Functions of banker plants for biological control of arthropod pests in protected culture

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Abstract

Banker plant systems have been developed for the biological control of various pest species in protected culture. In such systems, non-crop plants, i.e. banker plants, are placed in the greenhouse and harbour alternative food and beneficials. The banker plant system is an effective strategy for biological control in greenhouses, with many benefits over the conventional release of beneficials. Moreover, they facilitate the reproduction of beneficials. However, the way banker plants function in this setting has not been clarified. The mechanisms of selection by beneficials between the banker plant, with its hosts or prey, and the crop plants, with its pests, is also not understood. The extent of selection of the banker plants by natural enemies may result in a lack of dispersal from the plants to crops and reduce pest control efficiency, because after selection of the banker plant, the natural enemy should disperse from it to the crop plant. There are many publications demonstrating the usefulness of banker plants as an alternative food source for the reproduction of beneficials. However, few publications have considered selection. Herein, we propose a theoretical basis for the banker plant system based on a consideration of its functions.

Keywords: Banker plant, Biological control, Greenhouse, Beneficials, Arthropod pests.

Review Methodology: Web of Science and Google Scholar were searched for relevant peer-reviewed articles since 2010, using 'banker plant' as a keyword. Several important articles using the banker plant method before 2010 are also cited. Articles reporting trial and error experiments using banker plant systems are not cited, but those pertaining to the biological functions related to these systems are cited.

Introduction

A 'banker plant system' can be defined as a rearing and release system consisting of three elements (banker plant, alternative food and beneficials) purposefully added to or established in a crop system, whether in greenhouses or in open fields, for the control of pests [1–3]. The banker plant is the plant component of the banker plant system; alternative food is the prey or host or other alternative food added to or produced by the banker plant, and beneficials are the predators, parasitoids or insect pathogens released on the banker plant [2]. Banker plant systems have been introduced in many countries for the biological control of various pest species in protected cultures [1–4]. They are an effective strategy for biological control in greenhouses, with many benefits over the conventional release of beneficials [2].

Banker plant systems were first developed as a refinement of the 'pest in first method'. Tomato seedlings infested with a small number of the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) were used as banker plants for the introduction of the aphelinid parasitoid *Encarsia formosa* Gahan [5]. Since commercial producers hesitated to adopt a deliberate pest release strategy, methods using non-crop banker plants infested with non-pest herbivores were developed [6–8]. The most commonly used combination of banker plant and alternative host is wheat or barley with the bird cherry-oat aphid *Rhopalosiphum padi* (L.) for the braconid wasp *Aphidius colemani* Viereck, to control aphids. Maintenance of alternative herbivores on banker plants is not easy. In addition, propagation of secondary parasitoids often hampers the use of this system [9]. If pollen feeders, such as predaceous mites, are used as natural enemies in a banker plant system, plants that produce sufficient pollen to maintain natural enemies can be used as banker plants. Caster beans, *Ricinus communis* L., were successfully used as the banker plants for the predatory mite *Amblyseius degenerans* Berlese for thrips control of greenhouse sweet peppers [10, 11]. This type of banker plant system is limited to omnivorous predators, such as predacious mites or mirid bugs.

Two important reviews of biological control using banker plant systems have been published recently [2, 4]. They summarized many examples of trial and error experiments using banker plant systems. However, the complex functions underlying this system have not been well-explored. Moreover, theoretical studies of the banker plant system in relation to its functions have not been fully reviewed. Thus, this review focused on the functions of banker plant systems and the theoretical basis of this system.

Functions Operating in the Banker Plant System

Parolin et al. [3] discussed the functions of secondary plants used for biological control. Secondary plants are plants added to a crop system with the aim of increasing the efficiency of a biological control system. Examples include insectary and banker plants. The authors concluded that the main function of a banker plant is to maintain populations of natural enemies [3]. The goal is to sustain a reproducing population of natural enemies by provision of alternative foods on banker plants, thus providing long-term pest suppression within a crop system [4].

Continuous release of natural enemies from banker plants is another important feature of the banker plant system [12, 13]. In the case of continuous release of natural enemies from the banker plant to the crop plant, natural enemies produced on banker plants must move to the crop plants to control pests thereon. Since alternative hosts or prey on banker plants, as well as pests on crop plants, are both available and can serve as hosts or prey, natural enemies must select one of them. This selection of the banker plant system versus the crop system by natural enemies affects their dispersal from the banker plant. The selection of alternative hosts or prey implies that the natural enemies do not move to the crop plants, which hampers their effectiveness as biological control agents. Until the crops become infested by pests, the natural enemies will reproduce on the banker plants. We expect natural enemies to reproduce well on banker plants, and that natural enemies produced on banker plants move to the crop plants [14, 15].

In conclusion, the main function of the banker plant system is the reproduction of natural enemies by the provision of alternative food on banker plants. In addition, selection of the crop system over the banker plant system by natural enemies and dispersal to the crop system are other important functions of the banker plant system.

Reproduction of Natural Enemies on Alternative Food in the Banker Plant System

The main function of the banker plant system is the reproduction of natural enemies and therefore the maintenance of their populations. Natural enemies can reproduce, such that their numbers increase, on alternative hosts or prey on banker plants, and the pests are not found on crops. Two processes facilitate the reproduction of natural enemies in the conventional banker plant system: (1) the reproduction of alternative hosts or prey on banker plants and (2) the reproduction of natural enemies on alternative hosts or prey. The first process, i.e. an increase in alternative hosts or prey on banker plants followed by an increase in natural enemies on these alternative hosts or prey, seems to be more likely in general. However, when plant-derived alternative foods such as pollen are used, natural enemies can reproduce by feeding on banker plants directly.

The reproduction of alternative hosts or prey, with different combinations of hosts or prey species and banker plants, needs to be evaluated. Six species of legume or cereal aphids were assessed as alternative hosts of the braconid wasp *Aphidius gifuensis* (Ashmead), a parasitoid species that attacks the green peach aphid *Myzus persicae* (Sulzer) and the foxglove aphid *Aulacorthum solani* (Kaltenbach). The cereal aphid *Sitobion akebiae* (Shinji) showed the highest parasitism rate by *A. gifuensis*. The developmental rate of the parasitoid was comparable with that on *M. persicae* [16]. Development and reproduction of four cereal aphid species on sorghum and barley allowed for evaluating alternative prey for banker plant systems using the aphid predator aphidophagous gall midge *Aphidoletes aphidimyza* (Rondani). The results suggested that the combination of sorghum as banker plants and the sugarcane aphid *Melanaphis sacchari* (Zehntner) as alternative hosts could be suitable for use in hot seasons [17]. Bottom-up effects were evaluated using four cereal plant species with three levels of reproductive performance of *R. padi* and *A. colemani*, the most common banker plant system used worldwide. *R. padi*, on either wheat or barley, performed well in terms of aphid and parasitoid fitness and abundance [18]. Effects of monoculture or a mixture of four cereal plant species were evaluated according to the three levels of reproductive performance of *R. padi* and *A. colemani*. Mixtures did not increase the number of aphids or parasitoid mummies on banker plants [19].

The strategy of using plant-derived food as alternative food can be applied to omnivorous predators. Pollen can be used as a supplemental food to improve the establishment and performance of the omnivorous predacious mite, the *Amblyseius swirskii* (Athias-Henriot). Pollens from 21 plant species were assessed as food sources for this predator. The pollens of *R. communis* and the maize *Zea mays* L. have been recommended as supplemental foods, in banker plant systems [20]. *A. swirskii* can also reproduce on three varieties of ornamental pepper [21]. The omnivorous mirid bug *Nesidiocoris tenuis* (Reuter) reproduces on sesame plants in the absence of eggs of the Mediterranean flour moth *Ephestia kuehniella* (Zeller) [22]. Sesame plants may be a candidate banker plant species for this bug, which can suck plant fluid as a food source.

Banker plant species are sometimes used to maintain predators without any expectation of reproduction. Several candidate banker plant species were assessed as banker plant species for the minute pirate bug *Orius insidiosus* (Say) and 'Purple Flash' pepper showed the greatest potential [23]. 'Black Pearl' pepper pollen was also shown to increase *O. insidiosus* longevity, survival rate and female body size, while decreasing nymphal developmental time [24].

In all of the above cases, the natural enemies were shown to reproduce well on the alternative host or prey or plant-derived food. This reflected the fulfilment of a minimum requisite for the use of this method: good reproduction of natural enemies on the banker plant system. In the cited studies, good alternative foods, allowing reproduction of natural enemies, were selected.

Selection between Banker Plants with Alternative Hosts or Prey and Crops with Pests by Natural Enemies

Selection of the target pest on crops by natural enemies produced by the banker plant is important for an effective banker plant system. If a banker plant with alternative hosts is preferred, natural enemies do not move to crops with pests.

Barley or wheat plants with *R. padi* are commonly used banker plant systems worldwide for *Aphidius* parasitoids and *A. aphidimyza*, to control aphids. Oviposition selection between a banker plant system, barley plants with *R. padi*, and eggplant with *A. gossypii* by *A. aphidimyza* females was studied in a laboratory choice test and in a greenhouse. The females laid more eggs on eggplant plants with *A. gossypii*, both in the laboratory and greenhouse cage experiments [14]. Similarly, it was found that female parasitoids of *A. colemani* parasitized fewer *R. padi* than *A. gossypii*, and fewer offspring successfully completed their development in the context of *R. padi* versus *A. gossypii*. Ovipositing *A. colemani* encountered *R. padi* at a lower rate, and spent more time handling *R. padi*; moreover, parasitoid offspring died at a higher rate in the context of *R. padi* compared to *A. gossypii* [25].

To control *A. gossypii* infestation of eggplant during the hot season in Japan, a banker plant system for *A. aphidimyza* was developed using *M. sacchari* as an alternative prey on sorghum plants. An oviposition selection test of *A. aphidimyza* females, between this banker plant system and a system of eggplant with *A. gossypii*, showed that *A. aphidimyza* females always selected sorghum plants with *M. sacchari* to oviposit in the laboratory, but selected eggplant with *A. gossypii* in greenhouse cage experiments [15].

R. padi seems to be a less preferable host or prey for *A. aphidimyza* and *A. colemani* compared with *A. gossypii* and is thus a good alternative host or prey for these banker plant systems. The reason for the discrepancy in the preference of *A. aphidimyza* for *M. sacchari* versus *A. gossypii* in the laboratory versus the greenhouse is unclear, indicating the need for caution in applying laboratory results to greenhouse condition.

Dispersal from Banker Plants to Crops by Natural Enemies

Dispersal by natural enemies from banker plants to crops is an important function for an effective banker plant system. *A. colemani*, which is widely used in banker plant systems, is highly capable of flight [26]. On the other hand, non-flight type natural enemies, such as predatory mites, might have a low dispersal capability.

A. swirskii is used to control the broad mite *Polyphagotarsonemus latus* (Banks) on peppers using the ornamental pepper as a banker plant. Within 24 h, *A. swirskii* dispersed within only 1 m from the banker plant. Canopy connectedness increased the number of predatory mites on the crop plants [27]. Spider mites are the most injurious pest in commercial plant nurseries. The predatory mite *Neoseiulus fallacis* (Garman), dispersing from arborvitae banker plants, was collected at 10, 20 and 30 m downwind, 10 weeks after release [1].

When corn plants are used as banker plants, and the spider mite *Oligonychus pratensis* (Banks) as an alternative prey for the predatory gall midge *Feltiella acarisuga* (Vallot) to control the two-spotted spider mite *Tetranychus urticae* Koch in greenhouse green beans, *F. acarisuga* was found to fly at least 7 m, 14 days after dispersal from a banker plant [28]. The dispersal ability of the aphelinid parasitoid *Encarsia sophia* (Girault & Dodd), from papaya banker plants to tomato plants infested with the sweet potato whitefly *Bemisia tabaci* (Gennadius), was investigated. It was found that *E. sophia* could disperse at least 14.5 m away from papaya plants to target tomato plants within 48–96 h [29].

The dispersal ability of natural enemies must be considered when choosing the optimal spatial arrangement of banker plants in a glasshouse. For example, the dispersal of natural enemies to crop plants with pests might be affected by the production of volatile chemicals by infested crop plants.

Behavioural Manipulation of Natural Enemies Using Volatile Chemicals for the Banker Plant System

The behaviour of natural enemies is regulated mainly by semiochemicals. The attraction of natural enemies using synthetic compounds similar to herbivore-induced plant volatiles (HIPVs) has been recently evaluated in outdoor crops [30]. However, the application of volatile semiochemicals for behavioural manipulations of natural enemies has been limited so far [31]. Since dispersal from banker plants to crop plants is necessary for biological control using the banker plant system, attracting natural enemies with volatile chemicals may be advantageous.

The chemical ecology of natural enemies has been the subject of several studies. Investigations of the natural enemies used in augmentative biological control in greenhouses have shown, for example, that the predatory mites *Phytoseiulus persimilis* Athias-Henriot [32] and *Neoseiulus californicus* (McGregor) [33], the anthocorid bugs *O. insidiosus* [34] and *O. sauteri* (Poppius) [35] and the mirid bug *N. tenuis* [36] are attracted by the HIPVs produced in host plants infested by pest species. Aphid parasitoids are stimulated by aphid sex pheromones to search for aphids [37]. The ladybird *Adalia bipunctata* L. is attracted by an alarm pheromone produced by aphids [38]. It was found that *A. aphidimyza* females were attracted via chemical cues derived from honeydew produced by *M. persicae* [39] and *A. gossypii* [40]. However, these studies were performed in the laboratory using an olfactometer or in a small glasshouse. The application of these volatile chemicals in the behavioural manipulation of natural enemies in the banker plant system will be evaluated on a commercial scale in the near future.

Theoretical Basis of Banker Plant Systems in Protected Culture

A simple food web created when a banker plant system is employed may comprise one natural enemy, two hosts and a two host plant system. There are two food chains allowing reproduction of the natural enemy in the banker plant system and stabilizing the dynamics of the natural enemy population: (1) banker plant–alternative hosts or prey–natural enemy and (2) crop plant–pest herbivore–natural enemy. Apparent competition in the indirect interaction between alternative hosts or prey and the pest has been demonstrated [2].

The banker plant method allows the prolonged release of natural enemies. However, recruitment of alternative hosts or natural enemies is sometimes necessary to maintain the system. Continuous dispersal from banker plants to the crop represents the key process in this system [12, 13]. Practically, it is important to minimize the extent of population fluctuation within the system. Previously, simulations were carried out to evaluate the release strategy for the aphelinid parasitoid, *E. formosa*, to control the greenhouse whitefly *T. vaporariorum* in greenhouses; the importance of multiple introductions for reducing the amplitude of population fluctuation was demonstrated [41, 42].

A prey–predator model featuring predator immigration from outside the system was built for evaluating banker plant systems. A simple model of the interaction between pest and predator in the crop was constructed, where the banker plant was included only as a source for predators. The model was developed for three different pest-predator systems and used to predict the conditions under which biological control of pest species is successful in a banker plant system. Theoretical analysis and simulations using the model showed that immigration of predators at a low initial pest density is crucial for successful control [43].

Conclusions

Banker plant systems promote the maintenance of a natural enemy population in a greenhouse, by allowing the rearing of natural enemies through provision of an alternative food source. Such systems also allow the early release of natural enemies on the crop from the banker plants, and reduce the expenses associated with purchasing beneficials. Banker plant systems possess numerous benefits compared to conventional release of beneficials. Despite this, banker systems are still not widely used, especially in Europe, where conventional release of natural enemies remains very popular [2]. Difficulties related to the use of a banker plant system probably stem from the difficulty in maintaining the system. Alternative hosts or prey sometimes multiply to high densities, which can induce death of the banker plants before an increase in the natural enemy number has occurred. In other cases, the natural enemies on the banker plants kill all alternative hosts or prey and then become extinct themselves. It is therefore critical to maintain a proper balance between the numbers of alternative hosts or prey and natural enemies, perhaps by recruiting new banker plants. In addition, propagation of secondary parasitoids renders a banker plant system useless for parasitoids. Technical innovations must be developed to overcome these difficulties: simple banker plant systems, which are easy to treat and manage, are needed. To avoid the effects of secondary parasitoids, the use of banker plants for predators, such as predatory mites or predatory bugs, is one possibility. These omnivorous predators, which can reproduce on plant-derived food such as pollen, might also be effective to control multiple pest species. The dispersal of natural enemies from banker plant systems is affected by the choice made between the banker plant system and the crop–pest system. Such behavioural processes in banker plant systems have not been well-studied. Chemical cues that induce these responses must be identified. Further studies in this research field are expected in the future.

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