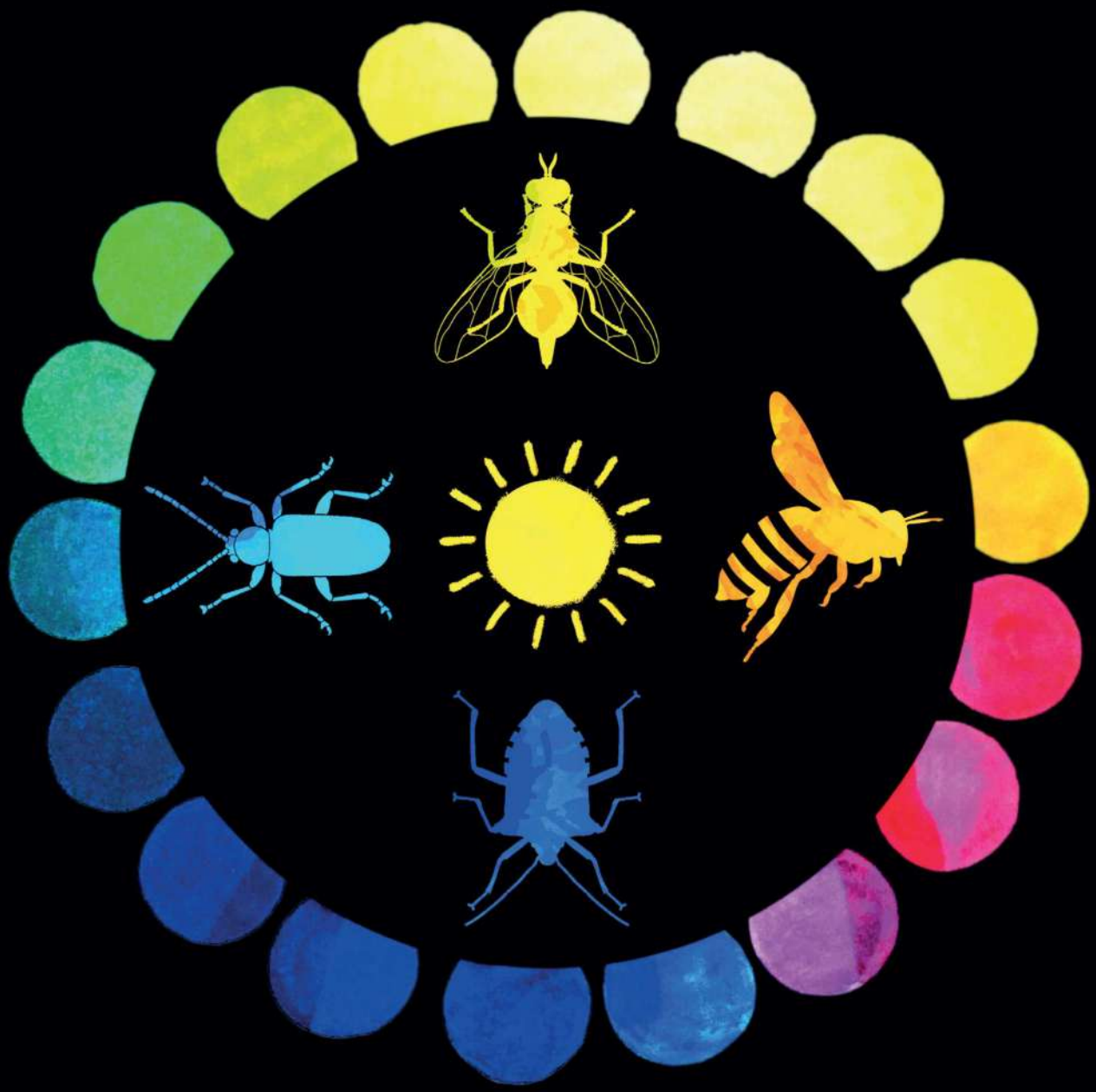
# Optical Manipulation of Arthropod Pests and Beneficials

Edited by **David Ben-Yakir**



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# Optical Manipulation of Arthropod Pests and Beneficials

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Arthropods as pests in crops, vectors of diseases, pollinators, and natural enemies of pests are of huge economic importance. They affect livestock, human health and food supplies around the world. This unique book examines and reviews how light and colour can be used to enhance pest management in agricultural and medical applications by manipulating the optical responses of arthropods.

Arthropods use optical cues to find food, oviposition sites and to navigate. Light also regulates their diurnal and seasonal activities. Plants use optical cues to attract or deter various species of arthropod. In this book, an international team of experts show how light can be used successfully to attract, arrest, confuse and deter arthropods as well as to disrupt their biological clocks. The book:

- Presents an up-to-date and thorough summary of what is known about how arthropods of agricultural and medical importance respond to visual cues.
- Describes techniques that use light to manipulate pests and beneficial insects and mites.
- Presents a broad discussion of the potential use of optical manipulation of arthropods to improve the health of plants, domestic animals and humans.

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# 1 Introduction and Summaries of Chapters

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## 1.1 Introduction

The phylum Arthropoda contains about 84% of all known species in the animal kingdom (Minelli *et al.*, 2013). Arthropods live in most habitats on Earth, and they are usually well adapted to their environment. In this book, we focus on arthropods in the class Insecta (insects) and the subclass Acarina (mites). Arthropod pests are a major cause of reduction in quantity and quality of agricultural products (Oerke, 2005). Some arthropod pests are important vectors of microbial diseases that they transmit to humans, animals and plants (Eigenbrode *et al.*, 2018; Mullen and Durden, 2018). Thus, arthropod pests cause significant harm to human health, food, wood and other resources. However, beneficial arthropods are important pollinators of many cultivated plants and serve as natural enemies that control many pests (Alford, 2019).

Toxic chemicals are currently the main means of protecting human interests against arthropod pests. Frequent applications of pesticides create health hazards for humans and their environment. Moreover, continuous use of pesticides often induces resistance in pest populations and harms beneficial arthropods. Therefore, alternative methods for protecting against arthropod pests are needed. In this book, we present several possibilities for using optical manipulation as a method for pest management.

Light is one of the most powerful environmental cues that influence organismal biology (Björn, 2008). Arthropods use the information encoded in light to reach their destinations and to adapt to changes in their environment (Cronin and Douglas, 2014). Much knowledge has been accumulated on the vision of arthropods (Warrant and Nilsson, 2006; Land, 2009; Land and Nilsson, 2012) and on their neural and behavioral responses to optical cues (Song and Lee, 2018; Cronin *et al.*, 2014). This book deals mainly with optical

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cues perceived by arthropods from their hosts and their environment. It excludes optical cues given by the arthropods themselves to other organisms. It mainly covers arthropods that affect agricultural production and a few that affect the health of humans and their domesticated animals.

Because light is the main energy source for plant growth, most manipulations of light in the agricultural environment are aimed at improving the quantity and quality of plant products (Rajapakse and Shahak, 2007; Ilić and Fallik, 2017). Some manipulations of light are done to improve the production of domesticated animals (e.g. Bédécarrats and Hanlon, 2017). Optical manipulation of arthropod pests as a method of protecting agricultural crops was introduced by Antignus (2000) and was followed by studies by Ben-Yakir *et al*. (2012), Shimoda and Honda (2013), and Tazawa (2014). However, so far, the use of light manipulations for protecting against arthropod pests, or for enhancing the activity of beneficial arthropods, has been limited. The potential for using optical manipulation of arthropods is particularly high in protected crops (Vänninen *et al*., 2010; Johansen *et al*., 2011; Ben-Yakir *et al*., 2012).

In this book, we present the current knowledge on arthropod vision and the results of successful manipulations of arthropods. We also suggest new methods for using optical manipulation to protect against arthropod pests and to improve the performance of beneficial arthropods. Developing new methods for optical manipulation should be based on knowledge about light (both natural and artificial, and unpolarized and polarized), and on arthropod vison and behavior. Therefore, developing new methods requires the multi-disciplinary collaboration of basic and applied researchers. We hope that this book will enhance the use of optical manipulation as a component of integrated pest management.

This book was written mainly by applied scientists and is addressed to plant protection professionals. Due to the applied nature of this book, only brief overviews of the knowledge about light, vision and behavior are included (Chapters 2 and 3). The main applied information is presented in Chapters 6–9. The information in Chapters 3 and 7 is classified by the orders and families of the arthropods. The references included in this book are only a fraction of the published knowledge in the various topics. An emphasis has been put on recent publications, reviews and books that the readers can use for obtaining further knowledge.

## 1.2 Chapter 2: Light in the Agricultural Environment

Light is a transversal electromagnetic radiation characterized by its intensity (or radiance), wavelength and polarization. In the agricultural environment, light is usually a mixture of electromagnetic waves with wavelength-dependent intensity and polarization. The electromagnetic radiation of the Sun that reaches the Earth's surface is the major source of energy and light for most biological processes. Unobstructed radiation from the Sun reaches the surface as direct light (sunlight), but if it is scattered or reflected, it reaches

the surface as diffuse light (skylight). About half of the electromagnetic radiation of the Sun reaching the Earth's surface ranges from ultraviolet (UV) to the end of the visible spectrum (100–780 nm). The visual systems of most animals have specific receptors for light within this range. The pattern of the angle of polarization of skylight is very important for the navigation of many arthropod species. The reflecting object determines the characteristics of the reflected light. The fraction of solar radiation that is reflected (surface albedo) by wet soil, forest, meadow and crop plants ranges from 5% to 25%. Water surfaces, shiny black horizontal plastic sheets used in agriculture and dark grey asphalt roads reflect sunlight with high degrees of horizontal polarization. The sunlight that reaches crop plants may be augmented by reflective surfaces below the plants or reduced by shading materials above the plants. In recent years, colored shading nets and optically active cladding sheets and nets are used for improving crop production. Artificial light sources are used as supplemental light for protected crops to increase the growth and yield of the plants. These include fluorescent, high-pressure sodium, metal halide, incandescent and light-emitting diode (LED) lights. Artificial lights, especially monochromatic LEDs, have high potential as tools for optically manipulating arthropods. Artificial light sources during the night interfere with the visual perception and natural behavior of both nocturnal and diurnal insects. Direct exposure of insects to light can have deleterious effects on them. Blue light (400–500 nm) can have lethal effects on various insects and may be used for pest control. In addition, direct exposure of plants to certain lights can indirectly have deleterious effects on insects.

## 1.3 Chapter 3: Arthropod Vision

Animal vision starts by detecting chromatic inputs using photoreceptors in the eye and continues by extraction and integration of the chromatic information in the brain. Arthropods have both simple and compound eyes. Simple eyes cannot focus, and function mainly as detectors of the horizon and light intensity. Compound eyes are composed of densely packed units called ommatidia. The iris cells surround each ommatidium and prevent the entrance of light from neighbouring ommatidia through the sides. Most day-active insects have apposition eyes, in which each ommatidium receives light exclusively from its own facet lens. Most nocturnal insects have refracting superposition eyes, in which light entering from several neighbouring ommatidia is focused on to a single photoreceptor. The partial overlapping of visual fields of the two compound eyes enables the insect to have stereoscopic vision. The visual acuity of the compound eye is determined by both spatial and temporal resolving powers. The number of ommatidia in each eye, and their spatial arrangement, determines the spatial resolving power of an arthropod. Visual cues must be large enough to be detected by at least one ommatidium to be resolved. Compared with vertebrates, the spatial resolution of arthropod eyes is lower and the temporal resolution is higher. Therefore, arthropods cannot see well-focused objects, but they can detect

their motion very well. Under natural conditions, the visual acuity of arthropods is also affected by the light intensity, optical contrast and relative speed of movement. The vision of an arthropod is studied by measuring the electrical responses of the eye to lights of various wavelengths and intensities using the technique of electroretinography. In recent years, monochromatic LEDs have been used in studies of arthropod vision. Most insects have photoreceptors whose spectral sensitivity peaks in the UV (350 nm), blue (440 nm) and green (530 nm) ranges. The visual pigments usually have wide spectral sensitivities. Therefore, various colors can generate a very similar response in a specific receptor (equiluminant colors). To distinguish between equiluminant colors, arthropods require input from one or more different receptors. Visual signals can be interpreted in the arthropod brain as broadband, narrowband and color opponent. Aphids employ a color-opponent mechanism in which a positive input from the green receptor is coupled with a negative input from the UV or blue receptor resulting in the specific attraction to yellow. Some terrestrial arthropods detect skylight (UV or blue) polarization and use it for navigation or locating their hosts and oviposition sites. Flying insects use visual cues to stabilize their movement by determining the horizon and assessing their ground speed and drift. The movement of insects in response to light is termed phototaxis and can be positive (attract) or negative (repel). In the rest of this chapter, the visual mechanisms of some arthropod species of agricultural importance are reviewed.

## 1.4 Chapter 4: Direct and Indirect Effects of UV Radiation

UV radiation affects agroecosystems by complex interactions among several trophic levels. Insects use UV light to fly towards the sky during take-off. Usually, insects prefer environments with a relatively higher intensity of UV radiation. Most insects are attracted to artificial sources of UV light. However, aphids and whiteflies are repelled by high-intensity UV light. The strong attraction of many arthropod pests to UV light can be used for efficient monitoring and as a means to divert pests away from crop plants. UV light often affects the distribution of arthropods on their host plants. The absence of UV radiation usually has negative effects on the immigration, development and dispersal of insect pests. Therefore, cladding materials that block UV radiation can provide protection against some insect pests such as aphids. Pollinators, such as honeybees and bumblebees, forage less and develop more slowly under UV-blocking films. Direct exposure of arthropods to UV radiation is usually harmful for them. UV-induced morphological and physiological changes in plants usually have negative effects on the arthropods that feed on them. UVB radiation induces the synthesis of plant stress-related metabolites that are often harmful for arthropods pests. Exposure of young crop plants to artificial UV light provides protection against arthropod pests.

## 1.5 Chapter 5: Visual Interactions Between Plants and Arthropods

During their long period of coexistence, plants and insects have evolved a complex set of interactions including several modes of visual communication. Plants reflect sunlight with characteristic colors, patterns, contrasts, polarity and intensity. Plants use visual signals and cues to attract arthropod pollinators and to reduce arthropod pests. The intensity and patterns of sunlight reflection of crop plants are sometimes correlated with the degree of their susceptibility to arthropod pests. Plants that have high pubescence usually reflect an intense silvery light that can deter arthropod pests. Wild plants have evolved various visual cues to decrease arthropod pests: (i) masquerading, such as looking like a stone, animal droppings, or plants that are old, damaged, dry or sick; a visual masquerade may be enhanced by olfactory cues; (ii) warning (aposematic) coloration; (iii) mimicry of competitive and predatory organisms; (iv) delayed greening of young leaves; (v) bewildering images and dazzling coloration; (vi) camouflage; and (vii) visual exposure of arthropod pests to their natural enemies. Flower colors serve as a visual cue that attracts arthropods to a source of pollen and nectar. Yellow is the most common color of flowers and is very attractive to many arthropods that visit flowers. Honeybees and bumblebees have strong preferences for blue flowers as well. Many flowers have a pattern of UV reflectance on their petals that attracts and guides pollinators. The visual characteristics of wild plants that deter pests or attract pollinators and natural enemies may be introduced to crop plants by selective breeding or genetic modifications.

## 1.6 Chapter 6: Deterrence of Pests

The optical characteristics of a host, or its environment, are usually the main cues that initiate the approach of arthropods to their hosts. Therefore, making hosts and their environment visually unattractive, or repellant, can improve pest management. High-intensity lights, even of attractive wavelengths such as UV and blue, can deter both pests and beneficial arthropods. Deterring landing and establishment of pests on hosts can be achieved by: (i) reflective mulch (silver plastic as a soil cover); (ii) reflective coating (spray plants with aluminium silicate clay mineral); (iii) combining methods (i) and (ii); and (iv) reflective cladding materials, floating row covers or shading nets. Covering the soil with green or yellow plastic sheets or with living plants camouflages the crop plants by reducing their contrast with the background. Zebra stripes are a visual pattern that seems to act as a deterrent for biting flies. Creating an unfavourable optical environment by reducing light intensity (shading) below the favoured level, or eliminating UV radiation, often deters arthropods from entering. A deterring light can be produced by photoselective cladding materials or by artificial light sources. Red and UV LEDs have been used successfully to deter thrips and spider mites, respectively, away from

crop plants. Arthropods that are active during the night or that develop in dark habitats (e.g. soil pests, stem borers, storage pests) are often repelled by light. Blue light effectively repels cigarette beetles.

## 1.7 Chapter 7: Attraction of Pests

During escape, take-off and migration, arthropods are most attracted by sources of short-wave light (UV, violet, blue) located above their locus. The attractive short-wave lights are very effective for monitoring pests and mass trapping, especially in shaded or dark environments. During host seeking, plant-feeding arthropods are most attracted to green and yellow light, and are repelled by high-intensity short-wave light. Tree pests are often attracted to tall, vertical shapes that are colored black or red. Blood-feeding dipterans are attracted by linearly polarized light that simulates the light reflected from their hosts' skin or their aquatic oviposition sites. The attraction to a visual cue is affected by the stage of development and the physiological state of the insect. The response of arthropods to visual cues depends on their light intensity, size, shape and contrast to the background. The size of the visual target must be large enough to be resolved by the specific arthropod at the desired distance. During landing, the target should contain small visual details that can be resolved by the specific arthropod from a close distance. It appears that the contrast of the target from its background is the most basic cue required by host-seeking arthropods. Reflective colored sticky traps are the main tool for monitoring arthropod pests. The types of colored traps used are water pans, sticky cards, cups, cylinders (poles) and balls. In recent years, LED technology has provided efficient and selective lamps to attract arthropods. For optimal performance, colored traps should be easily visible and oriented towards the light source during the period of peak locomotion activity of the pest. The glue used on colored sticky traps often acts as an optical filter that modifies the light reflected from the traps. The trapping efficacy of light-reflective traps is enhanced by adding LED light or combining it with olfactory attractants. Visual attraction has been used for reducing pest infestations by diverting and arresting them away from their hosts (mass trapping; attract and arrest; attract and kill). Yellow, blue and UV lights attract many insects and may negatively affect local insect populations, including predators and pollinators. In this chapter, we summarize some recent results from laboratory and field studies aimed at developing attractive and selective traps for a specific insect pest in a specific agricultural environment. This information is presented by orders and families of the insects.

## 1.8 Chapter 8: Attraction of Beneficials

To date, optical cues have rarely been used to enhance the efficacy of beneficial arthropods in the agricultural environment. This is probable because beneficial and pest arthropods are attracted to similar optical cues. Using

selective light and application time to attract beneficial arthropods can reduce the risk of attracting pests. A few natural enemies, such as *Orius* spp., *Exorista japonica* and *Nesidiocoris tenuis*, are most attracted to violet light (405 nm). While pests such as thrips and whiteflies are active during the day, their predatory bugs are also active during the early hours of the night. Thus, illuminating crop plants with violet light during the early hours of the night can recruit the predators without attracting these pests. In Japan, predatory bugs have been successfully recruited to field-grown aubergines by illuminating them daily with violet LED lights from 17:00 to 20:00; recruitment of the predatory bugs resulted in a significant reduction of thrips on the plants. Similarly, the predatory bug *N. tenuis* was successfully recruited from banker plants to tomato plants in a greenhouse. Thus, optical recruitment of natural enemies is a promising method, requiring further research and development. Color markings of beehives can assist foraging bees and newly mated queens to recognize the entrance to their own hive. Some patterns that combine blue, black and white are clearly distinguished by bees and can serve as entrance marks. Visual cues can also serve as signposts that direct the bees on their routes, especially in environments without UV light.

## 1.9 Chapter 9: Manipulation of Chronobiology

Light is critical to the entrainment of the circadian clock, an endogenous time-keeping mechanism that controls essential physiological and behavioral processes of arthropods. Light also exerts longer-term effects, as progressive changes in day length (photoperiod) regulate the seasonal adaption and development of arthropods. Synchronizing the time of maximum susceptibility of an arthropod pest with the time of applying a toxic or pathogenic treatment is likely to improve the efficacy of control and reduce the risk of inducing resistance. To minimize harm to beneficial arthropods, control measures can be applied during the time when they are least susceptible. Extending the photophase or scotophase beyond their natural range often has negative effects on arthropods. This method has been used successfully to reduce the reproduction, development and survivorship of arthropod pests. The induction of diapause was disrupted by extending the photophase with artificial light. Another method of disrupting biological clocks is by a light pulse(s) administrated during the scotophase. Preventing the onset or termination of diapause of arthropod pests has been achieved using light pulses. The efficacy of beneficial arthropods often decreases during winter due to the short photophase. This decrease can be prevented by extending the photophase using artificial light. The year-round production of insects for food, fibre and natural enemies often depends on rearing them under a controlled photoperiod. In greenhouses, it may be possible to modify the light/dark cycle for timely enhancement of crop plant resistance to pests. Manipulation of the biological clock of arthropods must be performed using specific wavelengths of light and at selective times to avoid harmful effects to crop plants. Optical manipulations of the biological clocks of arthropods are more feasible and

effective in greenhouses and storage facilities. However, the increased use of agricultural drones (unmanned aerial vehicles) may allow their use for optical manipulation in field crops.

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