# PLANTS IN THE REARING OF ARTHROPOD PREDATORS AND PARASITOIDS: BENEFITS, CONSTRAINTS AND ALTERNATIVES

**Patrick De Clercq**

Department of Plants and Crops, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

Email: Patrick.DeClercq@ugent.be

**Highlights**

- Plants or parts thereof fulfill various roles in the rearing of arthropod predators and parasitoids
- Tritrophic rearing systems can be economically viable but also have important limitations
- Omnivorous natural enemies can acquire essential or supplementary nutrients from plants
- Plant materials may also pose risks due to the presence of antinutritional factors and contaminants
- Artificial water or sugar sources and oviposition substrates may be viable alternatives for plants

# PLANTS IN THE REARING OF ARTHROPOD PREDATORS AND PARASITOIDS: BENEFITS, CONSTRAINTS AND ALTERNATIVES


## Abstract

This review explores the roles of plants in rearing systems for arthropod biological control agents, addressing benefits and drawbacks. The utilization of plant materials in mass rearing processes for predators and parasitoids serves various purposes. Natural rearing systems require plants for cultivating hosts or prey. Whereas these rearing systems can be economically viable, they also have important practical limitations. Alternative rearing strategies make use of plant components as sources of moisture or nutrients, and as living or oviposition substrates. Plant-derived foods, such as honey and pollen, can be used as stand-alone foods for the rearing of several omnivorous parasitoids and predators. Certain omnivorous predators show enhanced life table parameters when suboptimal food is supplemented with plant materials. However, the integration of plants into rearing systems introduces complexities that challenge their efficiency, as plant defenses and contaminants can impact natural enemy fitness. Therefore, alternatives to plant foods or substrates in the rearing environment are discussed.

**Introduction**

In the process of mass rearing arthropod predators and parasitoids plants or plant materials may be incorporated for various purposes. In so-called natural rearing systems, plants are necessary for culturing the parasitoids' hosts or the predators' prey. Given that many arthropod predators and parasitoids are omnivores they may require or benefit from plant materials in their diet. Plants or parts thereof frequently serve as a source of moisture, may offer an oviposition substrate to adult females, or provide shelter, thereby diminishing instances of cannibalism.

Whereas there is a substantial body of literature on arthropod-plant interactions and the impact of plants on the life tables and functioning of arthropod natural enemies in the field, far less studies have focused on the role of plants in the (mass) rearing of predators and parasitoids. The limited amount of available data regarding the utilization of plant materials in the culturing of arthropod biological control agents may stem in part from a lack of public funding for rearing research as well as from the perception that advances in this field are often viewed as less significant by scientific journals and as a consequence do not receive publication; in the case of commercial production systems, such advances are most often treated as proprietary information and are consequently kept confidential [1,2].

The present review centers on the diverse roles of plants or plant materials in rearing systems designed for arthropod biological control agents, with examples drawn from different taxonomic groups of predatory insects and mites as well as insect parasitoids. Whereas plants may offer clear benefits to arthropod natural enemies in culture, they can also have important drawbacks and limit the cost-effectiveness and reliability of mass production systems. Therefore, alternatives to plant foods or substrates in the rearing environment are discussed (Figure 1).

**Tritrophic rearing systems**

Several arthropod parasitoids and predators are produced using natural rearing systems. These systems are essentially tritrophic, as they comprise three trophic levels: the parasitoid or predator, its herbivorous host or prey, and a suitable host plant [3]. They often involve more specialized natural enemies feeding on hosts or prey that in turn require a host plant for optimal growth. Such natural rearing systems can be economically viable like in the case of the aphelinid whitefly parasitoids, *Encarsia formosa* and *Eretmocerus eremicus*. These aphelinids are routinely reared on tobacco plants infested with the whiteflies *Trialeurodes vaporariorum* or *Bemisia tabaci,* which are also the target pests for the parasitoids [4-6]. Another widely used augmentative biological control agent that is usually mass reared in a tritrophic system is the phytoseiid mite *Phytoseiulus persimilis,* a specialist predator of *Tetranychus* spider mites. For mass rearing purposes, this is most often done according to a batch-wise production system that requires growing bean plants (*Phaseolus vulgaris* or *Vicia faba*) in a greenhouse, infesting these with spider mites and finally releasing the predatory mite on the infested plants [7]. Mass production methods for phytoseiid predators like *Amblyseius swirskii* and *Neoseiulus californicus* using wheat bran as a substrate for fungivorous astigmatid prey mites [7] can be considered as a special case of multitrophic rearing systems.

Whereas the plants in tritrophic rearing systems are basically intended as a feeding substrate for the host or prey, they may also affect the fitness and efficacy of the natural enemies, even if these do not feed directly from the plants. Natural rearing systems allow parasitoids and predators to learn by associating infochemicals produced by the target-pest infested plant, such as herbivore induced plant volatiles (HIPVs), to the presence of their target hosts or prey [e.g., 8-9]. Kruidhof et al. [10] pointed out that learning during the rearing phase may greatly enhance the foraging efficacy of parasitoids. On the other hand, natural enemies may experience adverse tritrophic effects from chemical or physical traits of the host plants of their hosts or prey [11]. These may be related to defence mechanisms of the plants [12-15] but also to their nutrient levels [5]. Effects from plant chemistry (allelochemicals,

nutrients) may be of particular relevance for omnivorous natural enemies that also feed on the host plant (see below).

Although natural rearing systems have proven to support the mass production of a range of predators and parasitoids, they do have a number of practical drawbacks which may compromise their efficiency and reliability [3,7,11]. Maintaining three trophic levels for mass production purposes requires large greenhouse surfaces, resulting in high costs for infrastructure, labor and energy. In addition, problems arising at the plant level may lead to discontinuity issues. Plants may require protection from diseases or from other pests or predators and need to be adequately irrigated and fertilized for optimal growth. Inadequate collection of the natural enemies from the host plants may result in the presence of contaminants in the end product, like plant pests or pathogens. The limitations of tritrophic rearing systems have led to a continuous search for alternatives, involving the use of factitious (unnatural) hosts or prey or artificial diets [3,11,16,17]. In some of these alternative systems, whole plants or parts thereof (e.g., leaves, sprouts, pods, pollen) are provided during the whole or part of the rearing process to serve various purposes [18].

**Plant materials as a sole food or as part of the diet**

Numerous arthropod natural enemies are omnivores, using plant-derived foods during part or the whole of their life cycle, including pollen, nectar, honeydew, plant sap, plant guttation, gall secretions and food bodies [19]. Life history omnivores are obligatory consumers of plant materials like nectar and pollen in part of their life cycle, usually the adult stage; these include many parasitoids, hoverflies, gall midges and certain lacewings. True (permanent) omnivores feed on plant-derived materials during their entire life cycle, usually as a supplement to their prey diet but in some cases to provide essential nutrients; examples are predatory mites, bugs and beetles [13,19-23]. Consequently, plant-derived

foods are also present in the mass rearing systems for different arthropod predators and parasitoids, supplying them with water and/or with essential or complementary nutrients.

*Carbohydrate sources for adults*

Adults of many parasitoids and some predators (e.g. hoverflies, gall midges) consume (extra)floral nectar or honeydew as a source of carbohydrates [19,23-25]. In culture, nectar is usually replaced by (diluted) bee honey as a factitious food [6,16], in some cases supplemented with sucrose. The composition of nectar varies considerably depending on plant species and environmental factors but is typically dominated by the monosaccharides fructose and glucose and the disaccharide sucrose; it may further contain low concentrations of other carbohydrates, as well as small amounts of amino acids, lipids, vitamins, and secondary plant metabolites [19 and references therein]. In honey the sucrose is largely converted to fructose and glucose and the water content is reduced to less than 20%. Besides the minor components present in nectar, honey also contains small quantities of compounds like gluconic acid and hydrogen peroxide, resulting from the addition of enzymes by honey bee workers, which contribute to its preservation [26,27]. While the positive impacts of supplying sugar sources, such as honey, to adult parasitoids and certain predators in rearing systems are evident [6,28,29], there is a scarcity of published data regarding how individual sugars present in nectar or honey influence the overall performance of adult parasitoids or predators [e.g., 30-34]. Several studies have addressed the potential adverse effects of secondary plant metabolites or pesticides in nectar to natural enemies [13,19,35]; these may also be present in honey, in addition to contaminants from beekeeping [27,36-38] and may hence pose risks to mass reared natural enemies. Synthetic sugar sources with a known and stable composition can offer a safe and effective alternative to honey in the mass rearing of parasitoids and predators [29].

*Pollen*

Pollen is a primary source of nitrogenous compounds (proteins, free amino acids) for a number of predatory arthropods (e.g., adults of syrphids and some chrysopids, juveniles and adults of certain mites). Besides, pollen contains lipids, sterols, carbohydrates (mainly starch), vitamins and minerals [13,19,23]. In culture, pollen is used as a sole protein source to support the adult stage of syrphids [16,39] and to a lesser extent of chrysopids [40,41] and to support the full life cycle of certain predatory mites. In the rearing of syrphids and chrysopids honeybee pollen can be used [e.g., 41,42], but this is highly variable in composition depending on origin and season. Pure pollen from various plant species has been found suitable for different phytoseiid predators [e.g., 43-47] and has been recommended as a sole food to support the culturing of generalist species like *Neoseiulus californicus, Amblyseius swirskii* and *Neoseiulus cucumeris* [48-51]. According to Vangansbeke et al. [7], however, basically only species within group IV as defined by McMurtry et al. [52], including *Euseius* and *Iphiseius* spp., can be cost efficiently mass reared on pollen alone. Other predatory mites that can be mass produced on pollen only are the iolinids *Pronematus ubiquitus* and *Homeopronematus anconai* [7,53]. As a drawback, most group IV phytoseiid and iolinid mite species cannot be reared off-plant as they need to feed on plants to acquire moisture [54]. Given that the use of whole plants complicates the mass rearing, detached leaves of succulent plants like *Crassula* sp. have been proposed as an alternative [7].

Differences in the performance of arthropods on pollen species can be related to varying levels of nutrients as well as antinutritional factors (i.e. antifeedant or toxic secondary plant metabolites), whereas morphological characteristics of the grains (exine and intine thickness, surface structure) may limit access to or digestibility of the contents [13,44,55,56]. Although pollens of certain entomophilous plants have been noted to be highly nutritious food sources for various predatory mites and insects, anemophilous plants like birch, castor, maize, and cattail (*Typha* spp.) are good pollen sources from a practical perspective as they produce copious amounts of easily collectable pollen [13,44]. Pollen of *Typha angustifolia* is available as a commercial product, mainly for food supplementation strategies in greenhouse crops [53]. In dry form, pollen can be conserved for a long period of time, but in a moist environment it rapidly declines in quality [19,57]. Residues of (systemic) insecticides and other

chemical contaminants may also degrade the value of pollen for the rearing of beneficial arthropods [13,35,36].

*Mixed diets*

Several authors have reviewed the potential benefits of supplemental plant feeding to omnivorous arthropod predators [21,58,59]. The overall conclusion of these reviews was that supplementing prey-only diets with plant food (leaves, pods/seeds, pollen) enhances developmental rate and survival of immature insects and mites, whereas the impact of a mixed diet on adult fecundity and longevity is variable. The benefits of diet mixing are species and stage specific and dependent of the nutritional quality of the plant material and of the prey. Predators feeding on low-quality prey generally benefit more from supplemental plant food than those with access to high quality prey [58,60,61].

In non-tritrophic rearing systems, omnivorous predators usually have access to nutritionally optimal prey. Often this is a factitious prey, like lepidopteran eggs which are offered to a range of heteropteran, coleopteran and neuropteran predators [17]. Any plant material present in the rearing environment generally functions primarily as a source of moisture, and/or serves one or more of the other functions discussed below. In such instances, it is often unclear whether the plant material substantially contributes additional nutrients to supplement the predators' diet [62]. On the other hand, supplementing a prey diet with plant materials may allow to reduce inputs of expensive prey materials (such as lepidopteran eggs) and thus lower production cost. Mendoza et al. [63] suggested selective breeding as a strategy to enhance the performance of an omnivorous predator on pollen as a suboptimal plant-based food source with this objective in mind. Conversely, when the prey is less than optimal, plant materials have been reported to increase the fitness of the predators. For instance, De Clercq et al. [64] found that supplementing *Ephestia kuehniella* eggs with moist bee pollen resulted in faster development and better fecundity and egg hatch in the coccinellid *Adalia bipunctata* as

compared with *E. kuehniella* eggs alone. Also, the suboptimal nutritional value of artificial diets for various heteropteran and coleopteran predators was (in part) compensated by offering the predators plant materials like leaves, sprouts, pods or pollen [62,65].

**Other functions of plant materials**

Many predatory insects and mites require a plant substrate to lay their eggs on or in. In cases where predators lay their eggs within plant tissue, the inclusion of plants or plant components frequently becomes a vital component of the production system. For example, plant materials used as oviposition substrates for anthocorid predators include pods and stems of green bean, seedlings, sprouts (e.g., potato, beans) as well as inflorescences, whereas tobacco plants or leaves have been utilized for mirid predators (see review by [62]). Further, plant materials may diminish cannibalism by providing hiding places during rearing or shipment. For instance, buckwheat or grain husks serve as a rearing substrate or carrier material for *Orius* bugs and predatory mites [7,62].

Due to the limitations associated with the utilization of fresh plants or plant materials in the mass production, efforts have been done to eliminate these from the rearing system of predatory insects and mites. This requires the availability of alternative moisture sources and artificial living and oviposition substrates. For instance, certain phytoseiid mites can be cultured on plastic substrates, with cotton strands serving as a substrate for oviposition [e.g., 15,66,67]. Plantless rearing systems have also been designed for *Macrolophus* and *Orius* spp. ([62] and references therein). These use various oviposition substrates like dental cotton rolls or cotton wool enveloped in Parafilm, and water-filled capsules made from Parafilm or a polymeric coating to provide water. Notably, Urbaneja-Bernat et al. [68] proposed Parafilm domes containing a sucrose solution for the rearing of a mirid predator, as this enhanced fecundity and decreased the number of *E. kuehniella* eggs consumed by the predator, ultimately contributing to a reduction in production costs. As an alternative or complementary strategy,

artificial selection may provide a means to create populations of omnivorous predators that are less dependent on plants [22]. However, adopting such an approach should be done with caution, as these selected populations may encounter difficulties to establish in the crop upon release, thus undermining their effectiveness in biological control [22,63].

**Conclusions**

While some parasitoids and predators require plants in the mass production process to rear their hosts or prey, others derive direct benefits from plant materials, using them for moisture, nutrients, or as a substrate for living and oviposition. However, production facility managers may have good reasons to move away from plants: the inclusion of plants in rearing procedures introduces complexity, posing challenges to cost efficiency and reliability. Chemical and structural defences of plants, as well as potential contaminants, can negatively affect the fitness of natural enemies. Therefore, the decision to include plants in mass rearing systems, especially in commercial settings, should be based on a thorough cost-benefit analysis.

Despite the substantial existing scientific literature regarding the life history of omnivorous natural enemies, there is a lack of understanding about the precise nutrients they obtain from plants. More work is also needed to gain deeper insights into how exposure to plants in the rearing process affects the subsequent performance of parasitoids and predators upon their release in the field. Furthermore, there is a significant need for practical research to develop artificial substrates and food sources that can replicate the functions of plants within a rearing environment without adverse effects on the quality of the natural enemies. Such innovations could play a pivotal role in upscaling and automating rearing procedures.

**Data availability**

No data were used for the research described in the article.

**Declaration of competing interest**

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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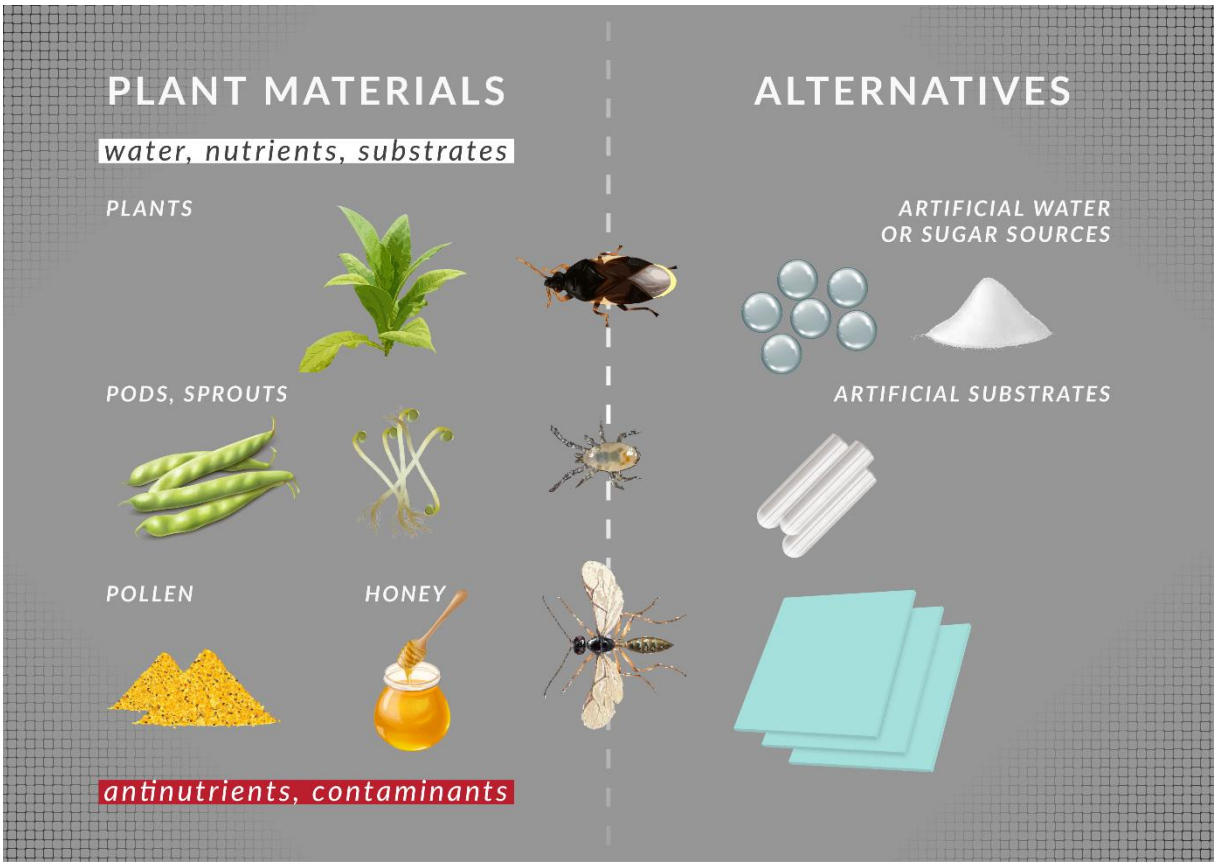
**Figure 1.** Plants or parts thereof fulfill various roles in the rearing of arthropod predators and parasitoids. Whereas omnivorous natural enemies can acquire essential or supplementary nutrients from plants, plant materials may also pose risks due to the presence of antinutrients (secondary plant metabolites) and contaminants. Artificial water or sugar sources and oviposition or living substrates (like dental cotton rolls for heteropterans or plastic plates for phytoseiids) may be viable alternatives for plants and can play a pivotal role in automating mass rearing procedures.



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