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Biological Control of Pests in Protected Cultivation: implementation in Latin America and successes in Europe

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Short title: Biological control in Protected Cultivation

Abstract: The area with greenhouse crops is estimated to be around 40,000 hectares in Latin America, of which approximately 60% is occupied with ornamentals. Several pests are responsible for losses in yield or quality of greenhouse crops production and pest control is still mainly by chemicals. However, there are several stimuli for the adoption of biological control strategies as an IPM component, not only for the export market of products, but also for increased use of sustainable plant protection methods as a result of the increased success of this methodology in European countries. In Latin America use of native natural enemies plays an important role in pest control and the procedure for development and implementation for biological control in protected cultivation should, therefore, not be based only on the importation and release of commercialized exotic natural enemies. Biological control can be developed making use of effective native natural enemies, or of those introduced a long time ago, and might be supplemented with exotic natural enemies for those pests where native biological control agents are ineffective. In Brazil, the reason for use of native agents is mainly due to concern about environmental risks of imported natural enemies and also because native or naturalized natural enemies are well adapted to local environmental conditions. In many countries, including Brazil, Colombia, Chile, Ecuador, Peru and Mexico, IPM and biological control programs are commercially used or are implemented in pilot greenhouses. Several successes of biological control programs used in Europe will be illustrated.

Key words: Augmentative biological control. Greenhouse crops. Parasitoids. Predators.

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Introduction

In the past 24 years the surface areas with greenhouses have increased more than 100%, with an increase of 4,4% per year. New areas, mainly in Asian, Mediterranean and Latin American countries showed a strong increase in protected areas stimulated by cultivation of high-value crops (Bueno 2005a,b). The estimated area with greenhouse crops in Latin America is around 40,000 hectares, and approximately 60% of this area is occupied with ornamentals (Bueno 2008; van Lenteren 2009a). The province of Almeria, Spain, houses approximately 27,000 ha of plastic covered horticultural crops, probably representing the most densely concentrated greenhouse area in the world (van der Blom et al 2009).

Thrips, whiteflies, aphids, leafminers, fungus gnats and mites are among the pests of general occurrence all over the world, which besides of it's their biotic potential, or high reproductive capacity, have also acquired resistance to many pesticides. According van der Blom et al. (2009) the low tolerance by growers to some of these pests has led to intensive chemical control programs, as a result of which the population of various pests have developed resistance against the applied active ingredients.

Although pest control is still mainly by chemicals, biological control in protected crops gained interest in the Americas and Japan, stimulated by the increased success of this methodology in the European countries. There are several stimuli pushing the growers for that, including limited or no legislative restrictions, safety for the workers, increase of pesticide resistance and absence of pesticides residues (Bader et al. 2005). Then, there are several stimuli for the adoption of biological control strategies as an IPM component, not only for the export market of products, but also for the more regular use of sustainable plant protection methods in developing greenhouse areas.

Pests in protected cultivation are actually managed by biological control on approximately 40,000 hectares all over the world compared to the 200 hectares in the year 1970 (van Lenteren 2000; van Lenteren 2009a). In the regions of Almeria and Cartagena (Spain) (Mediterranean area) the area with biological control was 6.200 ha in 2006, while today it is about 11,700 hectares. According to van der Blom et al. (2009) all together, biological control plays a vital role in about 80% of the greenhouse crops in Almeria.

Over 80% of the biological control used in protected crops in European countries is for control of pests in cucumber, tomato and sweet pepper, and all the horticultural crops together use around 90% of all commercialized natural enemies. However, since the year 1990, the use of biological control has increased in cut flowers (gerbera, orchids, roses and chrysanthemums) and in potted plants (poinsettia, anthurium) in greenhouses. An indicative factor of the success of this control method is the drastic reduction in the use of pesticides: in horticultural crops this reduction was approximately 80-95% (Bolkmans 2007). In European greenhouses, a change from chemical control to very advanced Integrated Pest Management Programs (IPM) took place in a time span of only 20 years. Nowadays, European growers annually introduce millions of natural enemies for pest control. About 150 species of beneficial organisms are commercially available for control of all important insect and mite pests. In the main vegetable crops most insect problems can now be solved without the use of insecticides. ²

However, in the case of Latin America, development and implementation of biological control in protected cultivation should not be based on mere import and release of commercially produced natural enemies. Biological control can be developed making use of effective native natural enemy, or on those introduced a long time ago, and might be supplemented with exotic natural enemies for those pests where native biological control agents are ineffective (van

Lenteren y Bueno 2003). In Brazil, the reasons for this are mainly due to concern about the environmental risks of imported natural enemies and also because native or naturalized natural enemies are well adapted to the local environmental conditions.

In many countries, including Brazil, Colombia, Chile, Ecuador, Peru and Mexico, IPM and biological control programs exist on commercial scale or are implemented in pilot greenhouse farms (Bueno 2005a,b; Bueno y Poletti 2009).

Success of the use of biological control in Europe

Successful IPM programs for greenhouse crops have a number of characteristics in common, such as (a) their use was promoted only after a complete IPM program had been developed covering all aspects of pest and disease control for a crop, (b) an intensive support of the IPM program by the advisory/extension service was necessary during the first years, (c) the total costs of crop protection in the IPM program were not higher than in the chemical control program, and (d) non-chemical control agents (like natural enemies, resistant plant material) had to be as easily available, as reliable, as constant in quality and as well guided as chemical agents (van Lenteren 2009b).

Today Europe has more than 30 commercial natural enemy producers including the world's three largest. These three largest companies serve more than 75% of the greenhouse biological control market world-wide. Of the more than 150 biological control agents that are marketed today for pest control in greenhouses, about 30 make up 90% of the total sales (van Lenteren 2003). Mass production of natural enemies has seen a very fast development during the past three decades. The numbers produced have greatly increased (up to 50 million individuals per week), the spectrum of species available has widened dramatically (from 2 in 1970 to more than 150 nowadays), and mass production methods clearly have evolved (van Lenteren & Tommasini, 2003). The larger arthropod mass production companies have now scientists employed who developed and apply quality control tests (van Lenteren 2003; van Lenteren 2009b).

In The Netherlands for example, more than 90% of all tomatoes, cucumbers, sweet peppers and egg plants are produced under IPM (van Lenteren 2000). According to van der Blom et al. (2009) biological control in Almeria (Spain) has been applied on small scale since over 15 years, initially with rather unpredictable results. However, due to the availability of new biological control agents and to the grown experience in the implementation of the IPM system, the system became technically viable and economically feasible. Biological control has recently been implemented in about 50% of the most important greenhouse crops in Almeria, including virtually all sweet peppers (Table 1). Sampson et al. (2009) reported that with the development of effective programs, the biological control inputs and cost of IPM programs have reduced because there are fewer residues of insecticides such as imidacloprid, which adversely affected natural enemy establishment. In 2008, the average usage by pepper growers was 2.25/m² *Orius laevigatus* (Fieber) (Hemiptera: Anthocoridae), 60/m² *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae), 2/m² *Eretmocerus mundus* and 0.15/m² *Aphidius colemani*. The costs of the IPM programs were 30% less than the chemical control programs (Table 2). Sampson et al. (2009) also showed that in Dutch chrysanthemum crops, the costs of the IPM programs were greater than that of chemical control and the yields were not significantly greater. However, returns to growers were 3% (*Neoseiulus cucumeris* release) and 7% (spraying BotaniGard) greater when using IPM (Table 3).

Table 1. Evolution of application of biological control agents (parasitoids and predators) as principal pest control strategy in the principal greenhouse crops in Almeria (Spain), expressed in hectares under biocontrol (van der Blom et al. 2009).

Crops	Periods (years)			Total surface In ha (autumn 2008)	% with biological control (2008-2009)
	2006- 2007	2007- 2008	2008- 2009		
Sweet pepper	650 ha	6,000 ha	7,500 ha	7,500	100
Tomato	500	1,400	2,000	8,500	25
Cucumber	150	600	1,100	4,000	26
Squash	50	310	500	2,000	25
Egg plant	50	400	600	1,500	40
Total	1,400 ha	8,710 ha	11,700 ha	23,500 ha	50

Table 2: The average costs and returns of IPM (emphasizing biological control) and chemical control strategies in Spanish protected pepper crops (Sampson et al 2009).

Pest Control Strategy	Chemical	IPM
Yield (Kg/m ²)	5.5	6.3
Price (€/m ²)	0.62	0.65
Return (€/m ²)	3.43	4.01
Crop Protection costs (€/m ²)	1.0	0.66
Margin over input costs (€/m ²)	2.43	3.35

Where IPM programs have been developed, integrating biological control agents to control pests in protected cropping is more cost effective and sustainable than relying solely on insecticides. Growers can be reluctant to try IPM as they perceive it as more expensive and complicate than chemical programs (Wearing 1988). These trials demonstrated that in the crops as pepper and chrysanthemum, even where costs were higher, the improved pest control, yield and quality resulted in greater returns to growers.

Table 3: Costs and returns of IPM and chemical control strategies per 10 weeks cycle, in protected chrysanthemum crops (Sampson et al. 2009).

Pest Control Strategy	Chemical	IPM with <i>N. cucumeris</i>	IPM with BotaniGard
Average Yield (stems/m ²)	50	50	50
Crop Price (€/100 stems)	22	22.5	22.5
Crop Protection Costs (€/m ²)	0.27	0.43	0.29
Other Operating Costs (€/m ²)	7.6	7.6	7.6
Margim over input Costs (€/m ²)	3.13	3.22	3.36

Status of biological control use in Latin America

The production under protected cultivation is a recent development in **Brazil**. The total area with greenhouse is approximately 17,000 ha and most of this area is used for ornamentals production (60%). In order to implement biological control programs the following objectives are being used (1) evaluate the development of pests and native natural enemies in the commercial greenhouse areas, (2) study of biology, behavior and influence of the climatic conditions; and development of mass-rearing methods, of native natural enemies and (3) release of natural native enemies in commercial crops in small areas (pilot programs), including studies on release ratios and use of banker plants or open rearing unit.

In strawberry, mites are considered primary pests and among them the most important species is *Tetranychus urticae* (Koch). The predatory mites *N. californicus* and *Phytoseiulus macropilis* have been found as natural enemies on *T. urticae*. According to Fadini et al. (2006), *P. macropilis* has been reported to feed on *T. urticae* populations in strawberry cultivation areas in the cities of Barbacena and Caldas, in Minas Gerais. It is suggested that his predator is responsible for keeping populations of spider mites at low densities on strawberry plants in these areas. Studies have also demonstrated that *N. californicus* is a very effective natural enemy for controlling the two-spotted spider mite in strawberry, and it is able to keep the population of this pest below the economic injury level if released when *T. urticae* populations are relatively low (< 5 mites/leaflet) (Poletti et al. 2008). The comparison between use of chemical and biological control of *T. urticae* indicated that in the area with chemical control the infestation of the *T. urticae* was approximately 18 spider mites/leaflet, which was 40 times higher than the value observed where the predatory mite *N. californicus* was released (bed treated with biological control (Figure 1) (Bueno y Poletti 2009). After this pilot program, we implemented the program in a commercial area of strawberry cultivation in low tunnels with the use of *N. californicus* against *T. urticae*. The use this predatory mite is part of an IPM program for strawberry crops, including the most important producing regions of Brazil, and also in rose, gerbera daisy and chrysanthemum crops in greenhouses.

The potential of the predatory mite *Stratiolaelaps scimitus* (Acari: Laelapidae) in controlling fungus gnat larvae (*Bradysia matogrossensis*) in protected azalea crops with inundative releases (200-predatory mite/m²) immediately after planting the seedlings, when fly infestations are still low, showed the success of this strategy (Figure 2) (Bueno y Poletti 2009).

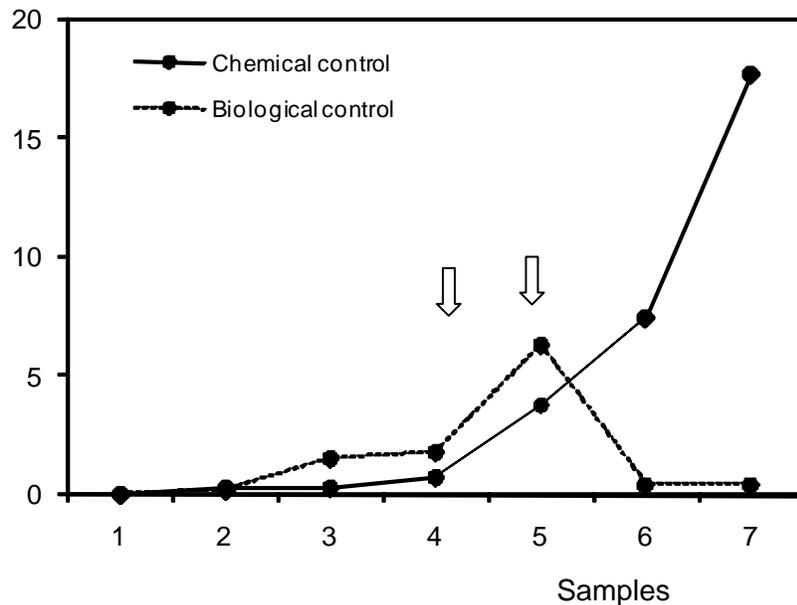


Figure 1: Average number of spider mites (*Tetranychus urticae*) in strawberry beds with chemical and biological control in a commercial low tunnel production system. Arrows indicate acaricide sprays in the strawberry bed with chemical control (Bueno y Poletti 2009).

In Brazil the mite *S. scimitus* is used to control fungus gnats larvae in citrus seedling production and nurseries with several ornamentals plants, such as azalea and anthurium.

The implementation of biological control programs of thrips are in development in Brazil. The predatory bug *O. insidiosus* was effective in controlling thrips populations, mainly the western flower thrips *Frankliniella occidentalis*, in rose crops under protected cultivation, and the carnation plant *Tagetes erecta* showed potential to be used as a banker plant in ornamental crops, such as roses, in conjunction with *O. insidiosus* (Bueno et al. 2009).

Other studies related to protected cultivation are being developed in Brazil involving searching for and evaluation of parasitoids of leafminers (*Liriomyza*) (Bueno 2009b) and parasitoids and predators of the tomato borer *Tuta absoluta* (Meyrick). The tomato borer is an important pest native to South America and now is creating severe problems in several European countries.

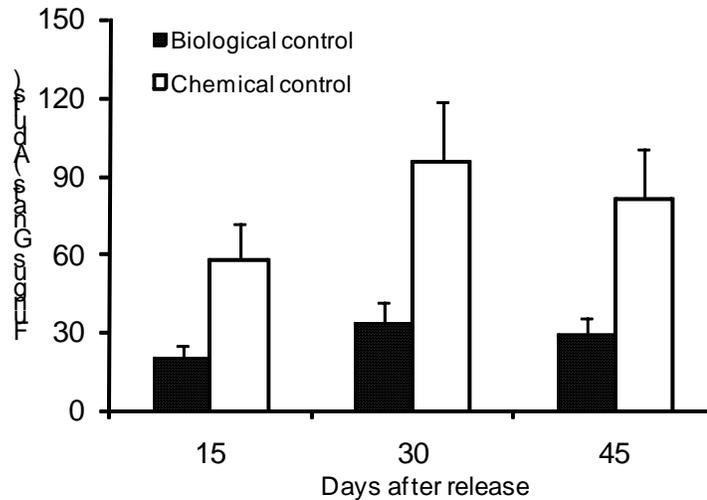


Figure 2: Mean number of *B. matogrossensis* adults in an azalea crop in an area where the predatory mite *S. scimitus* was used and in an area under chemical control (Bueno y Poletti 2009).

Colombia was one of the first countries in Latin America starting with the production of ornamentals in greenhouses. About 98% of the flower production in Colombia is for exportation. In 1996 the 'Florverde Program' was created and one of the objectives is to promote the implementation of IPM programs in flowers and ornamentals in greenhouses. According to Lee (2008), integrating the different pest management strategies on the farms remains a challenge, which several joint research projects should help to solve. Other studies in Colombia concern biological control of the leafminer *Liriomyza huidobrensis* in *Gypsophyla paniculata* crops by the introduction and conservation of *Diglyphus begini* and, of *Tuta absoluta* and whitefly in tomato crops with the use of *Apanteles gelechiidivoris* and *Encarsia formosa*, respectively. A biological control program in development in commercial greenhouse refers to the use of *N. californicus* against the spider mite *T. urticae* in roses (14.64 ha) and hortensias (1.56 ha) crops.

The greenhouse area in **Chile** is around 1500 ha. Biological control programs are being conducted in tomato crops (100 ha) for control of whitefly with the use of *E. formosa* and *Eretmocerus corni* and for the leafmining caterpillar *T. absoluta*, with the use of *Trichogramma nerudai*.

The greenhouse area in **Ecuador** is around 2500 ha with flowers (mainly roses) and 1000 ha with vegetables (mainly tomato). The biological control program refers to the release of the parasitoid *E. formosa* for biocontrol of whitefly in tomato crops; the predatory mite *N. californicus* for biological control of spider mites in rose crops and the parasitoid *Diglyphus* for control of the leafminer *Liriomyza*.

The greenhouse area in **México** is around 3500 ha. For the largest greenhouse vegetable crop, tomato, Mexico is known to apply IPM including biological control, on 110 ha; and also in sweet pepper on an area of 30 hectares.

In **Peru** the egg parasitoids *T. pretiosum* and *Trichogramma pintoii* are released for the control of *T. absoluta* on about 50 ha.

Challenges for more use of biological control in protected crops in Latin America

Greenhouses are of very different construction in developing areas, as in Latin America, and this strongly affects pest development and control. The area with greenhouses is strongly growing in these new regions. A negative observation is that pest control is still mainly by chemical pesticides and that several factors limit application of biological control and IPM in Latin America. A positive observation is that biological control and IPM are successfully applied in some countries in Latin America. Also many beneficial insects occur in Latin America and have proven to be good natural enemies for control of greenhouse pests.

Other challenges which are common to many Latin American countries include the still problematic mass production of high numbers and for many species of biological control agents. Research in this area should be stimulated, and also the collaboration between members of IOBC/NTRS, to develop greenhouse biological control networks in Latin America which may promote the use and implementation of biological control programs for pests in protected cultivation as example of excellent development of this method in European countries.

Future of IPM and Biological Control in Greenhouse

According to van Lenteren (2009a) the use of biological and integrated control in greenhouses will certainly increase, for several reasons:

1. Strongly reduced availability of chemical pesticides;
2. Pesticides development no longer targeted at greenhouse crops;
3. Compulsory testing of side effects of pesticides on non-target organisms for registration;
4. Implementation of "substitution principle": only ecologically safest control will be registered;
5. Registration of micro and microbial control agents;
6. Quality control of natural enemies;
7. Continued and better screening of new natural enemies;
8. Development of biological control of diseases;
9. Increased demand for pesticide-free productions;
10. Positive image for greenhouse industry.

During the first decades of this century crop production in greenhouses without conventional chemical pesticides could become a fact!

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