Chapter 4
Plants as Food for Adult Natural Enemies

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4.1 Introduction

From the time man started to develop monoculture agriculture, an ecological imbalance in agricultural systems occurred, resulting in increased arthropod pest species. However, synthetic pesticides were discovered in the mid-twentieth century, which effectively decreased certain pest infestations. Due to the indiscriminate use of these pesticides, a series of problems arose such as the selection of resistant populations, contamination of natural, cultivated, and aquatic environments, death of useful organisms, imbalances, and resurgence of secondary pests. Nowadays, agriculture is oriented toward sustainable production worldwide; this reaffirms the importance of developing integrated technologies that promote the survival and effectiveness of pest bioregulator agents.

Small Latin-American farmers face economic rationality and a relative scarcity of natural and capital resources (Benencia 1997). The decrease in pesticide use is therefore a priority, particularly in peasant family farming that cannot deal with the costs associated with pesticide use. Arthropod pest management strategies based on agroecological principles would allow peasant farmers to redesign their systems and reduce the use of these inputs. However, to advance in the implementation of agroecological strategies in these systems, it is necessary to understand how they work and the potentialities that can be developed, in order to improve the self-regulatory mechanisms that lead to greater stability and resilience to pests (Paleologos et al. 2008).

A negative trend of modern agriculture is the expansion of monocultures at the expense of surrounding natural vegetation that maintains biodiversity at the landscape level and plays a very important role in the conservation of auxiliary insects

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(Altieri and Nicholls 2002). Insect plants [plants with flowers that attract and maintain a population of natural enemies with their nectar and pollen resources (Landis et al. 2000; Jonsson et al. 2008; Parolin et al. 2012)] offer refuge for prey and alternative hosts, especially when the latter are scarce in the fields; insect plants also provide food in the form of nectar (floral or extrafloral), pollen, seeds, or plant juices (Alomar and Albajes 2005).

Many insect species visit flowers to obtain food in the form of nectar and/or pollen. These floral sources can provide the necessary energy for survival, maintenance, ovule maturation, and dispersal through adult flight. This suggests that food supplements from floral resources can increase the effectiveness of biological controllers in the field (van Lenteren et al. 1987; van Lenteren 1999; Gurr et al. 2005). The use of corridors or flower hedges in a crop, either outdoors or in greenhouses, can be a good option to improve the availability of food resources other than their prey for insects present in agroecosystems, thus promoting conservative biological control (CBC) (Fig. 4.1).

Agricultural habitat management contributes to biological pest management in crops through the incorporation of so-called insect plants. In these plants, natural enemies not only find protein sources but also refuge when faced with adverse climatic conditions and/or predators.

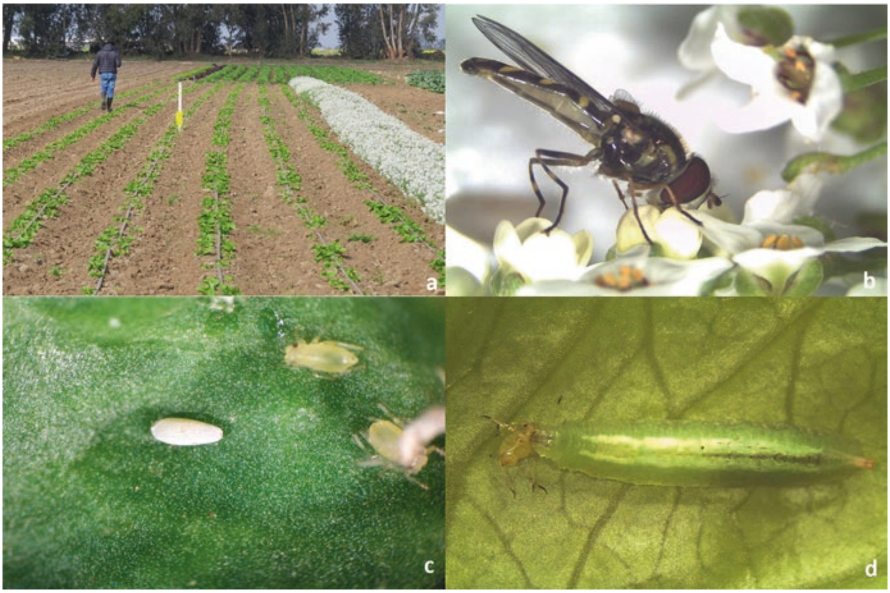

Fig. 4.1 *Lobularia maritima* flower beds as food sources to attract Syrphidae as aphid biocontrollers associated with commercial lettuce crops, Pan de Azúcar, Coquimbo Region, Chile. (a) Cultivation of lettuce in association with *Lobularia maritima.* (b) Adult of Syrphidae in flower of *Lobularia maritima.* (c) Syrphidae egg next to colony of aphids on lettuce. (d) Syrphidae larva preying on aphid on lettuce. (Photos: Claudio Salas)

The aim of this chapter is to present studies related to plants as a natural food source for natural enemies with a greater emphasis on those developed in Latin America.

4.2 Biodiversity and Its Influence on Natural Enemies: Field Experiments

Many comparative studies that show the impact of sustainable and conventional agricultural systems verify that habitat management affects the richness and abundance of arthropod communities (Pfiffner and Balmer 2011). This is due to the availability of a wide variety of vegetation structures such as polycultures, diversified crop-weed systems, and cover crops that conserve natural enemies by ensuring them a series of ecological requirements (Altieri and Nicholls 1994, 2004). It is very important to maintain and promote the increase in natural enemy populations through practices such as the availability of floral resources, because it is currently estimated that natural enemies are responsible for controlling 50–90% of arthropod pests in fields (Pimentel et al. 2005).

Some factors related to pest regulation in diversified agroecosystems include the increase of the parasitoid and predator population given greater alternative food availability and habitat, decrease in pest colonization and reproduction, food inhibition of plants unattractive to pests by chemical repellents, and prevention of movement and optimal synchronization between natural enemies and the pest. When the agroecosystem is more diverse and the diversity is less disturbed, trophic interactions increase, developing synergisms that promote population stability (Nicholls 2006).

4.3 Plants as a Food Source for Natural Enemies

Many natural enemies require carbohydrates and proteins for growth, basic metabolism, and reproduction. If the crop does not provide these compounds, natural enemies will search outside the crop for nectar, pollen, or host plants to feed on. These emigrants might not find their way back to the crop, thus reducing pest control. Small natural enemies, such as wasps of the genus *Trichogramma,* can die rapidly if the crop or agroecosystem does not offer resources such as nectar. On the contrary, crops or agroecosystems that provide nectar, pollen, or alternative prey will retain larger, better nourished, and more fertile natural enemy populations (Van Driesche et al. 2007). Therefore, the diversity of plant species in natural communities increases these requirements and prolongs their availability.

Monocultures with synchronized development can concentrate flowering in short periods of overabundance or eliminate them completely in certain crops. Crops that are adequate as habitats for parasitoids will depend on the particular needs of each species as well as field size compared with uncultivated neighboring areas and the vegetational composition in adjacent areas. Extensive monocultures without nectar and pollen sources and with few prey or alternative hosts offer few resources for natural enemies. Although mechanized crops need to be simplified, the availability of some functional plant species can be possible in well-studied systems and it is common in less intensive agricultural systems (Gurr et al. 2005).

Vegetation accompanying the crops contributes in maintaining beneficial entomofauna, among which are neutral phytophages, predators, and parasitoids. To reach normal fertility and longevity, these arthropods feed on nectar secretions (intra- and extrafloral), wound exudates, pollen, and alternative prey found in the vegetation (Mexzón and Chinchilla 2003).

Nectar secretions contain carbohydrates such as glucose, saccharose, and fructose as well as some essential amino acids (Baker and Baker 1973). Pollen is also rich in amino acids and it is a fundamental part of the diet of some insects (Leius 1967; Altieri and Whitcomb 1979).

On the other hand, plants emit chemical signals (kairomones) that are perceived by entomophagous insects, encouraging them to migrate from the surroundings to locate the habitat of their prey or hosts (Mexzón and Chinchilla 2003).

In Latin America and in the rest of the world, some studies in this area of biological control have been conducted to determine which requirements must be satisfied by some plants to provide refuge and food to natural enemies in fields or greenhouses with monocultures. These types of vegetation can be herbaceous or woody species, depending on the type of main crop. All of this is under the premise of making a CBC model. It is necessary to take into account certain criteria to determine which types of plants are best suited to meet the objectives of setting up hedges or strips of insect crops.

According to Rodríguez and González (2014), selection of the plants that constitute these ecological infrastructures is of vital importance. Some basic parameters to consider in habitat management aimed at promoting functional diversity are the use of native plants adapted to the edaphoclimatic conditions of the location that are not fungal or viral disease reservoirs, offer both food resources, such as nectar (floral and extrafloral) and pollen, and refuge. Another important factor to consider is the establishment of plant species that provide the above resources on a regular basis over time.

Jervis and Heimpel (2005) explain that at some point in their life cycle, parasitoids and predators feed on different plant parts, which are essential for their growth, development, survival, and reproduction. These authors classify them according to the location where they feed:

- *Directly* on plants, consuming floral and extrafloral nectar, pollen, seeds (either whole seeds or specific tissues) and, less frequently, materials such as sap (including fruit juices), plant exudates, epidermis, and trichomes (Majerus 1994 on Coccinellidae, Canard 2002 on Chrysopidae, Gilber and Jervis 1998 on parasite flies, Jervis 1998 on flies).

- *Indirectly* consuming the honeydew produced by Hemiptera-Sternorrhyncha such as aphids, mealybugs, and whiteflies (Evans 1993).

For a long time, most of the research about the feeding behavior of predators and parasitoids and population dynamics referred to the interaction of a natural enemy with its prey/hosts and ignored or overlooked its interaction with nonprey/nonhost food sources (Jervis and Heimpel 2005).

The phenomenon of phytophagy by natural enemies is one of the most important aspects of the biology of natural enemies; however, it is now the least studied and detailed concept in scientific literature if compared with studies about types of prey for each predator and parasitoid (Jervis and Heimpel 2005). However, the world's trend to develop sustainable agriculture that promotes CBC has produced great interest in understanding the importance of plant-derived foods on the behavior and ecology of parasitoids and predators (Evans 1993; Cisneros and Rosenheim 1998; Gilber and Jervis 1998; Heimpel and Jervis 2004).

4.4 Natural Enemies and Their Relationship with Host Plants in the Context of Food: Field Experiments

The range of plant materials under field conditions that are used as food by most predators and almost all parasitoids is not well known. An obvious potential food source is flowers. However, there are few scientific reports dedicated to a conclusive study of natural enemy behavior, whether parasitoid or predator, to generate a register of plant species that provide food that allows them to complete their life cycle in the field.

Since the early 1990s in Canada, as well as in European countries and the United States, some experiments have been conducted to implement flower hedges in monoculture fields and greenhouses to supply pollen to natural enemies for their sexual maturity to occur as well as to improve their longevity. For example, experiments in Canada with the parasitoid of the pine shoot moth *Rhyacionia buoliana* (Denis and Schiffmüller) (Tortricidae), which incorporated umbelliferous plants (e.g., carrot) in the surrounding area, increased pest control from 15% to 90%.

In Chile an apple export orchards, which maintained weed-free plots, strong foci of woolly aphid *Eriosoma lanigerum* (Hausmann) (Aphididae) and other insect pests were detected, while aphids were hard to find in other neighboring plots with flowering plants (Zuñiga 1987). The author indicates the importance of maintaining certain flower-producing vegetation on the edges of crops and plots or reproducing or promoting others such as fennel, carrot, radish, and wild herbs that are highly attractive and visited by entomophages to consume pollen and nectar.

Venzon et al. (2006) conducted studies with *Chrysoperla externa* (Hagen) (Chrysopidae), females fed with pollen from Indian hemp, pea, and castor bean in single diets or diets combined with honey to determine the preoviposition period, oviposition rates, and longevity. They also analyzed proteins present in each of the plant species under study and concluded that female *C. externa* did not oviposit when fed castor bean and honey diets as their only food; however, the oviposition rate increased 1.5 times with the Indian hemp and honey diet and 1.2 times with the pea and honey diet. It is inferred that a diet is efficient when it exhibits a correlation between protein and carbohydrate content present in each type of pollen. Thus, castor bean had higher protein content but lower carbohydrate content, followed by Indian hemp and pea. This shows that legumes have a poor carbohydrate/protein correlation.

In other studies conducted by Venzon and Carvalho (1992) in Brazil, it was determined that there was a higher fecundity rate in lacewings when these were subjected to maize pollen diets; this phenomenon is associated with the high percentage of carbohydrates in maize pollen due to its high starch content. Patt et al. (2003) indicated that vitamins, mineral nutrients, and sterols are important for digestion and other metabolic processes in addition to the nutritional value of the macronutrients found in pollen (Stanley and Linskens 1974; Waldbauer and Friedman 1991). It is expected that differences in nutrient digestibility and assimilation of different pollen species influence biocontroller fecundity.

Another Brazilian study by Morales and Köhler (2008) collected 1187 individuals of the Syrphidae family (74 species) visiting 51 plant species distributed in 23 botanical families; it was determined that the most visited families were Apiaceae and Asteraceae, which demonstrated their greater importance as foragers (75%) when compared with the other families. These authors also concluded that the frequency and abundance of visits by syrphids in the flowers of the different plant families are related to the type (shape and coloring), quantity, and ease of access to available resources. Therefore, dark-colored flowers that are scarce and have limited access to floral resources tend to exhibit fewer visitors than light-colored (yellow, white) flowers that are abundant and have easy access to floral resources.

Inflorescences of the Poaceae species are particularly important to provide pollen to small-sized Syrphidae (Proctor et al. 1996); this has been observed with the *Allograpta* sp. (OstenSacken) (Syrphidae) and *Pseudodorus clavatus* (Fabricius) (Syrphidae) species. However, some larger-sized species were collected, such as *Palpada* sp. (Mcquart) (Syrphidae), which visited species of this family.

Proctor et al. (1996) indicate that the elongated proboscis of syrphids is clearly associated with the foraging habit, but the great majority does not exhibit any specific adaptations because they usually feed on open flowers. Therefore, it was established in the study that the Syrphidae community is regulated by local interactions between species, mainly between environmental conditions and food resource availability. The Apiaceae and Asteraceae species are important to maintain the Syrphidae community because they have a large number of flowers and availability of abundant food resources.

Carrillo et al. (2006) conducted an assay with Brassicaceae in Colombia. Although these crops are attacked by a group of pests, such as aphids, Lepidoptera, and mollusks, they face the diamondback moth *Plutella xylostella* (L.) (Plutellidae), which is a more aggressive pest. Biological controllers associated with this pest are cited worldwide as being mainly or the Braconidae and Ichneumonidae species. In the latter family, *Diadegma insulare* (Cresson) (Ichneumonidae) is highlighted due to its good searching ability, high fecundity, ability to avoid superparasitism, and to regulate the development of its host (Idris and Grafius 1996).

Diadegma insulare is the main parasitoid of *P. xylostella* in several countries (Johanowicz and Mitchell 2000; Xu et al. 2001). In some cases, field parasitism exceeds 90%; however, the success of biological control has been reduced in many other cases because the food requirements of the parasitoid were not considered (Muckenfuss et al. 1990; Wratten et al. 2003). Understanding the relative importance of flowers as a food source for *D. insulare* is very important to improve its efficiency as a biological controller of *P. xylostella*. A floristic inventory was conducted in 13 vegetable-producing farms in several municipalities of the Bogota savanna to determine the effect of several nectariferous plants normally encountered in the Brassicaceae crops of this area, on the reproductive ability of *D. insulare* as well as the degree of acceptance and access to floral structures where food is found. Four species were selected for these studies as nectar sources for *D. Insulare*: turnip *Brassica rapa* (L.) (Brassicaceae), marigold *Calendula officinalis* (L.) (Asteraceae), rue *Ruta graveolens* (L.) (Rutaceae), and borage *Borrago officinalis* (L.) (Boraginaceae). Results of this assay indicated that the reproductive success of *D. insulare* measured in terms of its longevity and fecundity is influenced by the type of floral resources it can feed on.

Flower architecture and insect morphological characteristics influence the degree of accessibility of nectar sources. Among the evaluated plants, those with the widest and longest corolla prolonged longevity and increased parasitoid fecundity. Borage, *B. officinalis* was the best food source because it increased the longevity of *D. insulare* fourfold and fecundity fivefold compared with a honey solution. These results evidence the need to incorporate nectariferous plants to increase the effect of *D. insulare* on the management of *P. xylostella* in an integrated Brassicaceae crop management program in the Bogota savanna.

Studies conducted by Diehl et al. (2012) in Brazil with predatory mites and plants present in vineyards indicated that plants such as *Plantago tomentosa* (L.) (Plantaginaceae), *Sonchus oleraceus* (L.) (Asteraceae), and *Chromolaena laevigata* (R. M. King and H. Rob) (Asteraceae) exhibited a wealth of predatory mite species from the Phytoseiidae, Stigmaeidae, and Iolinidae families. This can be related to the morphophysiological characteristics such as the presence of pilosities, trichomes, and nerves along the leaf, which can provide shelter for these predators. In addition, these species constantly provide pollen for different species of predatory mites because they bloom all year-round (Lorenzi 2000).

Similar results were obtained by Collier et al. (2001) in apples *Malus domestica* (Borkham) (Rosaceae), demonstrating that the associated plants serve as a food source for the predatory mite *Neoseiulus californicus* (McGregor) (Phytoseiidae) by offering pollen or hosting secondary prey at an unfavorable time for the main prey.

Galaz and Navarro (2018) conducted a study in Chile to evaluate the effect of incorporating floral resources on the presence and abundance of arthropods in a commercial avocado orchard compared with the presence of these insects in spontaneous vegetation. The study was implemented in a commercial "Hass" avocado orchard located in the commune of Quillota, Valparaíso region. In a sector of the property, flower mixes or patches were established in 90 m^2 areas. The floral species were the following: *Papaver rhoeas* (L.) (Papaveraceae), *Calendula officinalis* (L.) (Papaveraceae), *Centaurea* sp. (L.) (Asteraceae), *Gypsophila elegans* (M. Bieb) (Caryopyllaceae), *Linaria maroccana* (Hook. F) (Plantaginaceae), *Lobularia maritima* (L. Desv) (Brassicaceae), *Phacelia campanularia* (A. Gray) (Boraginaceae), and *Zinnia elegans* (L.) (Asteraceae). Monitoring of the avocado trees adjacent to the floral mix and spontaneous vegetation led to the observation of two families of natural enemies, which are Coccinellidae and Syrphidae.

In the case of these biological control agents, the established floral resource was an important contribution thanks to the great attractiveness of the floral mixes, which can be used as refuge and/or food by the insects. As for the abundance of pests in avocado trees adjacent to the floral mix, it was possible to identify a decrease in mealy bugs *Pseudococcus viburni* (Signoret) (Pseudococcidae) and red spider *Tetranychus urticae* (C.L. Kock) (Tetranychidae).

Field studies conducted by Arias Roda (2012) in Honduras indicated that insect crops should be plants rich in nectaries and foliage. As for nectaries, they should not only be abundant but also accessible to the insects they maintain (Nicholls and Altieri 2012). In addition, this functional flora should not be attractive for arthropod pest species, not be prone to viruses and other fungal diseases, or inclined to be converted into weeds. Therefore, the objective of the study was to evaluate the adaptability of 30 plant species under the conditions found in El Zamorano, Honduras, and their ability to serve as refuge for natural enemies. Among the plants that demonstrated better behavior compared with the rest are carrot *Daucus carota* (L.) (Apiaceae), coriander *Eryngium foetidum* (L.) (Apiaceae), and dill *Anethum graveolens* (L.) (Apiaceae) to attract parasitoid wasps and Coleoptera of the Coccinellidae and Cantharidae families because their small flowers provide accessible nectaries for these insects. The most frequently encountered predators were the bedbugs of the Reduviidae family, Coleoptera of the Coccinellidae, Cantharidae, and Carabidae families, and flies of the Syrphidae family. Parasitoids of the Ichneumonoidea and Chalcidoidea superfamilies were also found. Among the families considered as phytophagous, individuals of the Miridae and Coreidae (Hemiptera) and Chrysomelidae (Coleoptera) families were detected.

Díaz et al. (2018), in a region of Argentina, evaluated the ability of buckwheat *Fagopirumesculentum* (Moench) (Caryophyllales: Polygonaceae) as a nectary plant in agroecological horticulture; they focused on a holistic approach to pest management and considered biodiversity promotion and/or conservation using floral plant resources. The objective of the study was to determine the entomofauna associated with buckwheat in order to consider its contribution to biological control in horticultural agroecosystems. Individuals were classified by order, family, and functional group (pests, pollinators, and natural enemies). The trophic structure revealed that pollinators were more abundant than natural enemies and phytophages. Natural enemies were represented by the Diptera order with the Dolichopodidae and Syrphidae (genera *Toxomerus* and *Allograpta*) families as predators and the Tachinidae family as parasitoids. In the Hemiptera order, the Reduviidae and

Nabidae families are highlighted as predators. Phytophages were in the Coleoptera and Lepidoptera orders. Traps were used to capture 424 individuals from the Diptera (44.3%), Hymenoptera (36.0%), Hemiptera (9.5%), and other (10.2%) orders. The authors concluded that buckwheat as an "insect plant" can attract insects that contribute to biological control and pollination of different agroecological horticultural crops.

4.5 Applications and Future Guidelines

A greater perception of risk by consumers regarding pesticide use is obliging farmers to reengineer agricultural landscapes and make them more environmentally friendly. This is achieved by conducting and implementing integrated pest management (IPM) programs, including CBC, focused on incorporating plants in field or greenhouse monocultures that, in addition to being a reservoir for natural enemies, are an essential food source to complete part of their life cycles.

However, the mere presence of flowering plants in an agroecosystem is not enough to guarantee improvements in agroecosystems. Several factors should be considered such as the type of crop to be established and the most suitable companion plants or insect crops to prevent agronomic interference. On the other hand, all insects have highly specific requirements and the selection of different floral resources is determined by several factors related to flower color, morphology, smell, and size as well as nectar and pollen quality, abundance and age, and markings of previous visitors (Ambrosino et al. 2006).

A plant can contain a lot of nectar that is not necessarily accessible to natural enemies; therefore, it is not useful for CBC. As well as nectar production, plant floral architecture and nectary location within the flower (hidden, shallow, or exposed) should also be considered.

There are certain aspects of plant morphology such as extrafloral nectaries or the presence of leaf trichomes that can greatly influence phytophagous insects, the natural enemies they attract, and their interactions. They can be located in different plant parts such as leaf edges, petioles, bracts, rachis, stipules, pedicels, and fruits; their size, shape, and secretions vary with plant taxa. However, extrafloral nectar is an important food source, independently of flowering, to provide food resources to adults of different natural enemy species that are essential for pest biological control such as chrysopids, phytoseids, parasitoids, or predatory flies. It has been ascertained that the presence of plants with extrafloral nectaries in fields can be advantageous for biological control (Koptur 2013).

An indispensable condition when designing a plantation for CBC is that it consists of plant species that bloom sequentially throughout the year. This is intended to ensure continuity in food resources and keep natural enemies close to the crops (Long 1995). It is also important to select plants that bloom during the winter when there is a shortage of flowering plants in the fields (Rodríguez and González 2014).

Another factor to consider is to determine whether the target natural enemy population belongs to the parasitoid or predator group because pest control performance of these biocontrollers is variable. Sabelis (1992) explains that many predators must consume several preys before they reproduce. Delayed reproduction often results in a slow numerical response to increase prey populations and reduces opportunities for acceptable control by some predators. The predator functional responses also stabilize faster than those of many parasitoids because predators are satiated with food, resulting in lower attack rates per unit of time spent searching for and handling prey.

In summary, increased biodiversity in agroecosystems can lead to a hierarchy of pest management benefits. Although there is a wide range of flowering plants that have been used for this purpose in agroecosystems, relatively little research has been done on the most appropriate plants. Plants of different species can have different effects on herbivores compared with their natural enemies, while many that enhance the activity of the parasitoid also increase that of the herbivore. This occurs as a result of the improved aptness of the herbivore by enhancing trophic processes or by masking odors that the host plant induces by affecting the parasitoid. This is the masking of odors (which parasitoids use to find hosts) by the odors of associated plants, such as those that can be achieved by the added floral resources (Lavandero et al. 2006).

It is inferred that the increased effectiveness of natural enemies in biological control programs can be achieved by providing selective floral resources. This can ensure the effectiveness of natural enemies without increasing the density or activity of the herbivore. For example, if flowering plant species improve the condition of herbivores, then there will be no beneficial effect of the floral subsidy in the natural enemy population because there is a positive effect on the herbivore; therefore, the action of the natural enemy will be masked or reduced (Lavandero et al. 2006).

Further studies are required to better focus on the use of these insect crops that provide refuge and food to these insects with the aim of reducing the indiscriminate use of insecticides and contribute to quality agriculture with safe products obtained in an environmentally friendly way. The key is to consider the above guidelines because each country, region, and even each field has a different ecosystem and the plants to be selected must completely fulfill their function.

4.6 Final Considerations

Knowledge about the crop, its pests and natural enemies, and where and what their preferences are in order to select the best floral mix is crucial. Thus, it is essential to continue conducting field and laboratory assays and correlate which are the best plant families that provide refuge and food and their sowing dates in the crop. This is to obtain the best benefits, decrease chemical pesticide use, and increase conservation crop management in the fields of Latin America to obtain and to offer attractive and safe products to buyers worldwide given the comparative advantages of this continent.

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