consequently favoring the ecosystem services provided by them.

Additional information about ways of enhancing the biological control agents could be found at:
https://projects.au.dk/coreorganicplus/research-projects/ecoorchard/
http://lodz.pzd.pl/ekologiczne-sposoby-na-szkodniki-uprawa-wspolrzedna
https://www.protect-garden.pl/otocz-sie-zywoplotem

REFERENCES

Abdel-Raheem, M. (2022). Effect of Insecticides on Natural-Enemies. In: Ramón Eduardo Rebolledo Ranz, Insecticides - Impact and Benefits of Its Use for Humanity, IntechOpen. doi: 10.5772/intechopen.100616 https://www.intechopen.com/chapters/79719

Altieri, M. A. and Letourneau, D. K. 1982. Vegetation management and biological control in agroecosystems.. Crop Protection, 1: 405–430.

Alvarez, ´ H.A., Jim´enez-Munoz, ˜ R., Morente, M., Campos, M., Ruano, F., 2021. Ground cover presence in organic olive orchards affects the interaction of natural enemies against prays oleae, promoting an effective egg predation. Agric. Ecosyst. Environ. 315, 107441 https://doi.org/10.1016/j.agee.2021.107441

Bajwa and Kogan 2004 Cultural Practices: Springboard to IPM., In: Integrated Pest Management: Potential, Constraints and Challenges (eds O. Koul, G.S. Dhaliwal and G.W. Cuperus), 21-38. CAB International 2004.

Banks J. & Laubmeier A. (2023). Compatibility of biological control and pesticides mediated by arthropod movement behavior and field spatial scale. Biological Control 177, 105125

Bartlett, B. R. 1964: Integration of chemical and biological control. In: Biological Control of insect pests and weeds (ed. De Bach, P.): 489-511. Chapman & Hall, London.

Brown, R.A., 1989. Pesticides and non-target terrestrial invertebrates: an industrial approach. In: Jepson, P.E. (Ed.), Pesticides and Non-target Terrestrial Invertebrates. Wimborne, Intercept, pp. 19–42.

Bugg RL. 1990. Farmscaping with insectary plants. Permaculture Activist. Summer. p. 1, 6–9.

Bugg RL. 1994. Using cover crops to manage arthropods of orchards: A review. Agric Ecosyst Environ. 50 (1): 11–28.

Cloyd R. (2005). Compatibility conflict: is the use of biological control agents with pesticides a viable management strategy? In: second international symposium on biological control of arthropods; Davos, Switzerland, 12-16 September 2005. USDA Forest Service Publication FHTET-2005-08 Vol. II; 2005

Cloyd, R. (2012). Indirect Effects of Pesticides on Natural Enemies. InTech. doi: 10.5772/48649

Colley MR, Luna JM. 2000. Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera: Syrphidae). Environ Entomol. 29(5):1054–1059.

Collier R., Jukes A., Daniel C. , Hommes M. (2016) Ecological selectivity of pesticides and pesticide application methods. Integrated Protection in Field Vegetables IOBC-WPRS Bulletin Vol. 118, 2016 pp. 94-98.

Collins, K. L., N. D. Boatman, A. Wilcox, J. M. Holland, and K. Chaney. 2002. Influence of beetle banks on cereal aphid predation in winter wheat. Agric., Ecosyst. Environ. 93: 337–350

Cook, S. M., Khan, Z. R. and Pickett, J. A. 2007. The use of push-pull strategies in integrated pest management.. Ann. Rev. Entomol, 52: 375–400.
Dainese, M., Montecchiari, S., Sitzia, T., Sigura, M., Marini, L., 2016. High cover of hedgerows in the landscape supports multiple ecosystem services in Mediterranean cereal fields. J. Appl. Ecol n/a–n/a. Defra, 2007. Hedgerow Survey Handbook A Standard Procedure for Local Surveys in the UK. Defra,
Dicke, M., 2015. Herbivore-induced plant volatiles as a rich source of information for arthropod predators: fundamental and applied aspects. Journal of the Indian Institute of Science 95, 35–42.
Dolbeer, R. A., N. R. Holler, and D. W. Hawthorne. 1994. Identification and assessment of wildlife damage: an overview, p. 2. In S. E. Hyngstrom, G. E. Larson, and R. M. Timm (eds.), The Handbook: Prevention and Control of Wildlife Damage. Vol 2. University of Nebraska-Lincoln.
Dondina, O., Kataoka, L., Orioli, V., Bani, L., 2016. How to manage hedgerows as effective ecological corridors for mammals: a two-species approach. Agric. Ecosyst. Environ. 231, 283–290.
Dufour, R. Farmscaping to enhance biological control: Pest management systems guide [Online]. NCAT. ATTRA-National Sustainable Agriculture Information Service. Available at: https://attra.ncat.org/product/farmscaping-to-enhance-biological-control/ (verified April 2023).
Fischer, J., Lindenmayer, D. B., & Manning, A. D. (2006). Biodiversity, ecosystem function, and resilience: Ten guiding principles for commodity production landscapes. Frontiers in Ecology and the Environment, 4, 80–86. [CrossRef]
Fisher, T. W., Bellows, T. S., Caltagirone, L. E., Dahlsten, D. L., Huffaker, C. B., & Gordh, G. (1999). Handbook of Biological Control: Principles and Applications of Biological Control. Academic Press.
Forman, R. T. (1995). Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press.
Fountain, M. T. (2022). Impacts of Wildflower Interventions on Beneficial Insects in Fruit Crops: A Review. Insects, 13, 304. https://doi.org/10.3390/insects13030304
Frank, S. D. (2010). Biological control of arthropod pests using banker plant systems: Past progress and future directions. Biological Control, 52, 8–16.
García, D., Miñarro, M., & Martínez-Sastre, R. (2021). Enhancing ecosystem services in apple orchards: Nest boxes increase pest control by insectivorous birds. Journal of Applied Ecology, 58, 465–475. https://doi.org/10.1111/1365-2664.13823.
Garcia, K., Olimpi, E., Karp, D., & Gonthier, D. (2020). The Good, the Bad, and the Risky: Can Birds Be Incorporated as Biological Control Agents into Integrated Pest Management Programs? Journal of Integrated Pest Management, 11(1), 1–11. doi: 10.1093/jipm/pmaa009

Garratt, M., Senapathi, D., Coston, D., Mortimer, S., & Potts, S. (2017). The benefits of hedgerows for pollinators and natural enemies depend on hedge quality and landscape context. Agriculture, Ecosystems and Environment, 247, 363–370.
Geiger, F., Bengtsson, J., Berendse, F., Weisser, W., Emmerson, M., Morales, M., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R. , Part, T., Bretagnolle, V., Plantegenest, M. , Clement, L., Dennis, C., Palmer, C., Onate, J., Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hanke, S., Fischer, C. , Goedhart, P., Inchausti, P. (2010). Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic and Applied Ecology, 11(2), 97–105.
Gregg, P. C., Del Socorro, A. P., & Hawes, A. J. (2016). Developing bisexual attract-and-kill for polyphagous insects: ecological rationale versus pragmatics. Journal of Chemical Ecology, 42, 666–675.
Gregg, P. C., Del Socorro, A. P., & Landolt, P. J. (2018). Advances in attract-and-kill for agricultural pests: beyond pheromones. Annual Review of Entomology, 63, 453–470.
Griffiths, G. J. K., Holland, J. M., Bailey, A., & Thomas, M. B. (2008). Efficacy and economics of shelter habitats for conservation biological control. Biological Control, 45, 200–209.
Groepper, S. R., Hygnstrom, S. E., Houck, B., & Vantassel, S. M. (2013). Real and perceived damage by wild turkeys: a literature review. Journal of Integrated Pest Management, 4, A1–A5.
Gurr, G. M., Scarratt, S. L., Wratten, S. D., & Berndt, L. (2004). Ecological engineering, habitat manipulation, and pest management. In G. M. Gurr, S. D. Wratten, & M. A. Altieri (Eds.), Ecological engineering for pest management: Advances in Habitat Manipulation for Arthropods (pp. 1–12). CABI Publishing.
Gurr, G. M., & Wratten, S. D. (1999). 'Integrated biological control': a proposal for enhancing success in biological control. International Journal of Pest Management, 45, 81–84.
Gurr, G. M., Wratten, S. D., Landis, D. A., & You, M. (2017). Habitat management to suppress pest populations: Progress and prospects. Annual Review of Entomology, 62, 91–109.
Hannon, L. E., & Sisk, T. D. (2009). Hedgerows in an agri-natural landscape: potential habitat value for native bees. Biological Conservation, 142, 2140–2154.
Hatt, S., Boeraeve, F., Artru, S., Dufrêne, M., & Francis, F. (2018). Spatial diversification of agroecosystems to enhance biological control and other regulating services: An agroecological perspective. Science of The Total Environment, 621, 600–611.
Hegarty, C. A., & Cooper, A. (1994). Regional variation of hedge structure and composition in northern Ireland in relation to management and land-use. Biological and Environmental Proceedings of the Royal Irish Academy. B, 94, 223–236.
Heimpel, G. E., & Jervis, M. A. (2005). Does floral nectar improve biological control by parasitoids? In F. Wäckers, P. van Rijn, & J. Bruin (Eds.), Plant-provided Food and Plant–Carnivore Mutualism (pp. 267–304). Cambridge University Press.

Heinz, K. M., Van Driesche, R. G., & Parella, M. P. (2004). Biocontrol in Protected Culture. Ball Publishing.
Hokkanen, H. M. (1991). Trap cropping in pest management. Annual Review of Entomology, 36, 119–138.
Holmgren, D. (2002). Permaculture—Principles and Pathways beyond Sustainability. Holmgren Design Services.
Holt, R. D. (1977). Predation, apparent competition and the structure of predator-prey communities. Theoretical Population Biology, 12, 197–229.
Hopwood, J., Lee-Mäder, E., Morandin, L., Vaughan, M., Kremen, C., Cruz, J. K., Eckberg, J., Foltz-Jordan, S., Gill, K., Heidel-Baker, T., Morris, S. (2016). Habitat Planning for Beneficial Insects, Guidelines for Conservation Biological Control. Xerces Society for Invertebrate Conservation, Serial Number, 16-020.
Hopwood, J. L. (2008). The contribution of roadside grassland restorations to native bee conservation. Biological Conservation, 141, 2632–2640.
Huang, N., Enkegaard, A., Osborne, L. S., Ramakers, P. M. J., Messelink, G. J., Pijnakker, J., & Murphy, G. (2011). The banker plant method in biological control. Critical Reviews in Plant Sciences, 30(3), 259-278.
IPM Toolbox. (2023). European Commission, Directorate-General for Agriculture and Rural Development, Farmer's toolbox for integrated pest management: Final report. Publications Office of the European Union.
Krebs, J., & Bach, S. (2018). Permaculture—Scientific Evidence of Principles for the Agroecological Design of Farming Systems. Sustainability, 10, 3218. doi:10.3390/su10093218
Lacey, L. A., Mesquita, A. L. M., Mercadier, G., Debire, R., Kazmer, D. J., & Lecant, F. (1977). Acute and sublethal activity of the entomopathogenic fungus Paecilomyces fumosoroseus on adult Aphelinus asychis. Environmental Entomology, 26, 1452-1460.
Lacoeuilhe, A., Machon, N., Julien, J. F., & Kerbiriou, C. (2016). Effects of hedgerows on bats and bush crickets at different spatial scales. Acta Oecologica International Journal of Ecology, 71, 61–72.
Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. Annual Review of Entomology, 45, 175–201.
Lautenbach, S., Kugel, C., Lausch, A., & Seppelt, R. (2011). Analysis of historic changes in regional ecosystem service provisioning using land use data. Ecological Indicators, 11, 676–687.
Letourneau, D. K., Shennan, C., & Siri-Prieto, G. (2011). Effects of natural enemy biodiversity on the suppression of arthropod herbivores in terrestrial ecosystems. Annual Review of Ecology, Evolution, and Systematics, 42(1), 123-142.

Lindell, C., Eaton, R. A., Howard, P. H., Roels, S. M., & Shave, M. (2018). Enhancing agricultural landscapes to increase crop pest reduction by vertebrates. Agriculture, Ecosystems and Environment, 257, 1–11.

Losey, J. E., & Vaughan, M. (2006). The economic value of ecological services provided by insects. Bioscience, 56, 311–323.

MacLeod, A., Wratten, S. D., Sotherton, N. W., & Thomas, M. B. (2004). 'Beetle banks' as refuges for beneficial arthropods in farmland: long-term changes in predator communities and habitat. Agricultural and Forest Entomology, 6, 147–154.

Marshall, E. J. P., & Moonen, A. C. (2002). Field margins in northern Europe: their functions and interactions with agriculture. Agriculture, Ecosystems & Environment, 89(1-2), 5-21. https://doi.org/10.1016/s0167-8809(01)00285-x

Marshall, E. J. P. (1988). The ecology and management of field margin floras in England. Outlook on Agriculture, 17, 178–182.

Martinez-Sastre, R., Minarro, M., & Garcia, D. (2020). Animal biodiversity in cider apple orchards: simultaneous environmental drivers and effects on insectivory and pollination. Agriculture, Ecosystems & Environment, 295, 106918. https://doi.org/10.1016/j.agee.2020.106918.

Mateos-Fierro, Z., Fountain, M. T., Garratt, M. P. D., Ashbrook, K., & Westbury, D. B. (2021). Active management of wildflower strips in commercial sweet cherry orchards enhances natural enemies and pest regulation services. Agriculture, Ecosystems & Environment, 317, 107485. https://doi.org/10.1016/j.agee.2021.107485

McClanahan, R. J. (1967). Food-chain toxicity of systemic acaricides to predaceous mites. Nature, 215, 1001.

McCravy, K. (2008). Conservation biological control. In Encyclopedia of Entomology, 2nd ed. Springer.

Miller, T. L. P., & Rebek, E. J. (2018). Banker Plants for Aphid Biological Control in Greenhouses. Journal of Integrated Pest Management, 9(1), 1-8. doi: 10.1093/jipm/pmy002

Morandin, L. M., Long, R. F., Pease, C., & Kremen, C. (2011). Hedgerows enhance beneficial insects on farms in California's Central Valley. California Agriculture, 65, 197–201.

Morandin, L. A., & Kremen, C. (2013). Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. Ecology Applications, 23, 829–839.

Nafziger, T. D., & Fadamiro, H. Y. (2011). Suitability of some farmscaping plants as nectar sources for the parasitoid wasp, Microplitis croceipes (Hymenoptera: Braconidae): Effects on longevity and body nutrients. Biological Control, 56, 225–229.

Naranjo, S. E., Ellsworth, P. C., & Frisvold, G. B. (2015). Economic value of biological control in integrated pest management of managed plant systems. Annual Review of Entomology, 60, 621–645.

Natural England. (2013). Entry Level Stewardship Environmental Stewardship Handbook, Fourth Edition – January 2013.
Nilsson, U., Porcel, M., Świergiel, W., & Wivstad, M. (2016). Habitat manipulation – as a pest management tool in vegetable and fruit cropping systems, with the focus on insects and mites. SLU, EPOK – Centre for Organic Food & Farming.
Nyffeler, M., Şekercioğlu, Ç. H., & Whelan, C. J. (2018). Insectivorous birds consume an estimated 400–500 million tons of prey annually. Science of Nature, 105, 47.
O'Rourke, M. E., & Petersen, M. J. (2017). Extending the 'resource concentration hypothesis' to the landscape-scale by considering dispersal mortality and fitness costs. Agriculture, Ecosystems & Environment, 249, 1–3.
Orr, D. (2009). Biological Control and Integrated Pest Management. In Integrated Pest Management: Innovation-Development Process (pp. 207-239). Springer.
Osborne, L. S., Landa, Z., Taylor, D. J., & Tyson, R. V. (2005). Using banker plants to control insects in greenhouse vegetables. Proceedings of the 118th Annual Meeting of the Florida State Horticultural Society, 118, 127–128.
Parker, J. E., Snyder, W. E., Hamilton, G. C., & Rodriguez-Saona, C. (2013). Companion planting and insect pest control. In Weed and Pest Control Conventional and New Challenges (pp. 1–30). InTech.
Parolin, P., Bresch, C., Desneux, N., Brun, R., Bout, A., Boll, R., & Poncet, C. (2012). Secondary plants used in biological control: A review. International Journal of Pest Management, 58(2), 91–100.
Philips, C. R., Rogers, M. A., & Kuhar, T. P. (2014). Understanding Farmscapes and Their Potential for Improving IPM Programs. Journal of Integrated Pest Management, 5(3), 1–8.
Pickett, C. H., Simmons, G. S., Lozano, E., & Goolsby, J. A. (2004). Augmentative biological control of whiteflies using transplants. BioControl, 49, 665–688.
Polidori, C., Russo, A., Pasqualini, E., et al. (2017). Can intercropping with legumes mitigate the use of synthetic insecticides in cherries? A case study with mirids. Journal of Pest Science, 90, 301–309.
Ponisio, L. C., M'Gonigle, L. K., & Kremen, C. (2016). On-farm habitat restoration counters biotic homogenization in intensively managed agriculture. Global Change Biology, 22, 704–715.
Poveda, K., Gomez, M. I., & Martinez, E. (2008). Diversification practices: their effect on pest regulation and production. Revista Colombiana de Entomología, 34, 131–144.
REGULATION (EC) No 1107/2009 OF THE EUROPEAN PARLIAMENT
Root, R. B. (1973). Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (Brassica oleracea). Ecological Monographs, 43, 95–124.
Rueegg, J., Eder, R., & Anderau, V. (2006). Improved application techniques: ways to higher efficacy of fungicides and insecticides. Outlooks on Pest Management, 80-84. DOI: 10.1564/16apr07

Samanta, S., Maji, A., Sutradhar, B., Banerjee, S., Shelar, V., Khaire, P., Yadav, S., & Bansode, G. (2023). Impact of Pesticides on Beneficial Insects in Various Agroecosystems: A Review. International Journal of Environment and Climate Change, 13(8), 1928-1936. Article no. IJECC.100932. ISSN: 2581-8627.

Sarkar, S. C., Wang, E., Wu, S., & Lei, Z. (2018). Application of Trap Cropping as Companion Plants for the Management of Agricultural Pests: A Review. Insects, 9, 128. https://doi.org/10.3390/insects9040128

Shave, M. E., Shwiff, S. A., Elser, J. L., & Lindell, C. A. (2018). Falcons using orchard nest boxes reduce fruit-eating bird abundances and provide economic benefits for a fruit-growing region. Journal of Applied Ecology, 55, 2451–2460.

Shelton, A. M., & Badenes-Perez, F. R. (2006). Concepts and applications of trap cropping in pest management. Annual Review of Entomology, 51, 285–308.

Song, B., & Han, Z. (2020). Assessment of the biocontrol effects of three aromatic plants on multiple trophic levels of the arthropod community in an agroforestry ecosystem. Ecological Entomology, 45, 831–839. https://doi.org/10.1111/een.12858

Song, B., Liang, Y., Liu, S., Zhang, L., Tang, G., Ma, T., & Yao, Y. (2017). Behavioral responses of Aphis citricola (Hemiptera: Aphididae) and its natural enemy Harmonia axyridis (Coleoptera: Coccinellidae) to non-host plant volatiles. Florida Entomologist, 100, 411–421. https://doi.org/10.1653/024.100.0202.

Special Report 05/2020. (2020). Sustainable use of plant protection products: limited progress in measuring and reducing risks. EUROPEAN COURT OF AUDITORS.

Tahvanainen, J. O., & Root, R. B. (1972). The influence of vegetational diversity on the population ecology of a specialized herbivore, Phyllotreta cruciferae (Coleoptera: Chrysomelidae). Oecologia, 10, 321–346. https://doi.org/10.1007/BF00345736

Theiling, K. M., & Croft, B. (1988). Pesticide side-effects on arthropod natural enemies: A database summary. Agriculture, Ecosystems & Environment, 21(3-4), 191-218. https://doi.org/10.1016/0167-8809(88)90088-6

Torres, J., & Bueno, A. (2018). Conservation biological control using selective insecticides – A valuable tool for IPM. Biological Control, 126, 53-64.

Tscharntke, T., Karp, D. S., Chaplin-Kramer, R., Bat´ary, P., DeClerck, F., Gratton, C., ... & Wratten, S. (2016). When natural habitat fails to enhance biological pest control – five hypotheses. Biological Conservation, 204, 449–458. https://doi.org/10.1016/j.biocon.2016.10.001.

Tuneu-Corral, C., Puig-Montserrat, X., Riba-Bertolín, D., Russo, D., Rebelo, H., Cabeza, M., & Lopez-Baucells, A. (2023). Pest suppression by bats and management strategies to favor it: a global review. Biological Reviews. doi: 10.1111/brv.12967

Turlings, T. C. J., Tumlinson, J. H., & Lewis, W. J. (1990). Exploitation of herbivore-induced plant odors by host-seeking parasitic wasps. Science, 250, 1251–1253. https://doi.org/10.1126/science.250.4985.1251.

Uvah, I. I. I., & Coaker, T. H. (1984). Effect of mixed cropping on some insect pests of carrots and onions. Entomologia Experimentalis et Applicata, 36, 159–167. https://doi.org/10.1111/j.1570-7458.1984.tb03422.x.

Vargas, R., Stark, J. D., Hertlein, M., Neto, A. M., Coler, R., & Pinero, J. C. (2008). Evaluation of SPLAT with spinosad and methyl eugenol or cue-lure for "attract-and-kill" of oriental and melon fruit flies (Diptera: Tephritidae) in Hawaii. Journal of Economic Entomology, 101, 759–768.

Vattala, H. D., Wratten, S. D., Phillips, C. B., & Wa¨ckers, F. L. (2006). The influence of flower morphology and nectar quality on the longevity of a parasitoid biological control agent. Biological Control, 39, 179–185.

Vinson, S. B. (1998). The general host selection behavior of parasitoid hymenoptera and a comparison of initial strategies utilized by larvophagous and oophagous species. Biological Control, 11, 79–96.

Wäckers, F. L., van Rijn, P. C. J., & Heimpel, G. E. (2008). Honeydew as a food source for natural enemies: making the best of a bad meal? Biological Control, 45, 176–184.

Wan, N.-F., Fu, L., Dainese, M., Hu, Y.-Q., Pødenphant Kiær, L., Isbell, F., Scherber, C. (2022). Plant genetic diversity affects multiple trophic levels and trophic interactions. Nature Communications, 13, 7312. https://doi.org/10.1038/s41467-022-35087-7.

Wan, N.-F., Ji, X.-Y., Jiang, J.-X. (2014). Testing the enemies hypothesis in peach orchards in two different geographic areas in eastern China: the role of ground cover vegetation. PLoS ONE, 9. https://doi.org/10.1371/journal.pone.0099850.

Wenny, D. G., Devault, T. L., Johnson, M. D., Kelly, D., Sekercioglu, C. H., Tomback, D. F., & Whelan, C. J. (2011). The need to quantify ecosystem services provided by birds. The Auk, 128(1), 1–14.

Westphal, C., Steffan-Dewenter, I., & Tscharntke, T. (2003). Mass flowering crops enhance pollinator densities at a landscape scale. Ecology Letters, 6(10), 961-965. https://doi.org/10.1046/j.1461-0248.2003.00523.x

Whelan, C. J., Şekercioğlu, Ç. H., & Wenny, D. G. (2015). Why birds matter: from economic ornithology to ecosystem services. Journal of Ornithology, 156, 227–238.

Yano, E. (2006). Ecological considerations for biological control of aphids in protected culture. Population Ecology, 48, 333–339.

Zhang, H., Guiguet, A., Dubreuil, G., Kisiala, A., Andreas, P., Emery, R.J.N., Huguet, E., Body, M., & Giron, D. (2017). Dynamics and origin of cytokinins involved in plant manipulation by a leaf-mining insect. Insect Science, 24, 1065–1078. https://doi.org/10.1111/1744-7917.12500.

Zehnder G. (2009). Farmscaping: Making Use of Nature's Pest Management Services. eOrganic, Available online at https://eorganic.org/node/2640

Useful lnks:

https://eorganic.org/node/2640
https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en
https://iobc-wprs.org/ip-tools/pesticide-side-effect-database/(IOBC-WPRS Pesticide Side Effect Database)
https://ipm.ucanr.edu/agriculture/peppers/relative-toxicities-of-insecticides-and-miticides-to-natural-enemies-and-pollinators/
https://ipm.ucanr.edu/PMG/PESTNOTES/pn74140.html#CONSERVATION (UC IPM)
https://mrec.ifas.ufl.edu/lso/BANKER%20IST/Banker%20Plant%20Workshop.htm
https://www.biobestgroup.com/en/side-effect-manual(Side effect manual Biobest)
https://www.eppo.int/ACTIVITIES/plant_protection_products/registered_products (List of databases on registered plant protection products in the EPPO region)
https://www.johnnyseeds.com/growers-library/farm-seed-cover-crops/library-farm-seed-farmscaping.html
https://www.johnnyseeds.com/growers-library/farm-seed-cover-crops/insectary-plantings.html
https://www.koppert.com/news-information/side-effects-database/ (Koppert Side effect database)
https://www.pesticide.org/pollinator_and_beneficial_insect_habitat
IOBC expert group Landscape Management for Functional Biodiversity
https://iobc-wprs.org/expert-group/landscape-management-for-functional-biodiversity/

Unit 3.3 Use of semiochemicals for control and management of crop pests

> Semiochemicals are substances or mixtures of substances emitted by plants, animals, and other organisms that evoke a behavioural or physiological response in individuals of the same or other species. SANTE/12815/2014.

Definitions of Seiochemicals are presented by Tinsworth, 1990; Suckling & Karg, 1998; El-Ghany, 2019). They include behaviorally active compounds as **pheromones** and **allelochemicals** as well **synthetic analogues** of such substances (substances referred to as natural-identical synthesized molecules). According to the compechensive review of semiochemicals made by Klassen et al. (2023), they can be intraspecific or interspecific.

Intraspecific

They are used for signaling between members of the same species (Blassioli-Moraes et al., 2019) Such sumeiochemicals are **Pheromones**. According to SANTE/12815/2014 Pheromones are produced by individuals of a species that modify the behaviour of other individuals of the same species. They are used by insects to fulfill different purposes and include aggregation pheromones, alarm pheromones, sex pheromones and oviposition-deterrent pheromones (Witzgall et al., 2010; Bangels & Belien 2012).

Aggregation pheromones - attract insects to food sites and reproductive habitats. They attract both sexes;
Alarm pheromones - released to alert neighboring individuals of predators;
Sex pheromones – attract insects from other sex, and are mainly used by females to attract males;
Oviposition - deterrent pheromones - used to discourage females from laying their eggs on the same site as another female.

Intraspecific

They are used for signaling between members of different species (El-Ghany, 2019).

Such sumeiochemicals are **Allelochemicals**. According to SANTE/12815/2014 they are produced by individuals of one species that modify the behaviour of individuals of a different species. Allelochemicals are the following categories:

Allomones - cause a response in the receiver that is beneficial to the individual emitting the chemical signal (Blassioli-Moraes et al., 2019) SANTE/12815/2014 (**emitting species benefits**);
Kairomones - similar to allomones except the effect of the chemical signal on the receiver is detrimental to the individual who originally emitted the signal (Blassioli-Moraes et al., 2019; SANTE/12815/2014) (**receptor species benefits**);
Synomones - have a beneficial effect for both the emitter and receiver (El-Ghany, 2019),(e.g. the scents given off by flowers to attract pollinators) SANTE/12815/2014 (**both species benefit**);
Antimones have a negative effect for both the emitting and receiving organisms (El-Ghany, 2019);
Necromones - chemical signals emitted from a non-living source (El-Ghany, 2019).

In addition to the above categories, there are also **anthropogenic semiochemicals know as prarpheromones**. Parapheromones do not originate from natural sources but are structurally similar to natural semiochemicals and, consequently, may have a similar signaling effect. (Manoukis et al., 2018; Martini et al., 2020; Vargas et al., 2018).

Semiochemicals as plant protection products

In recent years, semiochemicals have been increasingly used in plant protection strategies as attractants and repelents. (Oehlschlager, 2016; Preti et al., 2021; Renou & Guerrero, 2000; Klassen et al., 2023).

According to SANTE/12815/2014, the active substances that are emitted by plants, animals, and other organisms or natural-identical synthesized molecules and are used by these organisms for communication are reffered as '**s**emiochemical active substances' .

Semiochemicals ***are not considered as active substances****, when they are used* ***only to attract*** *arthropods which subsequently receive a lethal dose of an insecticide or are killed by other means, as in a bait. Further, semiochemicals used in traps to attract arthropods only for the purpose of monitoring are exempt from registration.*

Semiochemicals are often target specific and may be used at concentrations close to those present in nature, and may dissipate and/or degrade rapidly. For these reasons it is expected that many semiochemical products can pose low risk to human health and the environment. Efficacy, environmental and health studies have demonstrated that such substances may provide effective pest control at low volumes, and at minimal risk (SANTE/12815/2014).

Semiochemical **plant protection products** may provide full control, partial control or contribute to control. Often the measure of benefit is not in lethal dose to the pest, but in reduction of damage to the harvestable portion of the corp. (Klassen et al., 2023). Semiochemicals offer the promise of selective pest control (Foster & Harris, 1997; Raguso et al., 2015.). However, despite extensive research on behavioral manipulation with pheromones and kairomones, there are few semiochemical pest control products available to agriculture (Gregg et al. 2010; Weatherston & Stewart, 2002.. These are principally pheromones used in mating disruption (Landolt, 1997; Suckling, 2000, Witzgall et al., 2010). Despite numerous semiochemicals in use for pest monitoring, demonstrations of direct control by behavioral manipulations with semiochemicals are few, though increasing in number. Examples of commercially available semiochemical-based control measures are fewer yet.

Semiochemical plant protection product is released by dispenser what is a device able to release semiochemicals at controlled release rates. According to the Guidance document on semiochemical active substances and plant protection products (SANTE/12815/2014 rev. 5.2) the classification of the dispensers according to their retrievability, the mode of controlled release and/or their formulation type is as follows.

1. Retrievable dispensers

A) Passive dispensers.

The diffusion of the active ingredient occurs by equilibrium of permeation from the device into the air where the active ingredient becomes diluted.

Extruded Dispensers: The active ingredient is embebbed in a matrix, that is usually made from polymeric material. The dispensers are discrete units.

Reservoir Dispensers: The active ingredient is kept inside a container. The compound migrates through the walls of this container to the outer surface where it diffusses passively.

The general features for retrievable passive dispensers are: (1) Passive emission, (2) High number of emission points needed (50-1000 dispensers/ha), (3) Emission rate per dispenser (400-700 mg/ha/day = 20-275 g A.I. per ha / season), (4) Small area of influence per dispenser, (5) Pheromone released during the whole day, (6) Release dependent on weather conditions (SANTE/12815/2014 rev. 5.2).

B) Active retrievable dispensers

The diffusion of the active ingredient occurs by turbulence-enhanced equilibrium of permeation from the device into the air where the active ingredient becomes diluted. This technology works by periodical releasing of pheromone at the time of the day where the pest is active (usually during night period). Pheromone is actively loaded into the air, where it gets diluted.

The general features for retrievable active dispensers are: (1) Aerosol Formulation contains the active ingredient, (2) Active emission after activation, (3) Emission rate per dispenser (300-500 mg/ha/day= up to 110 g/ha/season), (4) Large area of influence per device, (5) Low number of emissions points (1,25 -

5 devices/ha), (6) Completely retrievable, (7) Pheromone released during flight activity. System is active during the night when the exposure of humans is unlikely, (8) Constant release at defined time intervals. (SANTE/12815/2014 rev. 5.2).

2. Non-retrievable Dispensers

A) Capsule suspension products: The active ingredient is formulated as a microencapsulation. Suspension of the concentrate in water and spraying into the field distribute millions of microdispensers that subsequently behave as passive dispensers.

General features (1) Capsule Suspension formulation, (2) Different microencapsulation processes. Sex pheromone components may be a limiting factor for the use of some processes, (3) Sex pheromone components contained inside polymers which are the walls of the microcapsule, (4) Microcapsule diameter: ≤ 200 μm, (5) As in any other passive dispenser, microcapsule release rates also depends on weather conditions. (SANTE/12815/2014 rev. 5.2).

B) Dosable matrix dispensers: Like for extruded passive dispensers the active ingredient is embebbed in a matrix, which in this case is made of a sticky polymeric material. They are not discrete units, so dosifying happens in-situ by sticking the polymeric mass directly into the plants

Same chemical compound can serve multiple purposes and that there can be overlap in the functions of semiochemicals such as pheromones, allomones, kairomones, synomones, antimones, and necromones. Sex pheromones, for instance, can function as kairomones for certain species since predators use them to track prey (Vosteen et al., 2016). The complex interactions caused by semiochemicals can lead to a complicated response in an ecosystem when these chemical signals are introduced (Stevens et al., 2019).

3.3.1 Pheromones

Rumen Tomov

The pheromons used in pest management (Pheromonal control) are synthetic produced to mimic their natural counterparts as closely as possible. They trigger a response in insects that draws them towards traps, draws them towards release points treated with insecticide, repels them from crops or interrupts mating and reproduction (Blassioli-Moraes et al., 2019; Lucchi et al., 2018, Zhang et al., 2019).

According to Klassen et al. (2023) the advantages of pheromones are: highly species-specific, what means that a pheromone will only affect the target insect species, minimal effect on the behaviour of non-target invertebrates like pollinators, natural pest predators or organisms in soil and water, individual pest controlled without disrupting the entire ecosystem. According to Blassioli-Moraes et al. (2019) the commercially used varieties are generally non-toxic, and do not pose the same health risks to humans as pesticides.

Pheromones are strictly species specific. This allows their precise use in cases where a fight against a species is necessary. However, this is a disadvantage in cases where a fight against several enemies has to be carried out (Klassen et al. (2023).
According to Bruce et al. (2005), in many cases it is better to combine pheromonal control with the other methods within IPM.

Pheromones in IPM

Pheromones are released by pheromone dispensers which according to Klassen et al. (2023), are classified into five e different types based on how pheromone is stored and released form the device:

(1) **Septum dispensers**, where liquid pheromone is stored in lures made form rubber or a polymer and released through evaporation.

(2) **Membrane dispensers**, where pheromone is encapsulated within the dispenser and released by diffusion through a membrane.

(3) **Matrix dispensers**, where pheromones are stored in a solid matrix and released gradually as the concentration gradient causes them to diffuse to the dispenser surface.

(4) **Sprayable formulations** including flowable formulations and wax-type formulations. These formulations are unique because of how they are applied to fields. Unlike other dispensers, they can be applied aerially or from a tractor as a spray that sticks directly to plant leaves (Stelinski et al., 2010).

(5) **Aerosol dispensers**, which are automated devices that release pheromone from a compressed gas canister according to a controlled dosage regime (J. R. Miller and Gut, 2015) They usually emit a far higher dosage of pheromone than membrane or matrix dispensers, so it is common to have as few as 3 dispensers per hectare.

Pheromones are used in IPM in two ways:
(1) pest monitoring and
(2) pheromonal pest control (Ioriatti & Lucchi, 2016).

Pest monitoring with pheromones consists of using a dispenser loaded with a pheromone that is attractive to the species of interest, usually that species' mating or aggregation pheromone, and placing it in a trap. The number of insects caught in the trap are then counted periodically to get an estimate of the population size. (Preti et al., 2021). Pheromone pest monitoring is a widely used in agriculture and there are many pehromone baited traps and dispensers commercially available.

Pheromonal pest control
According to El-Ghany (2019) the most common techniques for pheromonal control of pests are (1) mass trapping, (2) attract-and-kill, 3) repelling pests, (4) push-pull and (5) mating disruption.

Mass trapping is similar to pest monitoring except more traps are used so the number of caught insects is high enough remove a significant portion of the population present in fields. Pheromones are employed as lures to draw pests into traps (Czarnobai De Jorge et al., 2017). Theses pheromones are almost always either mating pheromones or aggregation pheromones (Witzgall et al., 2010).

Attract-and-kill
This strategy also use pheromones to draw pests to point sources placed throughout a field. In attract-and-kill, lures are loaded with an insecticide that kills the insects once they are drawn in by the pheromones (Czarnobai De Jorge et al., 2017)

Repelling pests
Repellent pheromones are useed to repel a target species form plants. They are often synthetic versions of antiaggregations pheromones, oviposition deterrent pheromones or alarm pheromones (Bohnenblust et al., 2011; Kunert et al., 2010). Oviposition pheromones function similarly, telling females not to lay their eggs on plants other members of their species have already laid eggs on. These are useful for controlling pest species in cases where the majority of crop damage results from feeding larvae (Segers et al., 2021). Alarm pheromones are chemical signals released by insects to warn other members of their species that a predator in nearby (Vandermoten et al., 2012)

Push-pull strategy
This technique uses two different pheromones to repel a target species form one area and draw it towards another. Usually, this means having traps treated with an attractive pheromone, exactly like in mass trapping, while crops are also treated with a pheromone that is repellant to the target species (El-Ghany, 2019). The repellent pheromones used in a push-pull strategy not only assist in driving pests toward tarps, but also help reduce feeding and crop damage from those pests that are not captured by traps and remain in the fields (Khan et al., 2016).

Attraction from synthetic plant volatiles or extracts, or from living plants, can be combined with repellence from similar sources in **push–pull systems** (Agelopoulos et al., 1999; Cook et al., 2007; Pickett et al. 2008). In many push–pull systems, the attractant (pull) is not combined with a toxicant. The aim is not destruction of pest populations but rather their redistribution to hosts or locations where they are less damaging (Cook et al., 2007). A similar approach for Carpophilus beetles in apples involves the placement of traps in trees that tolerate beetle damage, to reduce the numbers on more susceptible varieties (Hossain et al. 2013). In other cases, these redistributions may prove lethal to pests, as in the case of dead-end trap crops, to which pests have been attracted but which do not support the development of the next generation (Shelton & Badenes-Perez, 2006).

Mating disruption

Control of pests may be possible by permeating the atmosphere with the pheromone blend or structurally related inhibitory components to disrupt chemical communication between sexes, thus reducing the frequency of mating and subsequent larval development. Mating disruption has been the most successful approach for pest control over the past few decades, and is now an accepted control option for a number of lepidopteran pests of fruits, vegetables, and forests (Byers, 2007; Carde´& Minks 1995; Witzgall et al., 2010)

This technique uses the sex pheromones of the target pest species to confuse individuals trying to locate a mate, resulting in the population failing to mate successfully. Under normal circumstances, females of many common pest species, such as codling moth and other lepidopteran insects, release sex pheromone plumes to create scent trails that males use to find them when mating (Stelinski et al., 2007). The release of synthetic sex pheromones can disrupt this process through **(1) competitive** or **(2) non-competitive** mechanisms review by Klassen et al. (2023).

In **competitive mating disruption**, the number of pheromone dispensers required for effective control is variable since the ratio of pheromone dispensers to female insects matters (Miller & Gut, 2015). Pheromone dispensers are used to create false scent trails of sex pheromone that some males will be attracted to instead of those given off by the females. Three different mechanisms define the possible behaviours of males in response to these false scent trails:

(1) *Competitive attraction* occurs when males follow the false scent trails to the dispenser, fail to find any females there and then leave to follow a different scent trail.

(2) *Induced allopathy* is when males follow the false scent trails and aggregate near the pheromone dispenser.

(3) *Induced arrestment* is when the sex pheromone plumes released from dispensers result in an arrestive behaviour, where males exposed to the plumes stop moving and remain where they are This occurs because the males perceive pheromone plumes coming from multiple sources and cannot determine which to follow (Miller & Gut, 2015).

For non-competitive mating disruption strategies, there is a critical pheromone concentration that needs to be maintained in fields, which is independent of the size of the pest population (Miller & Gut, 2015). Non-competitive mechanisms include desensitization, where exposure of males to high pheromone concentrations causes their response threshold for that pheromone to become elevated. Consequently, they will **no longer respond** to sex pheromones emitted by females at normal environmental concentration (Miller & Gut, 2015)

Early application of synthetic sex pheromones may also cause induced allochrony, which is when the release of pheromones causes **males to become ready to mate before the females are.** This can result is males being exhausted or no longer prepared for mating by the time females start looking for mates (Miller & Gut, 2015).

Non-competitive mating disruption includes different techniques for masking sex pheromones emitted by female insects. If the area is saturated with a high enough pheromone concentration, no scent trails will be distinguishable to males, which is known as **signal camouflage or masking**. Adding off-isomers of pheromone molecules to the environment may also cause sex pheromones emitted by females to appear inauthentic to males, which is known as signal adulteration (Miller & Gut, 2015)

According to Witzgall et al. (2010). Competitive mating disruption requires pheromone dispensers to be in operation at the same time the target species is mating, While many non-competitive mating disruption techniques require application of pheromones earlier in the season. Additionally, mating disruption is less effective if the population density of the target species is high because males and females will tend to encounter each other and mate even if their signaling is being confused (Witzgall et al., 2010). For these reasons, mating disruption is not an effective strategy if a serious infestation has already taken hold and an immediate solution is needed to reduce pest numbers. However, if mating disruption is started early enough in the season and application is timed correctly, it has been shown to be very effective at preventing pest populations from growing beyond a size where the damage they cause to crops is noticeable (Judd & Gardiner, 2004).

Additional information for pheromonal pest control as an alternative to pesticide use in agriculture could be found in:

Klassen et al., 2023

Guidance Document Of European Commission Health & Food Safety Directorate-General On Semiochemical Active Substances And Plant Protection Products, (Sante/12815/2014 Rev. 5.2).

https://pacificbiocontrol.com/product/isomate-cm-lr-tt/

https://www.suterra.com/products/cm-xl

3.3.2 Parapheromones

Rumen Tomov, Roxana Ciceoi

Parapheromones, chemically related to natural pheromones, are synthetic compounds that mimic the natural chemical signals of insects. The utilization of these semiochemicals has gained considerable attention in Integrated Pest Management (IPM) programs, offering a more environmentally friendly and targeted approach to pest control compared to conventional methods.
Parapheromones are designed to replicate the action of natural pheromones, which are chemicals used by insects for communication. These synthetic analogs can be more stable, potent, or economical than their natural counterparts. They play a crucial role in manipulating insect behavior for pest management purposes, such as in mating disruption, mass trapping, and monitoring.

Parapheromones are synthetic and not naturally derived, yet their structure closely resembles that of natural semiochemicals, leading to similar communication effects. The most commonly employed parapheromones, namely trimedlure, methyl eugenol, and cuelure, are specifically targeted at males. These compounds are typically very volatile and versatile for use in different types of traps, making them extensively utilized in surveys targeting fruit flies. Detailed information about Para-pheromones could be found in ISPM 26; IAEA 2003; Coombs & Hall, 1998; Gordh & Headrick, 2001; NAL 2008; Manoukis et al., 2018; Martini et al., 2020; Vargas et al., 2018.

The agricultural sector has witnessed a substantial benefit from the use of parapheromones. Their application in mating disruption is a prime example, where parapheromones are released to confuse male insects, thereby reducing the likelihood of mating and subsequently lowering the population of pests. This method is particularly effective against moths and other insects that are detrimental to crops. Moreover, parapheromones are used in traps to monitor pest populations, enabling farmers to make informed decisions about the application of other pest control measures, thereby reducing the reliance on broad-spectrum insecticides.

Environmental and Health Benefits

One of the most compelling advantages of parapheromones is their specificity and reduced impact on non-target organisms, including beneficial insects, wildlife, and humans. This specificity aligns well with the principles of organic farming and sustainability, reducing the ecological footprint of pest management activities. By minimizing the use of traditional pesticides, parapheromones contribute to a healthier environment and lower the risk of pesticide residue in food products, thus promoting consumer health and safety.

Despite their advantages, the implementation of parapheromones faces certain challenges. The cost of development and deployment of these compounds can be significant, and their effectiveness can vary based on environmental factors and pest species.

Future research in this field should focus on developing cost-effective synthesis methods, broadening the spectrum of target pests, and enhancing the stability and efficacy of parapheromones under varying environmental conditions.

Parapheromones represent a groundbreaking development in the field of pest management, aligning with the growing demand for sustainable agricultural practices. Their role in enhancing the effectiveness of IPM programs, while minimizing environmental and health risks, is invaluable. As research continues to evolve, the potential of parapheromones in transforming agricultural pest control strategies remains immense, paving the way for a more sustainable and ecologically balanced approach to crop protection.

3.3.3 Antifeedants

Rumen Tomov, Roxana Ciceoi

Antifeedants can be described as allomone substances which inhibit feeding and do not kill the pest directly, but rather limit its development potential. (Guerrero et al. 2013).

According to some authors, any substance that reduces consumption (feeding) by an insect can be considered an antifeedant (feeding deterrent). According to Isman et al. (1996), the antifeedant is behaviourmodifying substance that deters feeding through a direct action on peripheral sensilla (= taste organs) in insects. Terrestrial plants produce a diverse array of secondary metabolites, likely more than 100,000 unique compounds, and there is compelling evidence that at least some of these are important in the defense of plants against herbivores (Schoonhoven, 1982).

Antifeedants can be found amongst all the major classes of secondary metabolites – alkaloids, phenolics and terpenoids (Frazier, 1986).

Antifeedants represent a pivotal strategy in the field of pest management, particularly in agriculture and forestry. As their name suggests, antifeedants are substances that deter or discourage pests from feeding on plants. Unlike insecticides, which kill pests, antifeedants primarily work by affecting the feeding behavior of insects, thus protecting crops and plants from damage.

The mode of action of antifeedants is primarily through altering the gustatory (taste) or olfactory (smell) perceptions of insects. When pests encounter these substances, their normal feeding behavior is disrupted. This can be due to the antifeedants' unpleasant taste, odor, or their ability to interfere with the insect's digestive processes. As a result, the pest either feeds less or avoids feeding on the treated plant material altogether.

Antifeedants can be derived from natural sources, such as plant extracts, or they can be synthetically produced. Natural antifeedants often include compounds like tannins, alkaloids, and terpenoids, which are found in a variety of plants. These naturally occurring substances have evolved as part of the plant's defense mechanism against herbivorous insects. Synthetic antifeedants, on the other hand, are designed to mimic these natural compounds or create entirely new substances that disrupt feeding.

In agriculture, the use of antifeedants has been a boon for controlling pests in a way that is less harmful to the environment and non-target species, including pollinators and beneficial insects. They are particularly useful in organic farming, where the use of conventional pesticides is limited. In forestry, antifeedants help protect trees from defoliators and bark beetles, thereby preserving forest health and biodiversity.

While antifeedants offer numerous benefits, there are challenges in their application. The effectiveness of antifeedants can vary depending on the pest species and environmental conditions. Additionally, the development and registration of new antifeedant products can be costly and time-consuming. Future research is expected to focus on identifying new natural antifeedants, improving the efficacy and specificity of synthetic variants, and understanding the long-term ecological impacts of their use.

Antifeedants play an essential role in modern pest management strategies, offering an effective and environmentally friendly alternative to conventional pesticides. Their ability to deter pests from feeding on crops and forest vegetation holds great promise for sustainable agriculture and forestry practices. As research advances, the potential of antifeedants in integrated pest management continues to expand, marking a significant step towards ecologically responsible pest control methods.

3.3.4 Kairomones

Rumen Tomov

The kairomone is a chemical or mixture of chemicals emitted by an organism, e.g. a plant, that induces a response in an individual of another species, e.g. an insect, that is beneficial to the receiving organism. Example: plant scent that makes the plant more easily identifiable to an insect pest (Maxwell & Jennings, 1980; Bijlmakers, 2008). Similar definitions are presented by (Resh & Cardé 2003; Auburn, 2008; Pedigo, 2002; Gordh & Headrick, 2001; Coombs & Hall, 1998; Coppel & Mertins, 1977).

Kairomones used for attract an kill of pest insects are some plant and microbial volatiles. Plant volatiles are plant-emitted substances that are evaporated at ambient temperatures and carry information to other organisms (Dudareva et al., 2006.).

Some volatiles, termed microbial volatile organic compounds (Davis et al., 2013), are produced not by plants themselves but by the actions of microorganisms such as yeasts, bacteria, and fungi on or in the plant tissue. These microbial volatile organic compounds may serve as aggregation pheromones, as oviposition stimulants, as a means to locate host and food resources, or as a way to signify unfavorable environmental conditions (Davis et al., 2013). In Spanish citrus orchards, mass trapping with synthetic plant volatile mixtures reduced the population of Mediterranean fruit flies (Ceratitis capitata) by up to 80% (102). Studies of tephritid flies also provide examples in which experimental mass trapping using fruit and microbial volatiles resulted in reduced damage (Navarro-Llopis et al., 2014; Yasin et al., 2014)

Definition and Function

Kairomones are chemicals emitted by one species that are advantageous when detected by another species. In the context of horticulture, plants release certain chemicals that can be used by pests to locate them. However, this same property can be exploited in pest management.

Application in Pest Control

- Attraction and Trapping

Kairomones are used in traps to attract pests. This method is effective for monitoring pest populations and can sometimes reduce their numbers.

- Disruption of Host-Finding

By using kairomones to confuse pests or lead them away from crops, they can be an effective tool in disrupting the host-finding process.

Advantages

Kairomones can target specific pests without harming non-target organisms, including beneficial insects. They offer an eco-friendly alternative to chemical pesticides, aligning with sustainable agricultural practices.

Kairomones offer a promising avenue in the field of integrated pest management, particularly in horticulture. Their ability to manipulate pest behavior in an environmentally friendly manner presents a valuable tool for sustainable agriculture. However, their effective implementation requires ongoing research and development to overcome challenges related to efficacy and cost.

REFERENCES

Alkofahi, A.; Rupprecht, J.K.; Anderson, J.E.; McLaughlin, J.L.; Mikolajczak, K.L.; Scott, B.A. Search for New Pesticides from Higher Plants. In Insecticides of Plant Origin; Arnason, J.T., Philogene, B.J., Morand, P., Eds.; Books on Demand: Norderstedt, Germany, 1989; Volume 387, pp. 25–43.

Agelopoulos N, Birkett MA, Hick AJ, Hooper AM, Pickett JA, et al. (1999). Exploiting semiochemicals in insect control. Pestic. Sci. 55:225–35

Auburn 2008, Auburn University. (2008). Entomology 2040 glossary. http://www.ag.auburn.edu/enpl/courses/glossary.htm

Bangels, E., Beli¨en, T. (2012). Consistent codling moth population decline by two years of mating disruption in apple: a Flemish case study. Commun. Agric. Appl. Biol. Sci. 77 (4), 653–655.

Bijlmakers, H. (2008). Glossary of entomology, crop protection, integrated pest management. http://www.bijlmakers.com/glossary/glossary.htm

Blassioli-Moraes, M., Laumann, R., Micheref, M.F., Borges, M. (2019). Semiochemicals for Integrated Pest Management. Springer, Cham. https://doi.org/10.1007/978-3-030- 17891-8_3.

Bohnenblust, E., Hull, L.A., Krawczyk, G. (2011). A comparison of various mating disruption technologies for control of two internally feeding Lepidoptera in apples. Entomol. Exp. Appl. 138 (3), 202–211. https://doi.org/10.1111/j.1570- 7458.2010.01089.x.

Byers JA. (2007). Simulation of mating disruption and mass trapping with competitive attraction and camouflage. Environ Entomol 36:1328–1338.

Bruce, T.J.A., Birkett, M.A., Blande, J., Hooper, A.M., Martin, J.L., Khambay, B., Prosser, I., Smart, L.E., Wadhams, L.J. (2005). Response of economically important aphids to components of Hemizygia petiolata essential oil. Pest Manag. Sci. 61 (11), 1115–1121. https://doi.org/10.1002/ps.1102.

Carde´ RT, Minks AK. (1995). Control of moth pests by mating disruption: successes and constraints. Annu Rev Entomol 40: 559–585

Cook SM, Khan ZR, Pickett JA. (2007). The use of push-pull strategies in integrated pest management. Annu. Rev. Entomol. 52:375–400

Coombs, J., and K. E. Hall. 1998. Dictionary of biological control and integrated pest management. 2nd edn. CPL Scientific Publishing Services

Coppel, H. C., and. Mertins J. W. (1977). Biological insect pest suppression. Springer-Verlag, Berlin, Germany.

Czarnobai De Jorge, B., Bisotto-de-Oliveira, R., Pereira, C.N., Sant'Ana, J. (2017). Novel nanoscale pheromone dispenser for more accurate evaluation of Grapholita molesta (Lepidoptera: tortricidae) attract-and-kill strategies in the laboratory. Pest Manag. Sci. 73 (9), 1921–1926. https://doi.org/10.1002/ps.4558.

Davis TS, Crippen TL, Hofstetter RW, Tomberlin JK. (2013). Microbial volatile emissions as insect semiochemicals. J. Chem. Ecol. 39:840–59

Dudareva N, Negre F, Nagegowda DA, Orlova I. (2006). Plant volatiles: recent advances and future perspectives. Crit. Rev. Plant Sci. 25:417–40

El-Ghany, N.M.A. (2019). Semiochemicals for controlling insect pests. J. Plant Protect. Res. 59 (1), 1–11. https://doi.org/10.24425/jppr.2019.126036_rfseq1

Foster SP, Harris MO. (1997). Behavioral manipulation methods for insect pest-management. Annu. Rev. Entomol. 42:123–46

Frazier, J. L. (1986). The perception of plant allelochemicals that inhibit feeding, pp. 1–42. In: Molecular Aspects of Insect-Plant Associations, L.B. Brattsten and S. Ahmad (Eds.), Plenum Press, New York

Gordh, G., and D. H. Headrick. (2001). A dictionary of entomology. CABI Publishing, Wallingford, UK

Gregg PC, Greive KA, Del Socorro AP, Hawes AJ. (2010). Research to realisation: the challenging path for novel pest management products in Australia. Aust. J. Entomol. 49:1–9

Guerrero A., Malo E., Coll J., Quero C. (2013). Semiochemical and natural product-based approaches to control Spodoptera spp. (Lepidoptera: Noctuidae) J Pest Sci. DOI 10.1007/s10340-0130533-7

Hossain MS, Hossain MABM, Williams DG, Chandra S. (2013). Management of Carpophilus spp. beetles (Nitidulidae) in stone fruit orchards by reducing the number of attract-and-kill traps in neighbouring areas. Int. J. Pest Manag. 59:135–40

IAEA (2003) (International Atomic Energy Agency). (2003). Trapping guidelines for area-wide fruit fly programmes. Joint FAO/IAEA Division, Vienna, Austria. 47 pp

Ioriatti, C., Lucchi, A. (2016). Semiochemical strategies for tortricid moth control in apple orchards and vineyards in Italy. J. Chem. Ecol. 42 (7), 571–583. https://doi.org/10.1007/s10886-016-0722-y.

Isman, M. B.; Matsuura, H.; MacKinnon, S.; Durst, T.; Towers, G. H. N.; Arnason, J. T. (1996). Phytochemistry of the Meliaceae: So many terpenoids, so few insecticides. Recent Advances in Phytochemistry, 30, 155–178.

ISPM 26. (2006) Appendix 1 Fruit fly trapping (2011). Rome, IPPC, FAO. Publication history last modified August 2011

Judd, G.J.R., Gardiner, M.G.T., 2004. Simultaneous disruption of pheromone communication and mating in Cydia pomonella, Choristoneura rosaceana and Pandemis limitata Lepidoptera: tortricidae) using isomate-CM/LR in apple orchards. J. Entomol. Soc. Br. Columbia 101, 14, 0), 314.

Khan, Z., Midega, C.A.O., Hooper, A., Pickett, J.(2016). Push-pull: chemical ecologybased integrated pest management technology. J. Chem. Ecol. 42 (7), 689–697. https://doi.org/10.1007/s10886-016-0730-y.

Klassen D , Lennox M , Dumont M-J, Chouinard G , Tavares J. (2023). Dispensers for pheromonal pest control. Journal of Environmental Management 325 (2023) 116590 https://doi.org/10.1016/j.jenvman.2022.116590

Kunert, G., Reinhold, C., Gershenzon, J. (2010). Constitutive emission of the aphid alarm pheromone, (E)-β-farnesene, from plants does not serve as a direct defense against aphids. BMC Ecol. 10 https://doi.org/10.1186/1472-6785-10-23.
Landolt PJ. (1997). Sex attractant and aggregation pheromones of male phytophagous insects.Am. Entomol. 43:12–22
Lucchi, A., Sambado, P., Juan Royo, A.B., Bagnoli, B., Conte, G., Benelli, G. (2018). Disrupting mating of Lobesia botrana using sex pheromone aerosol devices. Environ. Sci. Pollut. Control Ser. 25 (22), 22196–22204. https://doi.org/10.1007/s11356- 018-2341-3.
Manoukis, N.C., Cha, D.H., Collignon, R.M., Shelly, T.E. (2018). Terminalia larval host fruit reduces the response of bactrocera dorsalis (diptera: tephritidae) adults to the male lure methyl eugenol. J. Econ. Entomol. 111 (4), 1644–1649. https://doi.org/ 10.1093/jee/toy095.
Martini, X., Hughes, M.A., Conover, D., Smith, J. (2020). Use of semiochemicals for the management of the redbay ambrosia beetle. Insects 11 (11), 1–11. https://doi.org/ 10.3390/insects11110796.
Maxwell, F. G., and P. R. Jennings (eds.). (1980). Breeding plants resistant to insects. John Wiley and Sons, New York, NY, USA. (MCC) Marshall Cavendish Corporation. 1996. Encyclopedia of life sciences. Volume 11. Marshall Cavendish Corporation, Tarrytown, NY, USA.
Miller, J.R., Gut, L.J. (2015). Mating disruption for the 21st century: matching technology with mechanism. Environ. Entomol. 44 (3), 427–453. https://doi.org/10.1093/ee/ nvv052.
NAL, (2008). National Agricultural Library. 2008. Glossary. Agricultural Research Service, United States Department of Agriculture. Beltsville, MD,
Navarro-Llopis V, Primo J, Vacas S. (2014). Bait station devices can improve mass trapping performance for the control of the Mediterranean fruit fly. Pest Manag. Sci. 71:923–27
Oehlschlager, A.C. (2016). Palm weevil pheromones – discovery and use. J. Chem. Ecol. 42 (7), 617–630. https://doi.org/10.1007/s10886-016-0720-0.
Pedigo, L. P. (2002). Entomology and pest management. 4th edn. Prentice Hall, Upper Saddle River, NJ, USA
Pickett JA, Hassanali A, Herren H, Khan ZR, Woodcock CM. (2008). Integrated pest management: the push–pull approach for controlling insect pests and weeds of cereals, and its potential for other agricultural systems including animal husbandry. Philos. Trans. R. Soc. B 363:611–21
Preti, M., Knight, A.L., Favaro, R., Basoalto, E., Tasin, M., Angeli, S. (2021). Comparison of new kairomone-based lures for cydia pomonella (Lepidoptera: tortricidae) in Italy and USA. Insects 12 (1), 1–10. https://doi.org/10.3390/insects12010072.
Raguso RA, Agrawal AA, Douglas AE, Jander G, Kessler A, et al. (2015). The raison d’etre of chemical ˆ ecology. Ecology 96:617–30

Renou, M., Guerrero, A., (2000). Insect parapheromones in olfaction research and semiochemical-based pest control strategies. Annu. Rev. Entomol. 45 (February), 605–630. https://doi.org/10.1146/annurev.ento.45.1.605.
Resh, V. H., and R. T. Cardé (eds.). (2003). Encyclopedia of insects. Academic Press, Amsterdam, The Netherlands
Sante/12815/2014 Rev. 5.2 Guidance Document Of European Commission Health & Food Safety Directorate-General On Semiochemical Active Substances And Plant Protection Products.
Segers, A., Caparros Megido, R., Lognay, G., Francis, F. (2021). Overview of Bruchus rufimanus Boheman 1833 (Coleoptera: chrysomelidae): biology, chemical ecology and semiochemical opportunities in integrated pest management programs. Crop Protect. 140 (September 2020) https://doi.org/10.1016/j.cropro.2020.105411.
Shelton AM, Badenes-Perez E. (2006). Concepts and applications of trap cropping in pest management. Annu. Rev. Entomol. 51:285–308.
Stelinski, L.L., Lapointe, S.L., Meyer, W.L. (2010). Season-long mating disruption of citrus leafminer, Phyllocnistis citrella Stainton, with an emulsified wax formulation of pheromone. J. Appl. Entomol. 134 (6), 512–520. https://doi.org/10.1111/j.1439- 0418.2009.01453.x.
Stelinski, L.L., Mckenzie, D., Gut, L.J., Isaacs, R., Brunner, J. (2007). Comparison of female attractiveness and male response among populations of Choristoneura rosaceana (Harris) in western and eastern U.S. apple orchards. Environ. Entomol. 36 (5), 1032–1039. https://doi.org/10.1603/0046-225X(2007)36[1032:COFAAM]2.0. CO;2.
Stevens, M.M., Wood, R.M., Mo, J. (2019). Monitoring flight activity of Cryptolestes ferrugineus (Coleoptera: laemophloeidae) in outdoor environments using a commercial pheromone lure and the kairomone 1-octen-3-ol. J. Stored Prod. Res. 83, 227–235. https://doi.org/10.1016/j.jspr.2019.07.005.
Suckling DM, Karg G (1998). Pheromones and other semiochemicals. In: Rechcigl JE, Rechcigl NA (eds) Biological and biotechnological control of insect pests. CRC Press, Boca Raton, pp 63–99.
Suckling DM. (2000). Issues affecting the use of pheromones and other semiochemicals in orchards. Crop Prot. 19:677–83.
Tinsworth, E. F. (1990). Regulation of pheromones and other Semiochemicals in the Uni~ed States of America. In Behaviour modi.fYing chemicals for insect management, R.L. Ridgway, R.M. Silverstein and M.N. Insloe, Marcel Dekker Inc., pp 569-605.
Vandermoten, S., Mescher, M.C., Francis, F., Haubruge, E., Verheggen, F.J. (2012). Aphid alarm pheromone: an overview of current knowledge on biosynthesis and functions. Insect Biochem. Mol. Biol. 42 (3), 155–163. https://doi.org/10.1016/j. ibmb.2011.11.008.
Vargas, R.I., Souder, S.K., Rendon, P., Mackey, B., Clarke, A. (2018). Suppression of mediterranean fruit fly (Diptera: tephritidae) with trimedlure and biolure dispensers n coffea arabica (gentianales: rubiaceae) in Hawaii. J. Econ. Entomol. 111 (1), 293–297. https://doi.org/10.1093/jee/tox303.

Vosteen, I., Weisser, W.W., Kunert, G. (2016). Is there any evidence that aphid alarm pheromones work as prey and host finding kairomones for natural enemies? Ecol. Entomol. 41 (1), 1–12. https://doi.org/10.1111/een.12271.
Weatherston I, Stewart R. (2002). Regulatory issues in the commercial development of pheromones and other semiochemicals. IOBC WPRS Bull. 25:1–9.
Witzgall P, Kirsch P, Cork A. (2010). Sex pheromones and their impact on pest management. J. Chem. Ecol. 36:80–100 https://doi.org/10.1007/s10886-009- 9737-y.
Yasin S, Rempoulakis P, Nemny-Levy E, Levi-Zada A, Tsukada M, Papadopolus, N., Nestel, D. 2014. Assessment of lure and kill and mass trapping methods against the olive fly Bactrocera oleae (Rossi) in desert-like environments in the eastern Meditteranean. Crop Prot. 57:63–76.
Zhang, Q., Teschers, C.S., Callejo, R., Yang, M., Wang, M., Silk, P.J., Ryall, K., Roscoe, L. E., Cordes, D.B., Slawin, A.M.Z., O'Hagan, D. (2019). Fluorine in pheromones: synthesis of fluorinated 12-dodecanolides as emerald ash borer pheromone mimetics. Tetrahedron 75 (21), 2917–2922. https://doi.org/10.1016/j. tet.2019.03.025

https://www.hse.gov.uk/pesticides/pesticides-registration/active-substances/biopesticides.htm
https://cordis.europa.eu/project/id/840491 Pheromones for ecologically friendly pest control in fruit orchards (EcoFruit)
https://pacificbiocontrol.com/product/isomate-cm-lr-tt/
https://www.suterra.com/products/cm-xl
https://www.internationalpheromones.com/improving-our-pheromone-dispenser/

Unit 3.4 Use of natural substances for control of crop pests and pathogens

Rumen Tomov, Roxana Ciceoi

3.4.1 Botanicals

> Botanical Pesticides (BP) are organic substances of plant origin that have naturally occurring defensive properties. Such pesticides are becoming more and more popular in last few decades since they correspond to the rising public interest of environmentally friendly plant protection.

They have proven to exhibit several main advantages comparing to the synthetic pesticides:

- BP are biodegradable and leave no toxic load on food and other agricultural products and are reducing or eliminating pesticides persistence problems in the environment.
- BP posses target specificity and are less likely to harm species other than the target object and thus are safety to mammals including human beans.

- The chemical composition of BP include a numbe… natural components responsible for the pesticide activity, so they are tool for avoiding the pest resistance problems in agriculture often emerging in conventional plant protection practices.
- BP are considered as of economic feasibility since they are easily available at low cost.

There are some challenges in successful implementation of BP and providing an effective solution against the agricultural losses:

- Such biological agents are relatively slow in action thus making them unsuitable if a pest outbreak needs an immediate threat with fast result.
- High specificity of action of BP may require an exact identification of the target pest or pathogen.
- The composition of BP is usually unstable under UV rays of sun light, which can affect negatively their pesticide properties.
- BP can express variable efficacy due to the influences of diverse biotic and abiotic factors.

Although the doubts in the constantly reliable and sustainable efficiency of the BP all the application strategies with BP can be utilized for effective control of pest management.

This combined with the good public image they have makes them extremely suitable as alternative of chemical pesticides and an appropriate choice particularly in organic farming and in precision agriculture.

Different plant organs - flowers, leaves or roots may be directly used as botanical pesticides in their powdered form. But mostly the research is focused on the bioactive compound that could be obtained from the plants and used alone or in mixtures for the control of pest population. The most investigated are:
1) Plant extracts, incl. aqueous, ethanol, methanol, acetone extracts from various plant parts;
2) Essential oils, which are naturally produced by aromatic plants and contain a wide range of volatile molecules, mainly secondary metabolites, which possess several biological activities.

Biological active plant derived compounds or mixtures posses' specific pest activity. Most of them are referred as bio-insecticides. But quite high numbers of them are found to exhibit fungicidal, bactericidal or herbicidal activities.

Plant derived insecticides (Botanical insecticides - BI).
Essential oils, being of a mixture of compounds, have increased considerably application as insecticides because of their repellent, insecticidal, antifeedants, growth inhibitors,

oviposition inhibitors, ovicides, and growth-reducing effects on a variety of insects. (Hikal et al., 2017).

The other important group of natural substances playing an important role as insecticides of plant origin is alkaloids (Balandrin et al., 1985; Rattan, 2010), flavonoids and isoflavonoids (Simmonds, 2003; Simmonds and Stevenson, 2001; Gould and Lister, 2006; Goławska and Łukasik, 2012; Goławska et al., 2014; Santos et al., 2016), glycosides (Park and Coats, 2002; Zagrobelny et al., 2004; Wimmer et al., 2007), esters and fatty acids (Schmidt et al., 2008; Giner et al., 2012).

Botanical insecticides affect various insects in different ways depending on the physiological characteristics of the insect species as well as the type of the insecticidal plant. According to the ways BI affect the insects they can be classified into six groups: repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants (Rajashekar et al., 2012).

Plant derived insecticides (Botanical insecticides - BI)

Plants are known as producers of numerous secondary metabolites from decades. Among them the essential oils (EO) are most expansively studied for their activities against plant pathogenic fungi, oomycetes and bacteria (Lazar et al., 2010; Dean et al., 2012; Tabassum and Vidyasagar, 2013).

Plants are known as producers of numerous secondary metabolites from decades. Among them the essential oils (EO) are most expansively studied for their activities against plant pathogenic fungi, oomycetes and bacteria (Lazar et al., 2010; Dean et al., 2012; Tabassum and Vidyasagar, 2013). The most studied plant pathogenic fungi belong to the genera Alternaria, Botrytis, Fusarium, Penicillium, Rhizoctonia in this respect. Most of the experiments are maintained in vitro in Petri dishes. The response of the fungi is specific and vary depending of the plant source of the EO and the fungal species. (Ortiz de Elguea-Culebras et al., 2016; Božik et al., 2017). For example the EO of *Mentha piperita*, *Mentha spicata* and *Mentha suaveolens* demonstrated higher inhibiting activity against *Botryotinia fuckeliana*, and less active in suppressing of Fusarium oxysporum. Among the EO of three *Mentha* species studied the *Mentha suaveolens* EO is considered as most promising to to develop a botanical biofungicide (Giménez-Santamarina et al., 2022).

Plant derived herbicides (Botanical herbicides - BH)

Natural herbicides that that are released from plant species are considered as phytotoxins and several classes of plant secondary metabolites have been described as phytotoxins including naphtoquinones, amino acids, catechins, polyphenols and alkylamides. Plant EO are also demonstrated to poses herbicidial activity. For example Citronella oil derived from Cymbopongon species is primarily used as a mosquito repellent, but also has other insecticidal, acaricidal and herbicidal activity (Baker et al., 2018). But there are also a number of examples for ineffective EO against germination of weed seeds (Singh et al., 2005; Batish et al., 2007; Kordali et al., 2008)

The insecticide, fungicide or herbicide ability of botanical pesticides derived from plant parts or whole plants makes their application in modern agriculture an irrevocable necessity. Since now more than 6000 plant species have been identified to possess pesticides properties. Among them plant products derived from neem, custard apple, tobacco, pyrethrum, etc. have been proved and applied as safer insecticides in insect pest management (Koul, 2012). The future of plant protection practices belongs to the botanical pesticides and they are expected to gradually replace chemical pesticides. The current trend in the world agriculture towards a reduction of synthetic pesticides' use as well as an alleviation of the approval procedure for low-risk substances might enable plant derived products to be developed and used worldwide (Nawaz et al., 2016).

Plant-based natural products and their corresponding pesticide activity and targets may be found in Table 3 used as a mosquito repellent, but also has other insecticidal, acaricidal and herbicidal activity (Baker et al., 2018). But there are also a number of examples for ineffective EO against germination of weed seeds (Singh et al., 2005; Batish et al., 2007; Kordali et al., 2008)

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Plant-based natural products and their corresponding pesticide activity and targets may be found in Table 3

Compound/Product name	Plant species	Target species	References
Pyrethrin I/ Pyrethrin II	*Tanacetum cinerariifolium* (Trevir.) Sch. Bip.	Spider mites; flies; fleas; beetles	Casida and Quistad, 1998; Rattan, 2010
Himachalol/β Himachalene	*Cedrus deodara* (Roxb. ex D. Don) G. Don	cowpea weevil (*Callosobruchus analis Fabriciuss*) and Housefly (*Musca domestica L.*)	Singh and Agarwal, 1988
Decaleside I/ Decaleside II	*Decalepis hamiltonii Wight* and Arn.	Houseflies; cockroaches; stored grain pests	Rajashekar et al., 201
Cevadine R (*Veratridine* R)	*Schoenocaulon officinale* (Schltdl. and Cham.) A. Gray ex Benth - sabadilla.	Stinks, leafhoppers, caterpillars; housefly and thrips (*Scirtothrips spp.*)	Shivanandappa and Rajashekar, 2014; Copping and Duke, 2007; Hare and Morse, 1997; Ujváry, 2010.
RyanodinE	*Ryania speciosa Vahl*	Caterpillars; worms; potato beetle; lace bugs; aphids and squash bugs	Shivanandappa and Rajashekar, 2014; Bloomquist, 1999.
(Coumaran) 2,3dihydrobenzofuran	*Lantana camara L.*	Stored grain pests (*Sitophilusoryzae L.*; *Tribolium castaneum* herbst); Housefly pests (*Musca domestica*)	Rajashekar et al., 2014.
Thujone	*Artemisia absinthium* L.;*Juniperus sp.*; *Cedrus sp*	Western corn rootworm larvae (*Diabrotica virgifera*); Fruit fly (*Drosophila melanogaster Meigen*)	Höld et al., 2000
Carvacrol, Thymol, Pulegone	Purchased from Sigma–Aldrich Chemical Co.	*Periplaneta americana L.*	Tong and Coats, 2010.
Rotenone	*Lonchocarpus Kunth* (Fabaceae);*Derris Lour* (Fabaceae);*Rhododendron L.* (Ericaceae)	Beetles; caterpillars; lice; mosquitoes; ticks; fleas; fire ants	Rattan, 2010; Tooley, 1971
Precocene I (7-methoxy2,2dimethylchromene)	*Ageratum conyzoides L.* (Asteraceae)	Sawtoothed grain beetle (*Oryzaephilus surinamensis L.*); Milkweed bug (*Oncopeltus fasciatu Dallas*);Noctuid moth (*Spodoptera litura Fabricius*); Parasitic wasp (*Microplitis rufiventris Nees*)	Saleem and Wilkins, 1984; Singh and Kumar, 2011; Srivastva and Kumar, 1997; Khafagi, 2004.

Compound/Product name	Plant species	Target species	References
Precocene II (6,7-dimethoxy-2,2dimethylchromene)	*Ageratum conyzoides L. (Asteraceae)*	Desert locust (*Schistocerca gregaria Forskål*); Milkweed bug (*Oncopeltus fasciatus Dallas*); Noctuid moth (*Spodoptera litura Fabricius*); Parasitic wasp (*Microplitis rufiventris Nees*)	Singh and Kumar, 2011; Srivastva and Kumar, 1997; Khafagi, 2004; Eid et al., 1988
15-epi-4E-jatrogrossidentadione	*Jatropha podagrica Hook.* (Euphorbiaceae)	Moth (*Chilo partellus Swinhoe*)	Okwute, 2012
5isobutyryloxysilphinen-3-one 11-Acetoxy-5isobutyryloxysilphinen-3-one	*Senecio palmensis C. Sm.* (Asteraceae)	Colorado potato beetle (*Leptinotarsa decemlineata Say*); Aphids (*Myzus persicae Sulzer, Diuraphis noxia Kurdjumov, Rhopalosiphum padi L., Metopolophium dirhodum Walker, Sitobiona venae Fabricius*)	González-Coloma et al., 2002.
Cevadine R (*Veratridine* R)	*Schoenocaulon officinale* (Schltdl. and Cham.) A. Gray ex Benth - sabadilla.	Stinks, leafhoppers, caterpillars; housefly and thrips (*Scirtothrips spp.*)	Shivanandappa and Rajashekar, 2014;Copping and Duke, 2007; Hare and Morse, 1997; Ujváry, 2010.
Thymol	*Thymus vulgaris L.* (Lamiaceae)	Colorado potato beetle (*Leptinotarsa decemlineata*);Aphids (*Myzus persicae, Diuraphis noxia, Rhopalosiphum padi, Metopolophium dirhodum, Sitobiona venae*)	González-Coloma et al., 2002.
Linamarin	*Lotus corniculatus L.* (Fabaceae); *Trifolium repens L.* (Fabaceae)	Snails (*Arianta arbustorum L.* and *Helix aspersa O.F. Müller;* slugs (*Agriolimax reticulates O.F. Müller*); lemmings (*Lemmus lemmus L.*); aphids (*Aphis craecivora Koch, Nearctaphis bakeri Cowen ex Gillette and Baker*)	Nahrstedt, 1985.
Thujone	*Artemisia absinthium* L.;*Juniperus sp.*; *Cedrus sp*	Western corn rootworm larvae (*Diabrotica virgifera*); Fruit fly (*Drosophila melanogaster Meigen*)	Höld et al., 2000
(−)-homopterocarpin	*Pterocarpus macrocarpus Kurz* (Fabaceae)	Common cutworm *(Spodoptera litura F.)* and the subterranean termite *(Reticulitermes speratus)*	Morimoto et al., 2006.

Compound/Product name	Plant species	Target species	References
Asimicin	*Asimina triloba (L.) Dunal (Annonaceae)*	Mexican bean beetle (*Epilachna varivestis Mulsant*); striped cucumber beetle (*AcalymmabivittatumFabricius*); two-spotted spider mite (*Tetranychus urticae Koch*); melon aphid (*Aphis gossyphii Glover*) Blowfly larvae (*Calliphora vicina Robineau-Desvoidy*); mosquito larvae (*Aedes aegypti*) Nematode *Caenorhabditis elegans* (Maupas)	Ratnayake et al., 1993; Alkofahi et al., 1989.
(E)-β-caryophyllen	*Zea mays L.*	Nematodes (*Heterorhabditis megidis Poinar, Jackson and Klein*), natural enemy/parasite of corn root worm (*Diabrotica virgifera Leconte*)	Degenhardt et al.,2009
Terthiophene	*Tagetes minuta L.* (Asteraceae)	Tobacco hornworm (*Manduca sexta*); Lepidopteran (*Pieris rapae L.*); housefly (*Musca domestica*); Red flower beetle (*Tribolium casteneum Herbst*); mosquito larvae (*Aedes atropalpus*, *Aedes aegypti* and Aedes intrudens)	Nivsarkar et al., 2001
3-methyl-3-phenyl-1,4pentadiyne	*Artemisia monosperma Delile* (Asteraceae)	Housefly (*Musca domestica*) and Cotton Leaf worm (*Spodoptera littoralis Boisduval*)	Marchant and Cooper, 1987
Insecticides and fungicides			
Nicotine	*Nicotiana tabacum Velloso*	Aphids; thrips; mites; leaf hoppers; spider mites; fungus	Rattan, 2010
Azadirachtin	*Azadirachta indica A. Juss. (Meliaceae)*	Dandruffs eczema; stored grain pests; aphids; caterpillars; thrips; mealy bugs	Okwute, 2012;Copping and Duke, 2007; Mordue and Nisbet, 2000; Qiao et al., 2014; Mordue and Blackwell, 1993; Morgan, 2009
Decaleside II	*Decalepis hamiltonii Wight* & Arn	stored-product pests such as*Rhyzopertha dominica*, *Sitophilus oryzae*, *Tribolium castaneum* and *Callosobruchus chinensis.*	Rajashekar and Shivanandappa, 2014

Compound/Product name	Plant species	Target species	References
α -amyrin acetate Oleanolic acid	*Catharanthus roseus (L.) G. Don (Apocynaceae)*	cotton bollworm *Helicoverpa armigera Hübner*	Singh et al., 2003
Insecticides and herbicides			
Eugenol	*Syzygium aromaticum (L.) Merr.* and *L.M. Perry*	Insecticidal Repellent – Blood-sucking bug *Triatoma infestans* (Klug); fruit fly (*Drosophila melanogaster* (Meigen); American cockroach (*Periplaneta itrates*).Herbicidal – *Cassia occidentalis* and *Biden spilosa*	Kostyukovsky et al., 2002; Reynoso et al., 2019; Enan, 2005; Ismail et al., 2013
Fungicides			
Phaseollin Phaseollidin	*Zea mays L.*	*Botrytis cinerea* Pers.; *Colletotrichum lindemuthianum* (Sacc. and Magnus) Briosi and Cavara,; *Fusarium solani Mart.*; *Rhizoctonia solani J. G. Kühn* and *Thielaviopsis basicola* (*Berk.* and *Broome*) *Ferraris*	Jiménez-González, 2008; Soby et al., 1996
Medicarpin	*Medicago sativa L.* (Fabaceae)	*Colletotrichum phomoide* (Sacc.) Chester; *Stemphylium loti J.H. Graham*; *Stemphylium botryosum Walroth*; *Phoma herbarum Westendorp*; *Leptosphaeria briossiana* (Higgings) and *Cladosporium cladosporoides* (Fresen.) G.A. de Vries	Jiménez-González, 2008; Soby et al., 1996.
2H-chromen-2-one	*Lavandula angustifolia Mill.* (Lamiaceae)	*Ralstonia solanacearum Smith*	Chen et al., 2016
Herbicides			
5,6-dihydroxycadinan-3-ene-2,7-dione 5,6-dihydroxycadinan-3-ene-2,7dione	*Eupatorium adenophorum Spreng* (Asteraceae)	*Arabidopsis thaliana (L.) Heynh*	Zhao et al., 2009
m-Tyrosine	*Poaceae spp.*	Weeds	Bertin et al., 2007
Tryptophan	*Prosopis juliflora (Sw.)* (Fabaceae)	Barnyard grass *(Echinochloa crus-galli L.)*	Nakano et al, 2003

Compound/Product name	Plant species	Target species	References
(−)-Catechin	*Centaurea stoebe L.* (Asteraceae)	*Koeleria macrantha* (Ledeb.) Schult., and *Festuca idahoensis Elmer*	Duke et al., 2009
Citronellol, Citronellol	*Cymbopogon itrates (DC.) Stapf* (Poaceae)	*Cassia occidentalis L.*	Ismail et al., 2013
(E,E)-2,4-undecadien-8,10-diynoic acid (E,E)-2,4-undecadien-8,10diynoic acid isobutylamide	*Acmella oleracea (L.) R. K. Jansen* (Asteraceae)	Cress *(Lepidum sativum L.)* and barnyard grass *(Echinochloa crus-galli (L.) P. Beauv)*	Kato-Noguchi et al, 2019
Nona-(2Z)-en-6,8-diynoic acid 2-phenylethylamide	*Acmella oleracea (L.) R. K. Jansen (Asteraceae*	Cress *(Lepidum sativum)* and barnyard grass *(Echinochloa crus-galli)*	Kato-Noguchi et al, 2019
2H-chromen-2-one	*Juglans nigra L. (Juglandaceae)*	*Echinochloa crus-galli L.; Amaranthus retroflexus L.; Abutilon theophrasti Medik*	Curto, 2008; Narwal, 2000
Insecticidal, antiviral, antifungal, herbicidal effect			
Resveratrol	*Polygonum cuspidatum* Siebold and Zucc. *(Polygonaceae)*	Insecticidal - Oriental armyworm (Mythimna separata Walker*);* Cotton bollworm *(Helicoverpa armigera);* Corn borer *(Ostrinia nubilalis Hubner);*Anti-viral - Tobacco Mosaic Virus (TMV) Antifungal - *Alternaria solani; Botrytis cinerea; Fusarium graminearum Schwabe; Phytophthora capsici Leonian; Phytophthora infestans (Mont.) de Bary; Rhizoctonia solani J.G. Kühn; Sclerotinia sclerotiorum (Lib.) (Y. Nisik. and C. Miyake) Shoemaker, Rhizoctonia cerealis D. I. Murray* and *Burpee; Watermelon anthracnose* Herbicidal - *Digitaria sanguinalis (L.) Scop.; Echinochloa crus-galli*	Yang et al., 2019

3.4.2 Minerals

Zhelyu Avramov

The use of natural substances as non-chemical approaches for pest control and management is a major challenge posed by the new ecological trends in plant protection activities. Despite the fact that the application of these substances is difficult to implement in intensive agriculture, they find and gain good usability in urban agriculture. In the following pages I will introduce you to the nature of minerals, Baking soda, Copper, Diatomaceous earth, Herbaceous oil, Soap spray and Flour spray and give examples of their application. Everything around you is formed from chemical elements, or substances made up of only one kind of atom. There are 118 identified elements, of which 94 are natural and the rest are human-made. Most of these elements are found combined with other elements as chemical compounds.

Minerals are naturally occurring elements or compounds. Most are inorganic solids (apart from liquid mercury and a few organic minerals) and defined by their chemical composition and crystal structure. By weight, 99.5 per cent of minerals are formed from only 12 of the natural elements. Clearly, some elements are far more common than others. The same goes for minerals. Of the 5800 or so known minerals, only 10 make up 95 per cent of the Earth's crust.

Sources of Plant Mineral Nutrients

Nutrient	Source
Nitrogen	Haber/Bosch process
Potassium	Mining (Potash, Orthoclase feldspar)
Phosphorus	Mining (Rock phosphate)
Calcium	Mining (Lime) (CaCO3)
Magnesium	Mining (Dolomitic Lime)
Sulphur	Cleaning of fossil fuel(Removal of S)
Zinc	Mining
Boron	Mining (Colemanite, tincal, kernite)
Molybdenum	Mining (Molybdenite)(sodium molybdate)
Manganese	Mining
Copper	Mining
Iron	Mining

http://www.nstf.org.za/wp-content/uploads/2019/02/19IYPT_DAFF_HarryDube.pdf

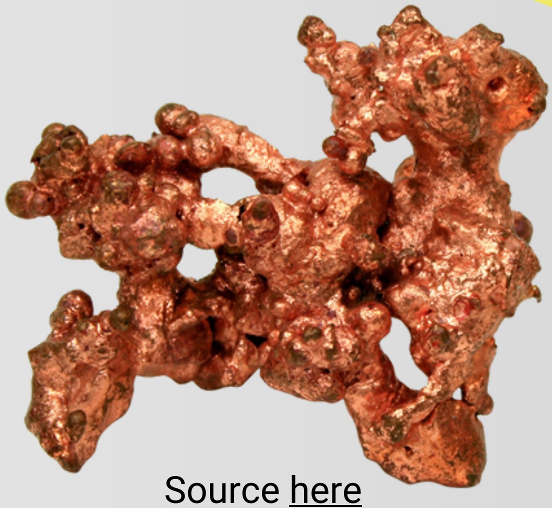
Some minerals are only made up of one element – we call these minerals “native elements”. They include metals, gemstones, simple ores and the only liquid metal mineral, mercury. Some, like gold, only combine with a small number of other elements. Others, like Sulphur, can combine readily with other elements, but also form alone under special chemical conditions. Some metallic elements mix easily with each other and are called alloys. An example of a natural alloy is osmiridium, which is made of two rare elements osmium and iridium. Usually, these minerals are mined as a type of fossil with various sources

There are two groups of native elements - Macro nutrients: Three primary and Three secondary (Nitrogen, Phosphorus, Potassium & Calcium, Magnesium, Sulphur) and Micronutrients: chlorine, boron, manganese, iron, copper, Zinc, Molybdenum cobalt, nickel. In an agriculture aria the good and productive soils maintain a healthy balance of these nutrients together with soil biota and organic matter.
Some minerals and their uses – Talc is used in powder and make-up; Gypsium is used in drywall or sheetrock; Fluorite is used in toothpaste; Quartz (find in sand) is used in making glass; Halite is used to deice roads, and to season/preserve food; Calcite is used in tums to help acid indigestion in cement; Copper is used in electrical wiring, jewelry, coins and agriculture like goods for plant protection.

The implementarry of these minerals are strictly coordinate in EU legislations for use for fertilization in Common agriculture policy (CAP). Protecting natural resources - soil, water and air are essential to the functioning of agriculture and forestry. The common agricultural policy ensures that these natural resources are managed responsibly across the EU.

COPPER = 29Cu

Copper is a chemical element with the symbol Cu (from Latin: cuprum) and atomic number 29. Copper is one of the few metals that can occur in nature in a directly usable metallic form (native metals). Copper compounds are used as bacteriostatic agents, fungicides, and wood preservatives. It is used against fungi of Oomycetes, some Ascomycetes (not Powdery Mildew), Basidiomycetes (not loos smoot, Ustilaginales), Deuteromycetes and has a bactericide effect. Cu2+ lyses the cell wall, denatures enzymes and proteins, and leaks the cytoplasm, turning the cell into a structureless mass. The production of copper-based Plant Protection Products: Bordeaux Mixture, Copper hydroxide; Copper oxychloride; Copper oxide; Tribasic copper sulphate.


Source here

Bordeaux Mixture

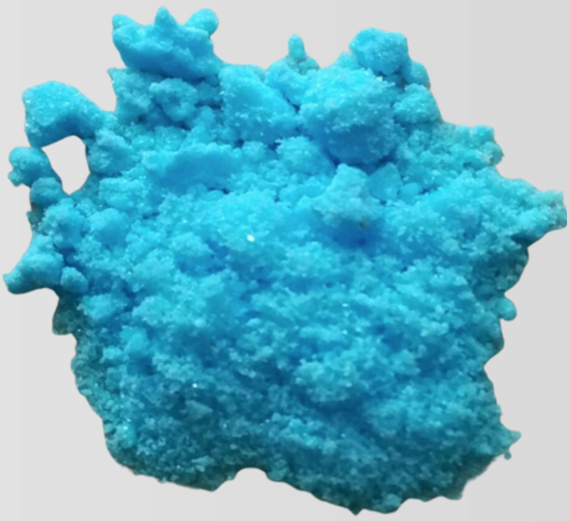
Contains Copper ≥ 245 g/kg Purity.

Against fungus and bacterial pathogens – $CuSO_4 4Cu(HCo_3)2.Ca(HCO_3)2$

On grapevine and fruit trees – 0,5 – 1 %;

On tomatoes, potatoes, pee, beens – 0,6 – 0,75 %;

On the plants out of vegetation – 2 %.


Source here

Copper hydroxide

≥ 573 g/kg Purity

Against Pseudomonas, Xanthomonas on tomatoes – 0,3 %;

Pythium, Phytophthora and Oidium - 0,15 %,

1,5 kg/ha in tobacco and potato

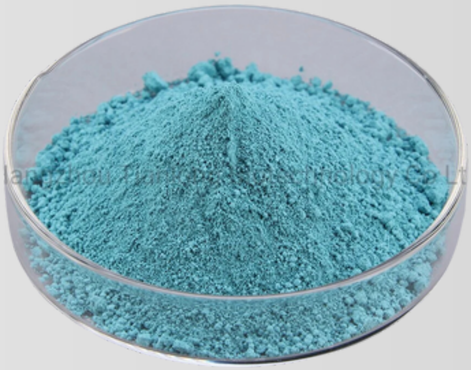
Copper oxychloride - $CuCl_2 .3Cu(OH)2.H_2O$

≥ 550 g/kg Purity

For crops with phytotoxic reaction against Bordeaux mix

With small reaction against bacterial infection

On grapevine, potato, tomato – 2,5 kg/ha



Source here

Tribasic copper sulphate

≥ 490 g/kg Purity

Venturia, Peronospora, Phytophthora and Pseudomonas – 0,3 %

Possibility leaves fertilization

Copper oxide

≥ 820 g/kg -

This component is used to made ship bottom anti-fouling paint (to kill the lower marine planta and animals); it shows excellent effects to inhibit and kill the Myxobacteria, algae, Shelled creatures, waterweeds and other common microbes in water. It is a main raw material to produce bactericide in farm chemical industry.

The currently limited used COPPER by the European plant-protection legislation to a maximum of 28 kg per ha over a period of 7 years (status 2021) (regulation (EU) 2018/1981.

According the requirements all products have to be corresponding before the approvement to Regalements of European Commission. Commission Implementig Regulation (EU) 2018/1981 of 13 December 2018 Renewing the Approval of the Active Substances Copper Compounds, as Candidates for Substitution, in Accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council Concerning the Placing of Plant Protection Products on the Market, and Amending the Annex to Commission Implementing Regulation (EU) No 540/2011. 2018. Available online: http://data.europa.eu/eli/reg_impl/2018/1981/oj.

Baking SODA

Sodium bicarbonate (IUPAC name: sodium hydrogencarbonate, 2017), commonly known as baking soda or bicarbonate of soda, is a chemical compound with the formula $NaHCO_3$. It is a salt composed of a sodium cation (Na^+) and a bicarbonate anion (HCO_3^-). Sodium bicarbonate is a white solid that is crystalline, but often appears as a fine powder. It has a slightly salty, alkaline taste resembling that of washing soda (sodium carbonate). The natural mineral form is nahcolite. It is a component of the mineral natron and is found

According the requirements all products have to be correspondissolved in many mineral springs (Mineral springs, 2010).

Source here

Baking soda is the common name for sodium bicarbonate, an ingredient that got its start 4 million years ago when salt lakes around the world evaporated and formed trona deposits. Trona is the rock that's processed into soda ash (sodium carbonate), a naturally occurring mineral. Soda ash can then also be processed to make baking soda. The world's largest deposit of trona is in Wyoming. The area produced more than 17 million tons of the mineral in 2018, for export around the world. (Wyoming Mining Association, 2017).

Pesticide remover for fruit and veggies. Many people are concerned about pesticide residue on foods. Pesticides are used to protect crops from insects, germs, rodents, and weeds, but many have harmful effects on human health. Peeling fruit is the best way to remove pesticides. However, it also means you don't get the important nutrients, such as fiber, vitamins, and minerals, found in the skins of many fruits. Interestingly, recent research indicates that a baking soda wash is the most effective way to remove pesticides from fruits and veggies without peeling them. The soaking apples in a solution of baking soda and water for 12–15 minutes eliminated most part of the pesticide residue.

Homemade weed killer. Weeds often have deep roots, making them hard to eradicate without using chemical weed killers. Notably, baking soda makes a cheaper, safer alternative. That's because baking soda is high in sodium, which creates a harsh environment for weeds. Sprinkle a few handfuls of baking soda over weeds in areas like the cracks of your sidewalk or driveway. However, avoid using baking soda to kill weeds in your flowerbeds and gardens, as it may harm your other plants as well.

Natural pest product. Encourage to use flower bloom cleaner with soda backing against fungal spores and spots. Put 15 grams soda in 1liter water. Mix well and treat this on your plants with buds or unopened flowers. It will use to clean the leaves to removing the dust and dirt encourage better photosynthesis and helps in better growth of plants. The best application of the soda in the gardens is like universal fungicide and pesticide. If you prepare this pesticide it is possible to treat almost all types of pests in your gardens like the aphids, mealybugs, trips, mites, wither flies, worms, caterpillars, leaf miners, soil fungus, plant fungi like powdery mildew, black spot rose diseases, leaf rust and many more. To prepare it is necessary to use container with 1 liter of water, 15 grams of backing soda, or 20 grams if you feel the pest attack is too big. Add 5-6 milliliters of Neem oil or other like olive oil, but have to know that the Neem oil is the best to preparing of universal pesticides solution. Other components to add is Clove oil or Eucalyptus oil in volume of 5-6 milliliters to make it potent. And the final add 2 milliliters of liquid soap. Mix well and spread like a fog infected plant.

Before the start treatment on your plant, please if it is possible to perform a patch test on a leave it for 1 – 2 hours to see potency and phytotoxic reaction of the plant species. If the leaves wilts or stunt, you need to dilute it further or stop treatment on this species.

To eliminate Slugs and Snails. There are two ways to use backing soda for this purpose. Firstly Sprinkle backing soda directly on slugs and snails to kill them; this might look cruel for some people troth. The second method is to draw a boundary around the pots to prevent slugs and snail. The second method is to draw a boundary around the pots to prevent slugs and snails invasation.

Cleaning you garden stuff. Prepare the solution including 12 grams soda and equal quantity liquid soap per liter water to clean dirty pots, garden tools and even garden furniture with this solution. This is important activity to stop speading of pests from plant to plants and from garden to garden.

Soil hack pH. If you do not have a electronic pH meter, you can roughly check whether you soil pH is alkaline or acidic. You will need soda and vinegar to perform tis test. Collect samples of your garden in small containers from different areas in your garden, and take 100 grams of soda and 100 milliliters vinegar. This is simple school chemistry – Acid pH is below 7, alkaline pH is above 7 and 7 is neutral pH reaction. When you put vinegar into the soil sample and if the soil begins to bubble it is alkaline, meaning the pH rate is above 7. And after you have to mix soil with soda and water. If the soil bubbles, it means the pH level is bellow 7, and it is acidic soil.

Kaolin spray

Rocks that are rich in kaolinite, and halloysite, are known as kaolin or china clay (Pohl, 2011). Kaolin spray is a pest control that has kaolin as the main ingredient. Kaolin spray is a pest control that has kaolin as the main ingredient. The practice has been in recorded use from 2000 B.C.E. in China. More recent studies have shown that kaolin sprays can promote photosynthesis and are effective in reducing insects and disease on plants. Kaolin sprays are used for pest control and sunburn protection in both conventional and organic food production in all over the world. More recently, kaolin mixed with spreaders and stickers and applied to plants as a spray at 1–6% concentration in water form has been shown to be an effective approach to agricultural pest control and to protect plants from environmental stresses. Kaolin-based sprays have been studied extensively since 1999 and research has established that these sprays deposit a "particle film" that has numerous beneficial effects on plants and in insect pest control. The kaolin barrier created by the particle film also protects the treated plant surfaces from diseases (Glenn et al., 2001) and insects (Puterka and Glenn, 2008). Studies show that kaolin clay is usually preventive good against pathogens and is most effective against following insects and others: Apple maggot, Colorado potato beetles, Cucumber beetles, Grasshoppers, Leafrollers, Mites, Moths, Thrips, Psylla, Flea beetles, Japanese beetles, Stink bugs.

How to Prepare and Use the Kaolin Spray

To prepare and use a kaolin spray, you have to mix all the substances thoroughly and apply them with a sprayer so that the mixture can be spread evenly on the whole parts of your plants. This spray should be applied like preventive measure before the pests come and can be used until it is time to harvest. The yields have also to be washed before being consumed. The following methods may help you mix kaolin and other substances to form a natural pesticide: Mix 1 liter of kaolin clay and 15 ml of liquid soap with 7.5 liter of water. Apply the mixture on your plants every 7 – 21 days for four weeks at the least. The spray should effectively work out after

3 applications if the mixture has been made in the same doses. The treatment will also prevent damaging birds from coming for bugs as their food. (YUKAMI, 2021).

Diatomaceous earth

This product known as Diatomite contains 100% natural, diatomaceous earth is formed by the superposition of the deposits of ancient crustacean shells. Consistency of powder, extremely finely processed and soft to the touch. With white, gray, pink color.

Depending on the granularity, this powder can have an abrasive feel, similar to pumice powder, and has a low density as a result of its high porosity. The typical chemical composition of oven-dried diatomaceous earth is 80–90% silica, with 2–4% alumina (attributed mostly to clay minerals), and 0.5–2% iron oxide. (Antonides, 1997).

Antiparasitic effect of diatomaceous earth is to use to rub into the fur of pets, as well as against parasites in the home, apartment, house or yard /ants, cockroaches, fleas, bedbugs/ by pouring and direct powdering around the places where insects pass.

The EC implements legislation for use this product have to fully complete requirements for chemical contains and size of mishearing (REGULATION (EU) 2020/2101). One of the very important use is to reduce pest control. According this legislation we have to implement this product with purity of 1 000 g/kg with minimum content of amorphous silica of 800 g/kg. The following impurity must not be exceeded in the technical material: Crystalline silica with particle size below 10 µm – maximum of 1 g/kg (REGULATION (EU) 2020/2101). Diatomite is valued as an insecticide due to its abrasive and physicsorbative properties (Fields et al., 2002). The fine powder adsorbs the lipids from the waxy outer layer of the exoskeletons of many insect species; this layer acts as a barrier that opposes the loss of water vapor from the insect's body.

Arthropods die as a result of a lack of water pressure, based on Fick's laws of diffusion. This also works against gastropods and is commonly used in gardening to defeat slugs. Diatomaceous earth is sometimes mixed with an attractant to increase its effectiveness. Some applications, such as that for snails and slugs, work best when a specially shaped diatomaceous earth like needles is used
Source: (https://www.youtube.com/watch?v=D5xMZGY3odA).

Please pay attention!!! NOTE

Dangerous for the lungs if inhaled!

Keep away from children!

Prolonged exposure to diatomaceous earth may cause itching of the skin.

Oils like pesticides

There are two groups of oils - mineral and plant oils. Mineral oil is any of various colorless, odorless, light mixtures of higher alkanes from a mineral source, particularly a distillate of petroleum (Mineral oil (Dictionary.com) Wayback Machine, 2023). Most often, mineral oil is a liquid by-product of refining crude oil to make gasoline and other petroleum products. This type of mineral oil is a transparent, colorless oil, composed mainly of alkanes (The EFSA Journal. 2004) and cycloalkanes, related to petroleum jelly. It has a density of around 0.8–0.87 g/cm3 (0.029–0.031 lb/cu in). It has a density of around 0.8–0.87 g/cm3 (0.029–0.031 lb/cu in) ("Mechanical properties of materials". Kaye and Laby Tables, 2008).

For Plant protection use is very difficult for a paraffin or petroleum jelly containing, and they have a possibility to accumulate in plant and goes to a phytotoxic reaction. Plant oils – this is our object for natural substances for pest management.

There are two groups triglycerides and essential oils. Triglycerides - esters of higher fatty and unsaturated acids with glycerin like Sunflower oil, castor oil, cottonseed oil, corn oil, rapeseed oil, olive oil, soybean oil, etc. The all fatty acids contain 6-carbon saturated C6 (caproic acid) to 12-carbon saturated C12 (lauric acid) are active against phytopathogens – in – Vanilla, Ginkgo, African oil palm, coconut milk, coconut oil laurel oil, West Indian bay tree, or ciliment est.

More than C12 is Myristic acid with 14 carbon atoms, Palmitic acid with 16 carbon atoms, and Stearic acid with 18 carbon atoms are against mites and insect population and littles be less to phytopathogens in Nutmeg, Iris, Olive, Soybean, Sunflower, Karukas, African shea tree est. Applies like dilution with concentration from 0,2 to 1 – 1.2 %. Products on the base of plant oil extraction - HELIOSOUFRE S ® much more than a Sulphur based fungicide. High-quality, easy-to-apply liquid – sulfur in combination with pine terpenes. NeemAzal®-T/S – Botanical Insecticide – Extract of tropical Neem (Azadirachta indica) used for control of thrips, white fly, aphid (also Nasinovia ribis nigri), caterpillar, scale insects, mealy bug.

Soaps as a substance against pests

Soaps – alkaline salts of higher fatty acids (oleic, stearic, palmitic, etc.). They are obtained by processing with potassium hydroxide, sodium hydroxide and carbonates on vegetable oils, animal fats or resins. In the Plant protection mainly uses potassium soap, known as "soft", containing 40% fatty acids, 0,1% free hydroxides, 2,5% free carbonates and about 0.5% insoluble components. Highly hygroscopic, alkaline colloidal solution with good wettability and low surface tension. As an insecticide, it is applied against aphids, trips, fly larvae, cicadas, fleas or storage insects up to 4% solution (HGIC 2771, 2021). As a fungicide used against Powdery mildews – 0,2% to 1%, Botrytis – 0,5 - 1%. Products - Bonide Insecticidal Soap RTU – 2 %; Garden Safe Insecticidal Soap Insect Killer RTU; Miracle-Gro Natures's Care Insecticidal Soap RTU; VerDeVivo - 60-80 ml/10l. Vitaterra – 0,2 %, BioFilm-K – 0,2 % and etc.

The main principles in preparing recipes for application of these substances

The all recipes have to contain the follows points: name or substance; method for use; the controlled pests; standard procedures for the preparation and application of homemade extracts, links and references. There are shown some examples for home use:

Flour spray

Flour, like soap, has been used as an old remedy for pest control. It has a sticky substance called 'dextrin', which is a sugar extracted from the plant starch by the action of heat. When applied as spray, dextrin adheres to the leaf surface and traps the pests until they die. It is important not to apply the filtrate during a cloudy day and/or when rain is expected.

Method (Stoll, 2000: p. 189) Add 2 cups of fine white flour into 5 -10 liters of water. Stir well. Apply on the infested plants early in the morning, during sunny weather. Pests controlled – Aphid, Spider mite

External links

Sierra Club of Canada. Pest control sprays you can make in your kitchen. http://www.sierraclub.ca/national/programs/health-environment/pesticides/non-commercial-pest-spray.pdf

Standard procedures for the preparation and application of homemade extracts Use utensils for the extract preparation that are not use for your food preparation and for drinking and cooking water containers. Clean properly all the utensils every time after using them.

Do not have a direct contact with the crude extract while in the process of the preparation and during the application. Make sure that you place the extract out of reach of children and house pets while leaving it overnight. Harvest all the mature and ripe fruits before extract application. Always test the extract formulation on a few infected plants first before going into large scale spraying. When adding soap as an emulsifier, use a potash-based one. Wear protective clothing while applying the extract. Wash your hands after handling the extract.

References

Stoll, G. (2000): Natural Crop Protection in the Tropics Margraf Verlag. Weikersheim.

Soaps use against pests

Soap spray - Soap has been used as an old remedy to control pests. Salts and fatty acids are found in many soaps which act as selective pesticides.

Method 1 Mix 8 ml of dishwashing soap with 4 liters of water (Schalau, 1999).

Method 2 Mix 16 ml mild detergent with 4 liters of water (Barrett, 2001).

How to use? Add soap to water. Use mild soap or potash-based soap. Start with a lower concentration and make adjustments of the strength after testing on few infested plants. Always try on few infested plants before going into full scale spraying. Soaps can cause burnt leaves on sensitive plants, like cole crops and certain ornamentals.

Several applications in short periods can aggravate drying of leaves. Apply on the infested plants thoroughly, including the undersides of the leaves. Spray early in the morning or late afternoon.

Pests controlled – Ants, Aphid, Fruit fly, Leafhoppers, Mealybug, Psyllids, Scales, Spider mite, Thrips, Whitefly, Black spot, Canker, Leaf spot, Powdery mildew, Rust

Standard procedures for the preparation and application of homemade extracts

Use utensils for the extract preparation that are not use for your food preparation and for drinking and cooking water containers. Clean properly all the utensils every time after using them. Do not have a direct contact with the crude extract while in the process of the preparation and during the application. Wash your hands after handling the extract.

Baking soda (Sodium bicarbonate) Home made fungicide

Baking soda is a white soluble compound that has fungicidal properties when used as spray on diseased plants. It also serves as protectant (on plants) from disease-causing pathogens.

Method - Mix 10 gr of baking soda and 15 ml of dormant oil or vegetable oil; Add 4 liters of water; Stir well; Add 6 ml of dish washing liquid soap; Stir it again.

Pest controlled - Powdery mildew; Black spot and other fungal diseases

How to apply?

1.Fill-in water can or sprinkler. Stir or shake the container from time to time to prevent soda from separating.

2. Repeat application every after 2 weeks.

3. Apply baking soda spray as soon as the symptoms appear. Be sure to include the undersides of the plants' foliage.

Standard procedures for the preparation and application of homemade extracts

1. Spray in the early morning or late afternoon.
2. Use utensils for the extract preparation that are not use for your food preparation and for drinking and cooking water containers. Clean properly all the utensils every time after using them.
3. Do not have a direct contact with the crude extract while in the process of the preparation and during the application.
4. Make sure that you place the extract out of reach of children and house pets while leaving it overnight.
5. Harvest all the mature and ripe fruits before extract application.
6. Always test the extract formulation on a few infected plants first before going into large scale spraying. When adding soap as an emulsifier, use a potash-based one.
7. Wear protective clothing while applying the extract.
8. Wash your hands after handling the extract.

Links: Several applications in short periods can aggravate drying of leaves. Apply on the infested plants thoroughly, including the undersides of the leaves. Spray early in the morning or late afternoon.
Pests controlled – Ants, Aphid, Fruit fly, Leafhoppers, Mealybug, Psyllids, Scales, Spider mite, Thrips, Whitefly, Black spot, Canker, Leaf spot, Powdery mildew, Rust
Standard procedures for the preparation and application of homemade extracts

Bordeaux mix - Home made fungicide

Materials needed to make a 4 L mixture: 40 gr of copper sulphate; 30 gr of hydrated lime; 4 liters of water; Wooden stick and Plastic bucket.

How to prepare?

Add copper sulphate and hydrated lime in water. Make sure to use plastic container. Stir well using a wooden sick or ladle. Protect self from direct contact with the solution.

How to use?

Spray plants thoroughly preferably early in the morning, in a dry and sunny day. In this way, the plants have the time to dry and the solution cannot penetrate into the leaves' tissues;
Constantly shake the sprayer while in the process of application to prevent the solution from clogging.
Pest controlled - Flea beetles on tomatoes and potatoes, Anthracnose, Bacterial blight, Bacterial wilt, Black spot, Downy mildew, Late blight on solanaceous crops, Powdery mildew, Rust and many other disease causing pathogens.

Standard procedures for the preparation and application of homemade extracts. Read and follow the label instructions carefully.

Monitor plants regularly and spray only when necessary as copper can accumulate into the soil. Spray in the early morning or late afternoon.Use utensils for the extract preparation that are not use for your food preparation and for drinking and cooking water containers. Clean properly all the utensils every time after using them. Do not have a direct contact with the crude extract while in the process of the preparation and during the application. Make sure that you place the extract out of reach of children and house pets while leaving it overnight.

Harvest all the mature and ripe fruits before extract application. Always test the extract formulation on a few infected plants first before going into large scale spraying. When adding soap as an emulsifier, use a potash-based one.
Wear protective clothing while applying the extract.
Wash your hands after handling the extract. Fill-in water can or sprinkler. Stir or shake the container from.

Links: http://www.oisat.org/

REFERENCES

Alkofahi, A.; Rupprecht, J.K.; Anderson, J.E.; McLaughlin, J.L.; Mikolajczak, K.L.; Scott, B.A. Search for New Pesticides from Higher Plants. In Insecticides of Plant Origin; Arnason, J.T., Philogene, B.J., Morand, P., Eds.; Books on Demand: Norderstedt, Germany, 1989; Volume 387, pp. 25–43.

Baker B. P., J.A. Grant, R. Malakar-Kuenen, 2018. Citronella & Citronella Oil Profile Active Ingredient Eligible for Minimum Risk Pesticide Use. Publisher New York State IPM Program

Balandrin M. F., J. A. Klocke, E. S. Wurtele, W. H. Bollinger, 1985. Natural plant chemicals: Sources of industrial and medicinal materials. Science, 7; 228 (4704), 1154–1160. https://doi.org/10.1126/science.3890182

Batish, D.R.; Singh, H.P.; Setia, N.; Kohli, R.K.; Kaur, S.; Yadav, S.S. Alternative control of littleseed canary grass using eucalypt oil. Agron. Sustain. Dev. 2007, 27, 171–177.

Bertin, C.; Weston, L.A.; Huang, T.; Jander, G.; Owens, T.; Meinwald, J.; Schroeder, F.C. Grass roots chemistry: Meta-Tyrosine, an herbicidal nonprotein amino acid. Proc. Natl. Acad. Sci. USA 2007, 104, 16964.

Bloomquist J. R. 1999. Insecticides: Chemistries and Characteristics. In Radcliffe's IPM World Textbook, 2nd ed.; University of Minesota: St. Paul, MI, USA.

Casida, J.; Quistad, G. Golden age of insecticide research: Past, present, or future? Annu. Rev. Entomol. 1998, 43, 1–16.

Chen, J.; Yu, Y.; Li, S.; Ding, W. 2016. Resveratrol and Coumarin: Novel Agricultural Antibacterial Agent against Ralstonia solanacearum In Vitro and In Vivo. Molecules, 21, 1501.

Copping, L.G.; Duke, S.O. Natural products that have been used commercially as crop protection agents. Pest Manag. Sci. 2007, 63, 524–554.

Curto, M.J.M. Ecologiaquímica: A comunicaçãoquímicananatureza. In Biossíntese de Produtos Naturais, 1st ed.; Lobo, A.M., Lourenço, A.M., Eds.; IST Press: Lisboa, Portugal, 2008; pp. 227–240.

Dean, R.; Van Kan, J.A.L.; Pretorius, Z.A.; Hammond-Kosack, K.E.; Di Pietro, A.; Spanu, P.D.; Rudd, J.J.; Dickman,M.; Kahmann,R.; Ellis,J.; et al. The Top10 fungal pathogens in molecular plant pathology: Top10 fungal pathogens. Mol. Plant Pathol. 2012, 13, 414–430.

Degenhardt, J.; Hiltpold, I.; Köllner, T.G.; Frey, M.; Gierl, A.; Gershenzon, J.; Hibbard, B.E.; Ellersieck, M.R.; Turlings, T.C.J. Restoring a maize root signal that attracts insect-killing nematodes to control a major pest. Proc. Natl. Acad. Sci. USA 2009, 106, 13213–13218.

Duke, S.; Blair, A.; Dayan, F.; Johnson, R.; Cook, D.; Bajsa-Hirschel, J. Is (−)-Catechin a Novel Weapon of Spotted Knapweed (Centaurea stoebe)? J. Chem. Ecol. 2009, 35, 141–153.

Eid, M.A.A.; Salem, M.S.; Taha, G.Z. Effects of precocene II on morphogenesis of the desert locust Schistocercagregaria. Biochem. Syst. Ecol. 1988, 16, 515–520.

Enan, E. Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils. Arch. Insect Biochem. Physiol. 2005, 59, 161–171.

Giménez-Santamarina S., Llorens-Molina J. A., Sempere-Ferre F., Santamarina C., Roselló J. & Santamarina M.P., 2022. Chemical composition of essential oils of thre Mentha species and their antifungal activity against selected phytopathogenic and post-harvest fungi, All Life, 15:1, 64-73, DOI: 10.1080/26895293.2021.2022007

Giner M., J. Avilla, M. Balcells, S. Caccia, G. Smagghe, 2012. Toxicity of allyl esters in insect cell lines and in Spodoptera littoralis larvae. Archives of Insect Biochemistry and Physiology, 79 (1), 18–30. https://doi.org/10.1002/arch.2012.79.issue-1

Goławska S., I. Łukasik, 2012. Antifeedant activity of luteolin and genistein against the pea aphid. Journal of Pest Science, 85, 443–450. https://doi.org/10.1007/s10340-012-0452-z

Goławska S., I. Sprawka, I. Łukasik, A. Goławski, 2014. Are naringenin and quercetin useful chemicals in pestmanagement strategies? Journal of Pest Science, 87, 173–180. https://doi.org/10.1007/s10340-013-0535-5

González-Coloma A.; Valencia, F.; Martín, N.; Hoffmann, J.J.; Hutter, L.; Marco, J.A.; Reina, M. Silphinene Sesquiterpenes as Model Insect Antifeedants. J. Chem. Ecol. 2002, 28, 117–129.

Gould K. S., C. Lister, 2006. Flavonoid functions in plants. In Flavonoids: Chemistry, biochemistry, and applications (pp. 397–443). Boca Raton, FL: CRC Press LLC.

Hare, J.; Morse,J. Toxicity, Persistence, and Potency of Sabadilla Alkaloid Formulations to Citrus Thrips(Thysanoptera: Thripidae). J. Econ. Entomol. 1997, 90, 326–332.

Hikal W. M., R. S. Baeshen, H. A. H. Said-Al Ahl, 2017. Botanical insecticide as simple extractives for pest control. Cogent Biology, 3:1, 1404274, DOI: 10.1080/23312025.2017.1404274

Höld, K.; Sirisoma, N.; Ikeda, T.; Narahashi, T.; Casida, J. α-Thujone (the active component of absinthe): γ—Aminobutyric acid type A receptor modulation and metabolic detoxification. Proc. Natl. Acad. Sci. USA 2000, 97, 3826–3831.

Ismail, A.; Hamrouni, L.; Hanana, M.; Jamoussi, B. Review on the phytotoxic effects of essential oils and their individual components: News approach for weed management. Int. J. Appl. Biol. Pharm. Technol. 2013, 4, 96–114.

Jiménez-González, L.; Álvarez-Corral, M.; Muñoz-Dorado, M.; Rodríguez-García, I. Pterocarpans: Interesting natural products with antifungal activity and other biological properties. Phytochem. Rev. 2008, 7, 125–154.

Kato-Noguchi, H.; Suwitchayanon, P.; Boonmee, S.; Iwasaki, A.; Suenaga, K. Plant Growth Inhibitory Activity of the Extracts of Acmella oleracea and its Growth Inhibitory Substances. Nat. Prod. Commun. 2019, 14, 1934578X19858805.

Khafagi, W. Effects of juvenile hormone I, precocene I and precocene II on the progeny of Microplitis rufiventris Kok. female when administered via its host, Spodoptera littoralis (Boisd.). J. Appl. Entomol. 2004, 128, 6–10.

Kordali, S.; Cakir, A.; Akcin, T.A.; Mete, E.; Akcin, A.; Aydin, T.; Kilic, H. Antifungal and herbicidal properties of essential oils and n-hexane extracts of Achillea gypsicola Hub-Mor. and Achillea biebersteinii Afan. (Asteraceae). Ind. Crop. Prod. 2009, 29, 562–570.

Kostyukovsky, M.; Rafaeli, A.; Gileadi, C.; Demchenko, N.; Shaaya, E. Activation of octopaminergic receptors by essential oil constituents isolated from aromatic plants: Possible mode of action against insect pests. Pest Manag. Sci. 2002, 58, 1101–1106.
Koul O. Plant biodiversity as a resource for natural products for insect pest management. In Gurr GM, Wratten SD, Snyder WE, Read, DMY. Biodiversity and Insect Pests: Key Issues for Sustainable Management. John Wiley & Sons Ltd., Sussex, UK, 2012, 85-105.
Lazar, E.E.; Jobling, J.J.; Benkeblia, N. Postharvest disease management of horticultural produce using essential oils: Today's prospects. Stewart Postharvest Rev. 2010, 6, 1–10.
Marchant, Y.Y.; Cooper, G.K. Structure and Function Relationships in Polyacetylene Photoactivity. In Light-Activated Pesticides; American Chemical Society: Washington, DC, USA, 1987; Volume 339, pp. 241–254.
Mordue, A.J.; Blackwell, A. Azadirachtin: An update. J. Insect Physiol. 1993, 39, 903–924.
Mordue, A.J.; Nisbet, A.J. Azadirachtin from the neem tree Azadirachtaindica: Its action against insects. An. Soc. DoBras. 2000, 29, 615–632.
Morgan, E.D. (2009) Azadiracthin, a scienctific gold mine. Bioorganic and Medicinal Chemistry, 17, 4096-4105. http://dx.doi.org/10.1016/j.bmc.2008.11.081.
Morimoto, M.; Fukumoto, H.; Hiratani, M.; Chavasiri, W.; Komai, K. Insect Antifeedants, Pterocarpans and Pterocarpol, in Heartwood of Pterocarpus macrocarpus Kruz. Biosci. Biotechnol. Biochem. 2006, 70, 1864–1868.
Nahrstedt, A. Cyanogenic compounds as protecting agent for organisms. Plant Syst. Evol. 1985, 150, 35–47.
Nakano, H.; Nakajima, E.; Fujii, Y.; Yamada, K.; Shigemori, H.; Hasegawa, K. Leaching of the allelopathic substance, -tryptophan from the foliage of mesquite (Prosopisjuliflora(Sw.) DC.) plants by water spraying. PlantGrowthRegul. 2003, 40, 49–52.
Narwal, S. Allelopathy in ecological agriculture. In Allelopathy in Ecological Agriculture and Forestry; Narwal, S.S., Hoagland, R.E., Dilday, R.H., Eds.; Kluwer Academic: Dharwad, India, 2000; pp. 11–32.
Nawaz M., J. I. Mabubu, H. Hua, 2016. Current status and advancement of biopesticides: Microbial and botanical pesticides. Journal of Entomology and Zoology Studies 4(2), 241-246
Nivsarkar, M.; Cherian, B.; Padh, H. Alpha-terthienyl: A plant-derived new generation insecticide. Curr. Sci. 2001, 81, 667–672.
Okwute S. K., Plants as Potential Sources of Pesticidal Agents: A Review. In Pesticides—Advances in Chemical and Botanical Pesticides, 1st ed.; eBook; Soundararajan, R.P., Ed.; IntechOpen: London, UK, 2012; pp. 207–232.
Ortiz de Elguea-Culebras, G.; Sánchez-Vioque, R.; Santana-Méridas, O.; Herraiz-Peñalver, D.; Carmona, M.; Berruga,M.I. In vitro antifungal activity of residues from essential oil industry against Penicillium verrucosum, a common contaminant of ripening cheeses. LWT Food Sci. Technol. 2016, 73, 226–232.
Park D. S., J. R. Coats, 2002. Cyanogenic glycosides: Alternative insecticides? The Korean Journal of Pesticide Science, 6 (2), 51–57.

Qiao, J.; Zou, X.; Lai, D.; Yan, Y.; Wang, Q.; Li, W.; Deng, S.; Xu, H.-H.; Gu, H. Azadirachtin blocks the calcium channel and modulates the cholinergic miniature synaptic current in the Central Nervous System of Drosophila. Pest Manag. Sci. 2014, 70, 1041–1047.
Rajashekar Y., N. Bakthavatsalam, T. Shivanandappa, 2012. Botanicals as grain protectants. Psyche, 2012, 1–13. doi:10.1155/2012/646740
Rajashekar, Y.; Raghavendra, A.; Bakthavatsalam, N. Acetylcholinesterase Inhibition by Biofumigant (Coumaran) from Leaves of Lantana camara in Stored Grain and Household Insect Pests. BioMed Res. 2014, 2014, 187019.
Rajashekar, Y.; Rao, L.; Shivanandappa, T. Decaleside: A new class of natural insecticide targeting tarsal gustatory sites. DieNat. 2012, 99, 843–852.
Ratnayake, S.; Rupprecht, K.; Potter, W.; McLaughlin, J. Evaluation of the Pawpaw Tree, Asimina triloba (Annonaceae), as a Commercial Source of the Pesticidal Annonaceous Acetogenins. In New Crops; Janick, J., Simon, J.E., Eds.; Wiley: New York, NY, USA, 1993; pp. 644–648.
Rattan R. S., 2010. Mechanism of action of insecticidal secondary metabolites of plant origin. Crop Protection, 29, 913–920. https://doi.org/10.1016/j.cropro.2010.05.008
Rattan R.S. Mechanism of action of insecticidal secondary metabolites of plant origin. Crop. Prot. 2010, 29, 913–920.
Reynoso, M.M.N.; Lucia, A.; Zerba, E.N.; Alzogaray, R.A. The Octopamine Receptor Is a Possible Target for Eugenol-Induced HyperactivityintheBlood-SuckingBugTriatomainfestans(Hemiptera: Reduviidae). J.Med. Entomol. 2019,57,627–630.
Saleem, M.A.; Wilkins, R.M. Precocene-1: An anti-juvenile hormone, a potential 4th generation insecticide against a malathionresistant strain of Oryzaephilus surinamensis (L.). Pak. J. Zool. 1984, 16, 195–201.
Santos P. C., V. H. M. Santos, G. F. Mecina, A. R. Andrade, P. A. Fegueiredo, V. M. O. Moraes, L. P. Silva, R. M. G. Silva, 2016. Insecticidal activity of Tagetes sp. on Sitophilus zeamais Mots. International Journal of Environmental & Agriculture Research, 2 (4), 31–38.
Schmidt S., C. Tomasi, E. Pasqualini, C. Ioriatti, 2008. The biological efficacy of pear ester on the activity of Granulosis virus for codling moth. Journal of Pest Science, 81, 29. https://doi.org/10.1007/s10340-007-0181-x
Shivanandappa, T.; Rajashekar, Y. Mode of Action of Plant-Derived Natural Insecticides. In Advances in Plant Biopesticides, 1st ed.; Singh, D., Ed.; Springer: New Delhi, India, 2014; pp. 323–345.
Simmonds M. S., 2003. Flavonoid–insect interactions: Recent advances in our knowledge. Phytochemistry, 64, 21–30. https://doi.org/10.1016/S0031-9422(03)00293-0
Simmonds M. S., P. C. Stevenson, 2001. Effects of isoflavonoids from cicer on larvae of Heliocoverpaarmigera. Journal of Chemical Ecology, 27, 965–977. https://doi.org/10.1023/A:1010339104206
Singh, D.; Agarwal, S.K. Himachalol and β-himachalene: Insecticidal principles of himalayan cedarwood oil. J.Chem. Ecol. 1988, 14, 1145–1151.

Singh, D.; Mehta, S.S.; Neoliya, N.K.; Shukla, Y.N.; Mishra, M. New possible insect growth regulators from Catharanthus roseus. Curr. Sci. 2003, 84, 1184–1186.
Singh, H.P.; Batish, D.R.; Setia, N.; Kohli, R.K. Herbicidal activity of volatile oils from Eucalyptusc itriodora against Parthenium hysterophorus. Ann. Appl. Biol. 2005, 146, 89–94.
Singh, S.; Kumar, K. Anti-JH compounds and Insect Pest Management. In Emerging TrendsinZoology; eBook; Srivastava, U.C., Ed.; Narendra Publishing House: Delhi, India, 2011; pp. 335–350.
Soby, S.; Caldera, S.; Bates, R.; VanEtten, H. Detoxification of the phytoalexins maackiain and medicarpin by fungal pathogens of alfalfa. Phytochemistry 1996, 41, 759–765.
Srivastva, S.; Kumar, K. Precocene I and II induced metamorphosis in a noctuid moth, Spodoptera litura Fabr. Proc. Natl. Acad. Sci. India 1997, 67, 213–226.
Tabassum, N. and Vidyasagar, G.M. Antifungal investigations on plant essential oils. A review. Int. J. Pharm. Pharm. Sci. 2013, 5, 10.
Tong, F.; Coats, J.R. Effects of monoterpenoid insecticides on [3H]-TBOB binding in house fly GABA receptor and 36Cl−uptake in American cockroach ventral nerve cord. Pestic. Biochem. Physiol. 2010, 98, 317–324.
Tooley, P. Crop Protection. In Food and Drugs; John Murray Albermark Street: London, UK, 1971.
Ujváry I., 2010. Pest Control Agents from Natural Products. In Hayes'Handbook of Pesticide Toxicology, 3rd ed.; Krieger R., Ed.; Academic Press: New York, NY, USA,; pp. 119–229.
Wimmer Z., A. J. F. D. M. Floro, M. Zarevúcka, M. Wimmerová, G.Sello, F.Orsini, 2007. Insect pest control agents: Novel chiral butanoate esters (juvenogens). Bioorganic & Medicinal Chemistry, 15 (18), 6037–6042. DOI: 10.1016/j.bmc.2007.06.043
Yang, W.; Li, F.; Xing, X.; Wang, Z.; Yu, X. Study in Pesticide Activities of Polygonum cuspidatum Extracts and its Active Ingredient Resveratrol. Nat. Prod. Commun. 2019, 14, 1934578X19861022.
Zagrobelny M., S. Bak, A. V. Rasmussen, B. Jørgensen, C. M. Naumann, B. L. Møller, 2004. Cyanogenic glucosides and plant-insect interactions. Phytochemistry, 65 (3), 293–306.
Zhao, X.; Zheng, G.W.; Niu, X.M.; Li, W.Q.; Wang, F.S.; Li, S.H. Terpenes from Eupatorium adenophorum and their allelopathic effects on Arabidopsis seeds germination (dagger). J. Agric. Food Chem. 2009, 57, 478–482.

"Mechanical properties of materials". Kaye and Laby Tables of Physical and Chemical Constants. National Physical Laboratory. Archived from the original on 11 March 2008. Retrieved 6 March 2008 (http://www.kayelaby.npl.co.uk/general_physics/2_2/2_2_1.html)

"Mineral Springs – an overview, ScienceDirect Topics", "Sodium Bicarbonate", (PDF). (https://web.archive.org/web/20110516015331/http://www.chem.unep.ch/irptc/sids/oecdsids/Sodium%20bicarbonate.pdf) (https://www.sciencedirect.com/topics/engineering/mineral-springs).

Anna LA TORRE, Valeria IOVINO and Federica CARADONIA (2018). Copper in plant protection, Phytopathologia Mediterranea, Vol. 57, 2, pp. 201-236. https://www.jstor.org/stable/26507086.

Antonides, Lloyd E. (1997). Diatomite (PDF). USGS. Retrieved December 12, 2010.

COMMISSION IMPLEMENTING REGULATION (EU) 2020/2101 of 15 December 2020 renewing the approval of the active substance kieselgur (diatomaceous earth) in accordance with Regulation (EC) No 1107/2009 of the European Parliament and of the Council concerning the placing of plant protection products on the market.

Curkovic T. S., (2016). Book: Detergents and Soaps as Tools for IPM in Agriculture. DOI: 10.5772/64343

Fields, Paul; Allen, Sylvia; Korunic, Zlatko; McLaughlin, Alan; Stathers, Tanya (2002). "Standardized testing for diatomaceous earth" (PDF). Proceedings of the Eighth International Working Conference of Stored-Product Protection. York, U.K.: Entomological Society of Manitoba.

HGIC 2771, Updated: Jul 30, 2021, INSECTICIDAL SOAPS FOR GARDEN PEST CONTROL, Factsheet, Printhttps://hgic.clemson.edu/factsheet/insecticidal-soaps-for-garden-pest-control/

http://www.oisat.org/control_methods/other_substances.html

Lucius Tamm, Barbara Thuerig, Stoilko Apostolov, H. Blogg, Esmeralda Borgo, Paola Elisa Corneo, Susanne Fittje, Michelangelo de Palma, Adam Donko, Catherine Experton, Évelyne Alcázar Marín, Ángela Morell Pérez, Ilaria Pertot, Anton Rasmussen, Håvard Steinshamn, Airi Vetemaa, Helga Willer, Joëlle Herforth-Rahmé, (2022). Use of Copper-Based Fungicides in Organic Agriculture in Twelve European Countries, Agronomy 2022, 12(3), 673, https://doi.org/10.3390/agronomy12030673 or https://www.mdpi.com/2073-4395/12/3/673.

Mineral oil (Dictionary.com) Archived 30 September 2015 at the Wayback. Machine"Definition of MINERAL OIL". merriam-webster.com. Retrieved 10 September 2018.

Nomenclature of Inorganic Chemistry IUPAC Recommendations (2005), IUPAC, p. 137, archived (PDF) from the original on 18 May 2017.

Reece, Jane; Campbell, Neil (2002). Biology. San Francisco: Benjamin Cummings. pp. 69–70. ISBN 978-0-8053-6624-2.

Richter Amy, Raman Ryan, Ajmera Rachael, (2023). 22 Benefits and Uses of Baking Soda, (https://www.healthline.com/nutrition/baking-soda-benefits-uses#household-uses)

The EFSA Journal. 2004. "Opinion of the Scientific Panel on Food Additives, Flavourings, Processing Aids and Materials in Contact with Food (AFC) on a request from the Commission related the use of mineral oils in jute and sisal bags" (PDF). Archived from the original (PDF) on 3 June 2018. http://www.efsa.europa.eu/sites/default/files/scientific_output/files/main_documents/162.pdf)

Wyoming Mining Association (2017). Wyoming Mining Association: Trona Mining Wyoming Mining Association. Retrieved on 2017-10-25.

Pohl WL (2011). Economic geology: principles and practice: metals, minerals, coal and hydrocarbons – introduction to formation and sustainable exploitation of mineral deposits. Chichester, West Sussex: Wiley-Blackwell. p. 331. ISBN 9781444336627.

Glenn, D. M., van der Zwet, T., Puterka, G., Gundrum, P., Brown. E. (2001). Efficacy of kaolin-based particle films to control apple diseases. Plant Health Progress doi: 10.1094/PHP-2001-0823-01RS. 2001.

Puterka, G. J., and D. M. Glenn. (2008). Kaolin-Based Particle Films for Arthropod Control. pp. 2075-2080, In (J. L. Capinera, ed.) Encyclopedia of Entomology, Kluwer Academic Publishers.

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Figure 1. A) Gray garden slug, B) Marsh slug, C) Slug eggs in corn residue. Photos by Maria Cramer

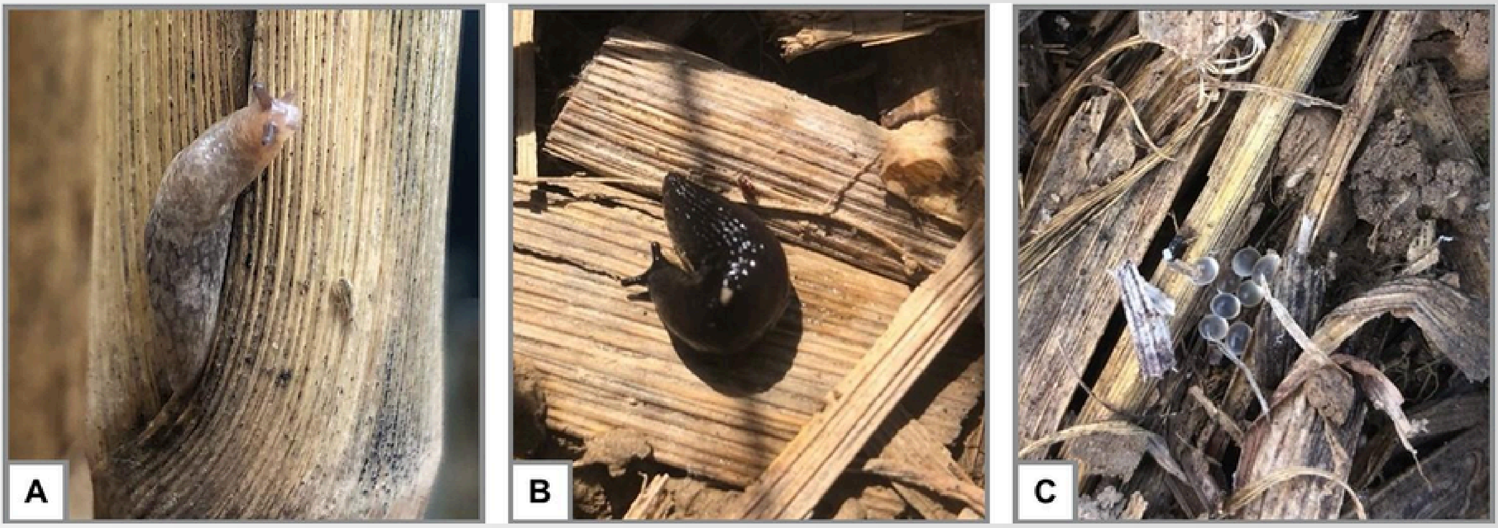
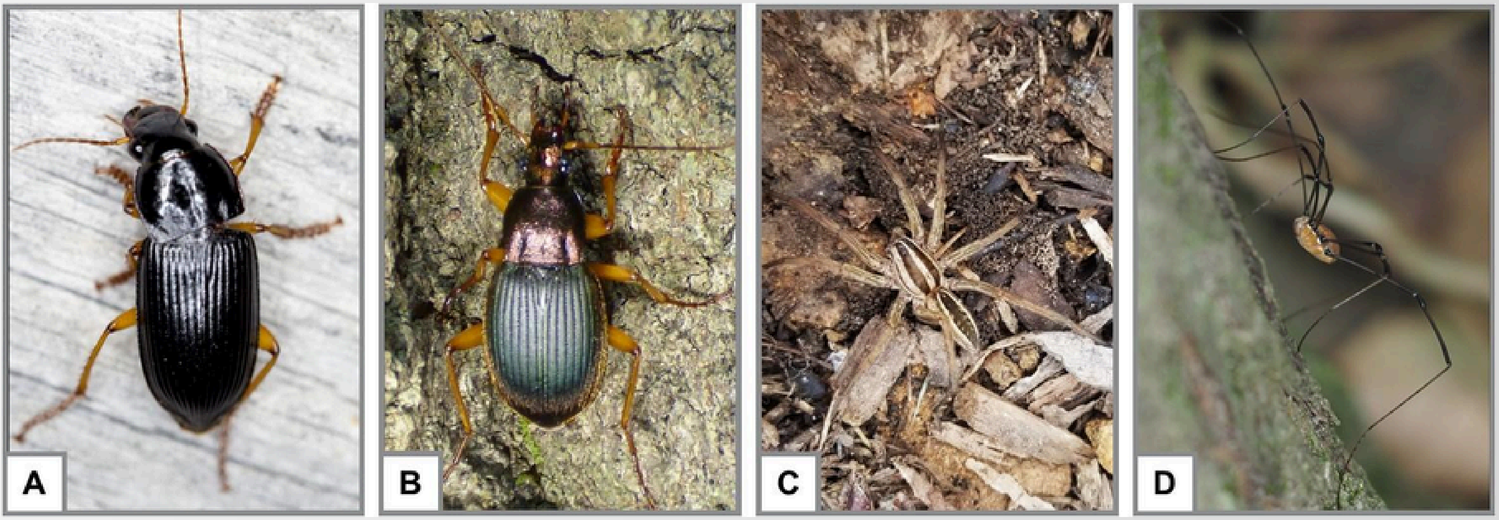


Figure 2. A) and B) Predatory ground beetles, C) Wolf spider, D) Harvestman, or daddy long legs. Photos by iNaturalist CCO



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