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Review

Almeria's Green Pest Management Revolution: An Opportunity That Arose from a Food Safety Alert

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Abstract: Almería, a province of Spain, is the leader in horticultural production on a Spanish and European scale. The specific conditions of greenhouse cultivation favor plant development, but also the proliferation of pests. This high incidence of pests was controlled in the past mainly by means of chemical phytosanitary treatments. The aim of the present work has been to analyze the tools facilitated by the Andalusian Government (Junta de Andalucía) to replace the usual pest management process, taking advantage of the context of the food safety alert arising from the detection of isophenphos-methyl in peppers from the province of Almeria in December 2007. The results illustrate that, unlike many programs of public subsidies which involve long-term expenditure, the aid in question took advantage of the socioeconomic situation following the food safety alert. The program led to substantial economic savings and met its objectives swiftly, achieving excellent results in terms of removing most of the pesticides used in the "conventional production system". In the 2006–2007 season, only 515 hectares in Almería used biological control organisms, four years later, it reached 20,081 hectares, and the average area during the last ten years was 24,953 hectares. This shows that Almeria's green pest management revolution had been consolidated.

Keywords: biological control; chemical control; pest management; isofenphos-methyl residues; horticultural crops

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1. Introduction

Almería is one of the eight provinces that make up the autonomous community of Andalusia in southern Spain. Over 32,554 hectares of this province are currently dedicated to greenhouse crops production (52,350 hectares cultivated in 2020/21 growing season, in 60.8% of the area, two crops are grown per year), mainly watermelon 12,575 ha, pepper 12,310 ha, tomato 8423 ha, zucchini 8061 ha, cucumber 5280 ha, melon 3205 ha, eggplant 2277 ha, and green bean 219 ha. Over the 2020/21 growing season, total greenhouse crops production reached 3,509,459 t (73.8% of which was exported with a sale value of 2803 million euros), which provided greenhouse growers with a total of 2121.3 million euros. Almería is undoubtedly the leader in greenhouse horticultural production on both the national and European scale [1].

The specific conditions of greenhouse cultivation favor plant development, but also the proliferation of pests. This high incidence of pests was controlled in the past by means of phytosanitary treatments, producing harmful effects on the health of handlers as well as environmental and eco-toxicological damage [2,3]. This scenario, combined with the drastic reduction of active substances allowed by the European Commission and additional restrictions imposed by the market, meant that numerous pests became more resistant to pesticides. This resistance is particularly relevant in the case of thrips and whitefly, which are present in all protected crops, and which act as vectors of several viruses which are especially aggressive towards certain crops.

Given these circumstances, as well as adjustments to food safety parameters due to increasing awareness and a greater demand for food quality (both at origin and particularly at the destination markets), it was merely a question of time before food safety alerts arose due to the presence of pesticide residues.

This moment arrived on 27 December 2006, when the European Commission's Rapid Alert System for Food and Feed (RASFF) sent the Spanish Agency for Food Safety (AESA) data from Germany informing of the detection of isofenphos-methyl residues in 9 of the 15 fresh pepper samples analyzed. This non-authorized substance was subsequently detected in fresh peppers in the United Kingdom, the Netherlands and Finland, among other countries. This organophosphate pesticide, banned for several years in the UE, had been used in Almería to control *Frankliniella occidentalis* (Pergande), the main virus vector in pepper, which at the time was seriously affected by TSWV (Tomato spotted wilt virus).

The Opportunity for a Change

The presence of isofenphos-methyl in peppers cultivated in Almería on December 2007 received widespread media coverage, giving rise to considerable concern in the sector, and of course, in Spanish and European consumers. The main distribution chains penalized Almería's growers, and as a result, imports of Spanish pepper to the UE fell by 20% to 324,000,000 kg (almost 108 t less than had been exported in 2002), putting an end to the upward sales trend since 2004. Shortly afterwards, other emerging markets, such as Russia, also announced that they were closing their frontiers to the import of pepper from Spain.

At the time of this phytosanitary alert, only 1.9% of the surface area of horticultural crops in Almería controlled pests by means of biological control organisms, but four years later, this figure had increased to 54% (92% in the case of pepper crops). After suffering this food safety alert, the entire sector, including the auxiliary companies, research centers and the Administration (Regional Government of Andalusia), did a big effort for the indispensable change from the traditional chemical control of pests and diseases to Integrated Production methods (IPM). This process is known as the "Green pest management revolution", turning the province of Almería into a Mediterranean and Worldwide reference about the successful application of Biological Control strategies [4]. Juntti and Downward [5] refer to IPM evolution in Almeria as one of the successful moves to "green" Almeria's horticultural production, driven by market demands.

Currently, fourteen years later (2020/2021 season), the cultivated area in which biological pest control is carried out is around 26,288 hectares, although with well-differentiated situations between crops. The pepper is the crop with the largest area under biological control 12,260 ha (99.6% of the crop area), followed by tomato 5372 ha (63.8%), cucumber 3637 ha (68.9%), aubergine 1704 ha (74.8%), zucchini 1407 ha (17.2%), watermelon 1285 ha (10.2%), melon 595 (18.6%) and green bean 28 ha (12.8%) [1].

The aim of the present work has been to analyze the tools facilitated by the Andalusian Government (Junta de Andalucía) to replace the usual chemical pest management process, taking advantage of the context of the food safety alert arising from the detection in international markets of isofenphos-methyl in fresh produce from the province of Almería.

2. How to Modify the Agrosystem

From 1980 to 1985, long before the aforementioned food safety alert arose and brought about the market crisis, the need to improve pest control systems and to seek viable alternatives was put forward. It was around this period that the Department of Agriculture and Fisheries for the Regional Government of Andalusia promoted a series of studies and trials in conjunction with phytosanitary enterprises, companies specializing in the production of organisms for the biological control of pests and especially agrarian associations, technicians and growers who were prepared to take the risk of applying these new techniques, thus laying the foundations for their subsequent development. This collaborative effort came to fruition in 2000, when the first Specific Regulations of Integrated Production (including Integrated Pest Management, or IPM) were published for several species of greenhouse horticultural crops [6]. In their section on pest control, these regulations listed both the autochthonous biological control organisms to be respected and the commercial ones that could be used, while stressing the importance of prioritizing the use of these organisms rather than phytosanitary products. Consequently, there was a sound base of technical knowledge on which to build up a system of pest control in which pesticides played a secondary role [7], allowing the creation of a public database on biological control organisms to control pest training use [8]. However, until the 2006/07 growing season, the farms which took advantage of this knowledge were like isolated "islands" which were seriously affected by the sea of neighboring farms surrounding them which continued to employ chemical substances for pest control.

This scenario changed drastically from 2007 onwards, when as a result of the isofenphos-methyl food safety alert [9], a legal framework was set up which allowed public subsidies to encourage growers to adopt biological pest control, particularly to control insect vectors of viruses in protected horticultural crops.

Indeed, in 2007, the Spanish government procured authorization from the European Union (no. 273/2007) to provide public funding to implement the compulsory measures foreseen in the national program for the control of insect vectors of viruses in horticultural crops which had been passed in 2004 [10]. This program was included in the decree which identified insect vectors as the principal phytosanitary problem and deemed their control to be in the public interest. The difficulty in controlling one of these insects, namely western flower thrips (*Frankliniella occidentalis*), had been at the origin of the food safety alert.

In this context, the Andalusian Department of Agriculture and Fisheries implanted two lines of aid to growers' associations: one aimed to foment the purchase of biological control organisms [11] as a means of controlling the insect vectors of viruses in the crops, subsidizing 50% of their cost; and another one whose purpose was to encourage quality production [12,13] by subsidizing the contracting of Pest Control Advisors for Integrated Production Groups (IPG), set up by growers with a view to obtaining high quality agricultural produce by applying the Regulations of Integrated Production (IPM programs).

The regulations on subsidies were drawn up to include a series of points aimed at attaining efficacy and efficiency in line with the public spending involved. These points and the measures implemented to ensure they are fulfilled are described below.

2.1. Establishment of Homogeneous Crop Areas

Ensuring homogeneous crop areas of sufficient size allows effective biological control (BC) of the insect vectors without interference from the use of chemical substances. Given the small size of horticultural farms in Almería, it proved crucial to involve growers that were grouped together in a variety of associations, mainly Agrarian Cooperatives (SCA) and Agricultural Processing Companies (SAT). Those growers that did not belong to such associations were given the opportunity to constitute an Integrated Production Group (IPG), an Integrated Treatments in Agriculture Group (ITAG), or an Ecological Production Group (EPG). In order to achieve this fundamental objective, subsidies were refused to individual growers who did not apply for aid as a member of one of the above-mentioned associations.

2.2. Pest Control Adviser (PCAs) Training

Technical training of a large number of "pest control advisers" (PCAs) was established over a short period of time, preparing them in methods of biological control in order to minimize mistakes in decisions on effective pest control. To this end, the administration commissioned the Andalusian Institute for Research and Training into Agriculture, Fisheries, Food and Ecological Production (IFAPA) to prepare and impart training courses. This organization had proven experience in this topic as well as suitable facilities in the province of Almería, and they were chosen due to the awareness that any credible and effective plan of biological pest control depended on suitable preliminary training. The training programs involved experts from the administration and the University of Almería, as well as the special collaboration of companies that produce and market biological control organisms (BCOs). Every PCA that passed the course and was willing to serve in the control programs of insect vectors of viruses was required to register on an official government list for subsequent monitoring and control.

To supplement the limited information available about GIP in protected crops, the Department of Agriculture and Fisheries published manuals and control over the use of BCOs of interest for technicians and producers [14]. It did this by taking advantage of important Internet coverage in rural areas which made it possible to develop online IPM manuals available at https://www.juntadeandalucia.es/agriculturapescaydesarrollorural/raif/manuales-de-campo (accessed on 1 February 2022).

2.3. Scope of the PCAs

In Almería, all growers have access to PCAs. However, these advisors do not all have the same aims, nor do they dedicate the same amount of time to the monitoring of crops. As a result, there are often major differences in the crop surface that they supervise. To minimize possible differences in the application of control plans, it was decided to set a maximum crop area for each PCA (supplier-affiliated or independent), depending on the type of crop and the average size of the greenhouses that they were to assess. Limit criteria were established to avoid sampling errors due to work overload, especially if the cultivation area supervised by each advisor was very large and the size of the greenhouses was small. The maximum area was set at 50 hectares for PCAs belonging to grower associations with an average surface area per greenhouse of less than 7500 m^2, and 80 hectares when the average surface area per farm was over 15,000 m^2. This limitation was intended to avoid differences in the monitoring of crops, such as those detected in California for almond crops, where supplier-affiliated PCAs managed a mean of 94.4 almond-bearing hectares, while independent PCAs managed a mean of 124.3 [15].

Since this limiting factor was liable to give rise to additional assessment costs for producer associations, they were offered the chance to set up an IPG, as this would allow them access to public subsidies to offset expenditure on PCAs.

2.4. Control and Monitoring

While the regulations on integrated production (IPM programs) were based on scientific and technical criteria, provision was made for adjustments according to the different requirements of crops and zones. An additional factor that might lead to diversity is whether the PCA is affiliated, for instance, to a supplier or rather is contracted by a growers' association (Independent PCA). This may result in differences in decision making that could have a bearing on the efficacy of plans, as happened in California in the cultivation of the almond tree where independent PCAs communicated more frequently with growers than PCAs who are employed by agricultural product suppliers. Growers who use independent PCAs tend to feel more knowledgeable about integrated pest management (IPM) and report the use of more complex pest-monitoring techniques and control practices [15]. Consequently, all PCAs are obliged to carry out the control of the production process and to fill out the farm logbook, in which they must note down all operations: release of BCOs, doses, application of phytosanitary products, pruning, etc. These logbooks are used to build up a database for establishing future adjustments and improvements to the plans, and all growers are obliged to follow the technical recommendations of their PCAs.

A sample of the farm logbook from four farms of each PCA must be sent weekly via a software program named TRIANA to a centralized database which determines the extent to which the plans are being put into practice and the effects they are having.

Another of the aims of TRIANA that has been maintained over time is the acquisition of knowledge of the phytosanitary state of crops and the building up of a series of records. The results have been published on the Department of Agriculture and Fisheries website: https://www.juntadeandalucia.es/agriculturapescaydesarrollorural/raif/informes-historicos1 (accessed on 1 February 2022).

2.5. Production Capacity and Price of BCOs

Exponential demand was expected, and there were doubts as to the capacity for large-scale production of BCOs. The production of insectaries requires suitable planning, and the experience acquired over previous cycles is therefore essential.

Prior to 2007, the demand for BCOs from the entities that participated in the control program of insect vectors of viruses in horticultural crops in the province of Almería was practically negligible. For a pepper crop surface area of 330 hectares under biological control, in the 2006/07 season (plan for control of insect vectors), 13-million-minute pirate bugs (*Orius laeviegatus*) were required to be released. If biological control methods were to be implemented in 50% of the pepper crop surface, demand for Orius would run to 164 million insects, which would have to be produced in few months. Prior to the 2006/07 cycle, production, and marketing of BCOs was in the hands of a few enterprises. Experience gained elsewhere with advanced IPM programs showed that although the periodic release of natural enemies has often been considered the most suitable of the three approaches to biological control in annual cropping systems [16], in fact there are few examples of the successful use of commercially produced natural enemies in field and row crops. Possible reasons for the lack of success include the high cost of commercial natural enemy production, economic feasibility, and the misconception that mass-reared natural enemies can be used as insecticides.

It was hoped that public subsidies for the purchase of BCOs would lead the powerful auxiliary industry in Almería to seize the opportunity to exploit a new market. The subsidy policy was expected to offset the initial outlay which had been one of the factors in the failure of other experiences involving the release of BCOs. The influx of new enterprises and the involvement of supplies companies were to play a fundamental role in balancing supply and demand, and therefore, in adjusting prices accordingly.

2.6. Maintaining the System over a Minimum Number of Cycles

This was necessary in order that the implantation should prove efficient and sustainable over time. Attaining a considerable crop surface area under biological control alone was not enough. It was important to maintain it to encourage other growers to join the movement. In such a limited production area, based principally on family farming, the best marketing ploy is undoubtedly "word of mouth". Once the control plans were running successfully, it was hoped that other growers would embrace this new form of pest control. In principle, the European Commission's authorization for subsidies on the purchase of BCOs would extend to 2011, and so this was the initial horizon that was contemplated. Subsidies were applied for on an annual basis and growers committed themselves to employing biological control methods on all crop cycles during the respective year. As regards subsidies to Integrated Production Groups to obtain quality production and contract PCAs, the duration was to be limited to five years, terminating at the end of the 2011/12 season. Unlike the subsidies for the purchase of BCOs of insect vectors, the IPG subsidies required a 5-year commitment, and if any group should not fulfill their obligation, all quantities received were to be repaid.

3. Results: The Success of "Almería's Green Pest Management Revolution"

3.1. Establishment of Homogeneous Crop Areas through Growers Associations

The data shown reflect the results of the plan for subsidies for the control of insect vectors of viruses in protected horticultural crops in the province of Almería over the 2007/08, 2008/09, 2009/10 and 2010/11 seasons. A total of 77 grower associations from three areas of the province took part. The municipality of El Ejido accounted for 32 enterprises (41.56%) and 42.57% of the greenhouse crop area.

Thirty-five of the 77 entities that benefited from the subsidies were producer associations (P.A.), 24 were Agricultural Processing Companies (S.A.T.) and 17 were Andalusian Cooperative Societies (A.C.S.). It should be mentioned that 19 of the 35 producer associations were set up around suppliers who committed themselves fully to the marketing of

BCOs to offset the fall in sales of phytosanitary products and offer a full range of products for pest control. This fact is significant in that the priority of all their PCAs shifted from recommending insecticides and acaricides to promoting sales of BCOs. This avoided, to a great degree, the danger that some PCAs affiliated to agricultural product suppliers would have a conflict of interest in recommending biological control methods. While these suppliers affiliated PCAs provide pest monitoring and consulting services for free, their employers stay in business by selling pest control products.

3.2. Pest Control Adviser (PCAs) Training

Between 2007 and 2008, 603 PCAs were trained in biological control, and the IFAPA ran 25 specific courses in Almería in which 335 PCAs participated directly in the program for the control of insect vectors (Table 1). These PCAs were therefore registered by the producer associations on the official government registry for subsequent monitoring and control. They included 298 university Technical Agricultural Engineers (degree holders), 27 Agronomic Engineers (Master graduates), 7 technicians qualified in specialized professional training and 3 Master graduates in Biological Science.

Table 1. IFAPA IPM courses held in the La Mojonera installations (Almería).

Year	N° Courses	Qualified Participants
2007	16	389
2008	9	214
2009	3	77
2010	2	38
2011	1	30

3.3. Scope of the PCAs

The PCAs who took part in the program were contracted in different ways, depending on the social aims of the association in question. In the producer associations (21 APC, 12 ACS and 7 PA), whose aim is the production and sale of horticultural produce, 82.58% of the PCAs were already employed by them (Table 2). However, those associations that were created around companies, whose aim is to sell agricultural supplies or to sell the horticultural produce (Auctions), only employed directly 29.03% and 8.57% of the technicians, respectively, outsourcing this service for the most part. In Almería, the determining factor regarding the type of PCA who provides services is not the size of the farm, but rather the aim of the producer association to which he/she belongs.

Table 2. Chart reflecting the human resources used in the provision of technical assessment between the period 2007–2011.

Social Aim of the Enterprise (Origin)	PCAs	% Crop Surface	Hectares/PCA
(a) Production & sales. Horticultural produce	Employees	82.58%	54.68
	Outsourced	17.42%	42.65
% a/(a + b + c)	a = 539	58.61%	
(b) Sales. Agricultural supplies	Employees	29.03%	49.15
	Outsourced	70.97%	43.53
% b/(a + b + c)	b = 349	32.51%	
(c) Sales. Horticultural produce (Auctions)	Employees	8.57%	30.35
	Outsourced	91.43%	37.04
% c/(a + b + c)	c = 118	8.88%	

3.4. Control and Monitoring

The Department of Agriculture and Fisheries for the Regional Government of Andalusia set up a field-sampling plan that would involve 100% of entities benefiting from subsidies, with samples being taken from at least 10% of the surface area for which the subsidies were awarded. Visits to the farms were carried out by technicians from the administration in the compulsory presence of the grower and the PCA. The farm's technical characteristics were checked, as were the data annotated in the compulsory logbook [17], to ascertain that the control plan was being correctly followed. All PCAs were obliged to register their intervention instructions (release of BCOs, phytosanitary treatments, etc.).

This procedure prevented growers with independent PCAs from receiving more frequent visits and written status reports than growers who used supplier-affiliated PCAs. It also prevented some growers from making use of more than one PCA in the hope of getting better technical advice, as has happened in California in the cultivation of cotton where 50% of farmers have 2 or more PCAs [18]. Though in California the type of PCA appears to play an important role, this is not the case in Almería.

The in situ field monitoring was complemented with data collection via the TRIANA software program, in which each PCA had to note the data from the field logbook over 4 consecutive winter seasons.

These two control mechanisms most likely contributed greatly to the success of the implementation of biocontrol, suitable use of BCOs was ensured to control pests, while at the same time, phytosanitary applications were kept to a minimum, and always in situations which were in no way to the detriment of the BCOs. The monitoring also allowed the authorities to determine an overall decrease in the presence and incidence of the main pests for horticultural crops: whitefly, thrips, aphids (all of which are insect vectors of viruses) and caterpillars. In pepper crops, this drop in incidence was particularly noteworthy. In 2007/08, thrips were found to be present in over 30% of plants, with 10% affected by TSWV in some areas and up to 9% of fruit affected [19]. However, during just three crop seasons, these values fell to 17.3%, 0.9% and 1.1%, respectively. The authors of [20] found that in field and row production, the annual nature of the crops, their greater level of seasonal disturbance, and the highly dispersive nature of many of the associated pests, are important barriers for the establishment and impact of introduced natural enemies. Nevertheless, here it has been shown that the same does not hold true for greenhouse crops. Despite the brevity of the crop cycles, the BCOs not only survived but their populations increased exponentially and held the main pests in check.

The supervision procedures also provided evidence on other crops, namely watermelon and melon, especially in the second crop cycle, showing a decrease in the number of releases and in the doses of BCO applications, possibly due to a fall in the amount of aid from the 2009/10 season onwards, among other reasons. The efficiency of the system implemented allowed rapid action to be taken, setting minimum compulsory doses for the control of insect vectors of viruses from September 2010 [21]. Correct application of these minimum doses was a condition sine qua non for growers to be awarded subsidies (Table 3).

Table 3. Pests to be controlled and minimum doses of BCO releases (no. BCOs/m^2) for each crop.

Pest	Pepper	Tomato	Eggplant	Green Bean
(a) Whitefly	**1** (50)	**4** (0.5)	**1** (50) + **4** (0.5)	**1** (25)
(b) Aphids	**2** (0.15)	-	**2** (0.1)	**2** (0.25)
(c) Thrips	**1** (50) + **3** (2)	**4** (0.5)	**1** (50) + **4** (0.5)	**1** (25) + **5** (50)
Pest	**Zucchini**	**Cucumber**	**Melon**	**Watermelon**
(a) Whitefly	**1** (25)	**1** (50)	**1** (25)	**1** (25)
(b) Aphids	**2** (0.2)	**2** (0.25)	**2** (0.2)	**2** (0.2)
(c) Thrips	**1** (25)	**1** (50) + **5** (100)	**1** (25)	**1** (25)

PEST: (a) Whitefly: *Bemisia tabaci* and *Trialeurodes vaporariorum*; (b) Aphids: *Aphis craccivora*, *Aphis gossypii*, *Aulacorthum solani*, *Macrosiphum euphorbiae*, *Myzus persicae*; (c) Thrips: *Frankliniella occidentalis*. **BCOs**: (**1**) *Amblyseius swirskii*; (**2**) *Aphidius colemani*; (**3**) *Orius laevigatus*; (**4**) *Nesidiocoris tenuis*; (**5**) *Amblyseius cucumeris*.

However, in certain exceptional circumstances, lower doses were allowed on qualified technical advice. It should also be pointed out that certain growers opted for placing among their plants pruned branches from other greenhouses into which BCOs had already been released, thus establishing high populations of these beneficial insects in the new crops. "Interplanting" is a technique which fosters the presence of BCOs, transferring them from autumn-cycle to spring-cycle crops.

The release of the BCOs until reaching the dose indicated in Table 3 was generally carried out in at least two moments. For the control of whiteflies, the most used OCBs were the predatory bug *Nesidiocoris tenuis* (Hemiptera: Miridae) and the predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae), which can be used alone or in combination depending on the crop, as shown in Table 3. For the control of thrips, in addition to the two OCBs indicated above, the predatory bug *Orius laevigatus* (Hemiptera: Anthocoridae) and the predatory mite *Amblyseius cucumeris* (Acari: Phytoseiidae), were used. The most common combinations for trips control according to crops are shown in Table 3. The predatory bugs were released on the plant canopy or by using an application box hung on the plant and the mites were released mainly in slow release hanging sachets. The control of aphids by the parasitic wasp *Aphidius colemani* (Hymenoptera: Aphidiinae) was carried out by using banker plant prior to the detection of aphids in the crop, based on introducing cereal aphids into a greenhouse on cereal plants and *A. colemani*.

Despite these and other actions intended to minimize abundant releases of BCOs, the demand for products was very high, and as a result, the number of enterprises involved in the commercialization of BCOs increased rapidly, reaching a plateau in 2011/12.

3.5. Production Capacity and Price of BCOs

At present, over 70% of the companies marketing the main BCO products registered in Spain for horticultural crops (*A. swirskii*, *A. colemani*; *O. laevigatus*, *N. tenuis* and *A. cucumeris*) are in Almería (16 of 23), and the 118 products they offer represent 88% of the total available on the market. A further indication of the importance of Almería in this market is the fact that 9 of the 10 companies with the highest number of registered products have their Spanish headquarters in this province (Table 4).

The rapid growth of enterprises in this market allowed a downward trend in costs to the grower due to the greater competition for distribution to a limited crop surface area. However, the adjustment in the doses of BCO releases constituted an additional factor in the reduction of costs. This was made possible by the decrease and gradual elimination of phytosanitary residues in the greenhouses, the greater know-how acquired, the perfection of techniques applied and the fall in incidence of crop pests with regard to 2007/08. To illustrate this final factor, in 2007/08, it was necessary to release 4 Orius laviegatus/m^2 to control *Frankliniella occidentalis* in pepper crops, whereas in 2010/11 many greenhouses were able to achieve this aim with only 1.7 Orius/m^2.

According to publications of the Research Institute of the Cajamar Foundation [22] from biological control's arrival on the scene in 2007/08 to the 2012/13 season, pest control cost (chemical control + biological control) fell by 32.16%.

Table 4. Companies marketing BCOs products registered in Spain in 2022. Source: MAPA, [23].

Enterprise	No. BCOs Products					Province/Country
	1	2	3	4	5	
Agrinature Producciones Agrícolas, S.L.	1	1	1	1		Almería (Spain)
Agrobio, S.L.	1	2	2	1	1	Almería (Spain)
Agrocontrol 2007, S.L.	1	1	1	1		Almería (Spain)
Agroquímicos Los Triviños, S.L			1			Murcia (Spain)
Bgreen Biological System, S.L.	1	1	1	1	1	Almería (Spain)
BICHELOS, Control Biológico S.L.		1	1	1		Valencia (Spain)

Table 4. *Cont.*

Enterprise	No. BCOs Products					Province/Country
	1	**2**	**3**	**4**	**5**	
Biobest Sistemas Biológicos, S.L.	5	4	3	1	4	Almería (Spain)
Biocolor Iberia, S.L.	1	1	1	1		Almería (Spain)
Biocontrol Del Mediterráneo, S.L.				1		Alicante (Spain)
Bioline Agrosciences Limited Iberia	1	3	1	1	1	Almería (Spain)
Bioplanet Ibérica, S.L.	5	4	2	2	3	Almería (Spain)
Biosur Productos Agrícolas, S.L.U.	3	2	1	1	2	Almería (Spain)
Certis Europe, B.V.	1	1	1	1	2	Alicante (Spain)
Entonova, S.L.	1		1	1		Almería (Spain)
Insectaria, S.L.			1	1		La Rioja (Spain)
Insectos Med, S.L.	1		1	1		Almería (Spain)
Koppert Biological Systems, S.L.	4	3	2	2	3	Almería (Spain)
Mip System Agro, S.L.	4	2	2	2	3	Almería (Spain)
Plant-E Productos Naturales S.L		1		1		Navarra (Spain)
Provi Agricola, S.L.		1	1	1		Almería (Spain)
Saniveg, S.L.	1	1	2	1	1	Almería (Spain)
Surinver El Grupo			1			Alicante (Spain)
Verde Ibérica, S.C.A.	1		1	1		Almería (Spain)
Total	32	29	28	24	21	Almería (Spain)

BCOs: (1) *Amblyseius swirskii*; (2) *Aphidius colemani*; (3) *Orius laevigatus*; (4) *Nesidiocoris tenuis*; (5) *Amblyseius cucumeris*.

Table 5 provides an overview of the annual production costs of a typical plastic greenhouse small holding expressed in euros/ha. Applying these data to the current total greenhouse surface area of 29,500 hectares, the growers' savings due to the introduction of biological pest control over the period in question would be over 43 million euros.

Table 5. Annual production costs by items in Almerian greenhouses, in euros/ha in 2006–2013. Source: [22].

Expense Item	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Water	1359	1416	1420	1379	1429	1448	1463
Biological control	0	1029	1092	908	964	807	785
Pesticide control	4565	2295	2363	2349	2339	2342	2312
Energy consumption	1121	1197	1201	1208	1223	1235	1280
Fertilizers	3744	5136	5998	3911	3973	3925	3929
Labor	20,466	21,223	21,902	22,077	22,541	22,744	22,812
Seeds and seedlings	4186	4353	4497	4623	4716	4892	4991
Services	5725	6351	4476	4079	4201	4179	4185
Total	41,166	43,000	42,949	40,534	41,386	41,572	41,757

In 2006/07, expenditure on pest and pathogen control was 100% on chemical methods, and after that date, expenditure is divided between chemical and biological techniques. Pesticide control methods, aimed principally at pathogen control (especially fungi), fluctuate slightly from 2007/08 onwards, whereas the cost of biological control methods fell steadily over the same period, thus reducing growers' expenditure on pest control.

3.6. Maintaining the System over a Minimum Number of Crop Seasons to Ensure Its Stable Implementation

Public subsidies were originally planned to be maintained over 4 agricultural years and to cover 50% of the purchase costs of BCOs. However, this plan fell through with the advent of the international recession which hit Spain in 2008 and the subsequent banking crisis in 2010. Public funds were no longer available to uphold the plan, and as a result, subsidies dropped in the 2009/10 and 2010/11 crop seasons to cover less than 25% of BCO purchases. This entailed the risk that some associations might opt out of the control plans and that other might not become involved. However, the other line of subsidies aimed at IPGs was maintained over the planned 5-year program, though in this case, the amounts involved were considerably lower.

Table 6 outlines the public subsidies paid for the biological control of protected horticultural crops in the province of Almería. A total of 31.5 million euros was destined to IPGs and to the purchase of BCOs over 5 crop seasons. Between 2007/08 and 2011/12 campaigns, the average annual subsidy per hectare for biological control was 450.41 €, 89.4% was dedicated for purchase of OCBs and 10.6% for contracting PCAs.

Table 6. Public subsidies paid for the biological control of protected horticultural crops in Almería.

Public Subsidies (€)			
Crop Season	**BCOs**	**IPGs**	**Total**
2007/08	10,719,014	1,229,618	11,948,632
2008/09	10,891,014	831,357	11,722,371
2009/10	3,728,485	735,986	4,464,471
2010/11	2,382,899	497,228	2,880,127
2011/12	0	494,484	494,484
Total	27,721,412	3,788,673	31,510,085

There is a clear drop in demand for subsidies for the purchase of BCOs from 2009/10 onwards. It would be a mistake to attribute this to a loss of interest in biological control. While it is true that certain growers' associations forewent subsidies due to the fact that the aid received did not offset expenses in administrative tasks, they did in fact continue to employ biological control organisms for pest control.

It is quite remarkable that the first two years proved sufficient to convince those growers who undertook biological control of the worth of this method, as Table 7 illustrates. It shows the percentage of greenhouse crop area in Almería in which biological control methods were implemented over 8 agricultural seasons between 2005 and 2013, detailing the number of hectares that received subsidies for the purchase of BCOs (against insect vectors) on the one hand, and for contracting PCAs on the other (IPGs).

Table 7. Evolution of greenhouse crop area in Almería with biological control since 2005/06 to 2012/13.

Crop Season	Biological Control Area (ha)	Area Receiving Aid for Purchase of BCOs (ha)	Area Receiving Aid for Contracting PCAs (ha)	Total Crop Area (ha)	% Biological Control Total/Total Crop Area
2005/06	129	129	129	40,233	0.32%
2006/07	756	756	756	39,583	1.91%
2007/08	10,447	9239	8281	38,987	26.80%
2008/09	18,807	15,541	17,853	39,251	47.92%
2009/10	19,525	11,141	17.621	39,087	49.95%
2010/11	20,081	8135	14.383	37,224	53.95%
2011/12	20,754	0	11.432	39,599	52.41%
2012/13	25,000	0	7.251	44,114	56.67%

Table 7 clearly reflects the exponential increase in biological control methods immediately after the food safety alert, coinciding with the offer of public aid. The initial sharp increase in crop area treated with these methods was followed by less marked increments in subsequent seasons, but with a steady upward trend.

In 2007/08, almost 90% of the crop area that was treated with biological control methods came under the umbrella of the aid plan for the purchase of BCOs, which acted as a driver to change in pest control systems. Two years later, over 40% of the crop surface under biological control received no subsidies, and this period coincided with the fall in the subsidies offered. Unlike the subsidies for the purchase of BCOs, those destined for

IPGs fell less sharply. In fact, this aid remained constant due to the 5-year commitment to the plan demanded of the growers at the outset.

BCOs can currently be considered the "conventional" pest control method in Almería. In the last eight years (2013–14 to 2020–21), the average area dedicated to biological control has been 25,472 ± 1262 hectares although with slight interannual modifications. Their efficiency in keeping pests in check and their relatively low cost (considerably less than insecticides and acaricides) have won over growers, who have embraced this method irrespective of the final market destination of their produce and of the quality certifications they use.

Two factors have contributed to solving the occasional problems that have arisen in connection with biological control in greenhouses in Almería: on the one hand, the mean size of farms in Almería means that growers are well aware of the phytosanitary conditions of their crops, and on the other, social, technical and business factors have combined to maintain a high level of interest and commitment to this pest control method. As a result, the planning and management of BCOs in IPM programs of greenhouse horticultural crops have become universal standards for the whole province. This uniformity within the greenhouses of the province constitutes a barrier to the arrival of major populations of new pests, and therefore provides the system with the stability which helps to maintain it.

4. Conclusions

It can be concluded from these results that, unlike many programs of public subsidies which involve long-term expenditure, the aid in question took advantage of the socioeconomic situation following the food safety alert due to the presence of isofenphos-methyl residues in exported fresh produce. The program led to substantial economic savings and met its objectives swiftly, achieving excellent results in terms of removing most of the pesticides used in the "conventional" production system. Similar results using IPM were obtained in California for over 35 years [24]. As such, they illustrate the importance of rapid regulation and intervention if public funds are to make the most of circumstances and benefit society as a whole, even when, as in this case, the initial scenario appears to be unfavorable.

This can be considered a pioneering experience which has shown that at a mean cost of 6.3 million euros a year (equivalent to 0.36% of the total value of horticultural production in the province of Almería) over a 5-year period, it has proved possible to promote a policy change in pest control methods. This has contributed to the stability of Almería's produce on national and international markets, improving its image and setting an example that has become known on an international scale as "Almería's green pest management revolution".

Juntti and Downward [5] refer to Almeria's horticultural production innovations, such as IPM and water efficient irrigation systems, that have been advanced through the remarkable "capillary system" formed by marketing organizations and agronomists working closely with auxiliary enterprises and farmers.

"Almeria's green pest management revolution" was the answer of this "capillary system" with the Regional Administration support to a food safety alert. Although there are other environmental challenges awaiting to be solved in Almería like in most of the intensive production systems worldwide, but even if IPM is seen as stemming from market demand, it is an important aspect of "greening" the industry and addressing health concerns of both consumers and producers.

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