Plastic barriers control Andean potato weevils (*Premnotrypes spp.*): large-scale testing of efficacy, economic and ecological evaluation and farmers' perception

Jesús Alcázar and Jürgen Kroschel

International Potato Center (CIP), Apartado 1558, Lima 12, Peru. j.alcazar@cgiar.org

Abstract

Andean potato weevils (*Premnotrypes* spp.) are key potato pests in the Andes. Insecticides are the most widely used control method employed by farmers. Recently, plastic barriers at field borders proved to stop the migration of flightless Andean potato weevil (*Premnotrypes suturicallus*) adults to potato fields and have been equally effective compared to farmers' practice of using insecticides. The objectives of this study were to further validate the efficacy of this technology in two Andean villages with the participation of 40 farmers, to evaluate costs and environmental impact compared to insecticides, and to assess farmers´ perception and preparedness to use this technology. Plastic barriers effectively reduced Andean potato weevil damage by 65% and 70% in the two villages compared to farmers´ practice using 2 to 6 insecticide applications. Plastic barriers proved to be also effective to control other weevil species, such as *P. solaniperda, P. latithorax and P. vorax* in potato agroecologies of Peru, Bolivia and Ecuador. The use of plastic barriers resulted in an excellent investment with mean net benefits of US$147/ha and US$807/ha for farmers of the two villages. The environmental impact quotient (IEQ) was five times lower for the plastic barriers (32.86) compared to farmers' practice (191.52) indicating the overall benefits of the technology to reduce the risks of insecticide applications for farmers, consumers and the environment. Farmers' opinion was very positive with more than 90% of interviewed farmers considering plastic barriers as a very useful and easy-to-install control tool, and interested to further promote this technology among other farmers.

Keywords: Potato, Integrated Pest management, Andean potato weevil, *Premnotrypes suturicallus*, physical control.

Introduction

Andean potato weevils (*Premnotrypes* spp.) are native in the Andean region and the most important pests of potato (*Solanum* spp.) at altitudes between 2,800 and 4,750 m. The species are widespread from Argentina to Venezuela covering a mountainous territory of a length of 5,000 km. The most severe crop damage is caused by larvae which feed on tubers and cause tuber infestations and losses of up to 100%, if no control measures are applied. Main control measures used by farmers are the application of hazardous insecticides (Ewell *et al.* 1990, Orozco *et al.* 2009). Adults of Andean potato weevils are flightless and hence migrate from previous years potato fields to new potato production sites. Recently, a new technology using physical barriers around potato fields have been successfully tested to control Andean potato weevil *Premnotrypes suturicallus* Kuschel (Kroschel *et al.* 2009). The objective of this study was to validate the plastic barrier technology with a large number of farmers in two Andean villages in comparison to farmers' traditional practices of using several insecticide applications to control Andean potato weevil, and to study their economics and environmental impacts compared to insecticide applications. Additionally, we studied farmers' perception about the use of plastic barriers in one Andean village, which was involved in the evaluation and use of the plastic barriers for several years.

Materials and methods

Large scale validation of the plastic barrier technology

The study was carried out in the villages Ñuñunhuayo (3,800 m a.s.l., Department of Junin, Peru) and Aymara (3,900 m a;.s.l., Department of Huancavelica, Peru) with a participation of 20 farmers in each of the communities. Participating farmers established subplots in their potato fields of a size of 225 m^2 (15 x 15 m), which were surrounded by a plastic barrier at the day of planting. The plastic was fixed on wooden stakes and installed 10 cm below soil with a total height of 50 cm above soil as described in Kroschel *et al.* (2009). Except of the plastic to prepare the barriers all other inputs (seed, fertilizer) were provided by farmers. Further, farmers were equally responsible for all cultural labors (weeding, hilling). In the plastic barrier plots no insecticides were applied but fungicides Cymoxanil for controlling late blight (*Phytophtora infestans* Mont. De Bary), when considered appropriate. Potatoes grown outside of the plastic barriers received insecticide (carbofuran, fipronil) applications according to farmers' practice. At harvest, treatment efficacy was evaluated with farmers' participation by scoring tuber damage caused by Andean potato weevils. In the plastic barrier subplots as well as in the overall farmers plots 5 x 3 m subplots of potato rows with a total of 10 potato plants each (50 potato plants per subplot) were randomly selected and the number and proportion of healthy and damaged tubers per plant as well as the total tuber yield determined.

Validation of the plastic barrier technology in different potato agroecologies

Additional individual field studies, using the methodology as described above, were carried out in other potato growing regions of Peru as well as in Bolivia and Ecuador to test the plastic barrier technology in different potato agroecologies, where other Andean potato weevil species prevail: Puno, Peru (3,900 m a.s.l.): *Premnotrypes solaniperda* Kuschel*;* Huancavelica, Peru (3,800 m a.s.l.): *Premnotrypes suturicallus;* Carchi, Ecuador (8 field experiments at altitudes of about 3,000 m): *Premnotrypes vorax* (Hustache)*;* Cochabamba, Bolivia (3,400 m a.s.l.): *Premnotryopes latithorax* (Pierce)*.*

Environmental impact of pesticides compared to the use of plastic barriers

The environmental impact for the use of pesticides was calculated by multiplying the Environmental Impact Quotient **(**EIQ) value for each insecticide (carbufuran, EIQ: 50.67; fipronil, EIQ: 90.92) and fungicide (cymoxanil, EIQ: 8.7) by the amount of pesticide used per hectare and the number of applications per season. EIQ values were taken from an updated table at Cornell University webpage: http://nysipm.cornell.edu/publications/eiq/files/EIQ_values.xls.

Farm survey on the adoption potential of plastic barriers

The adoption potential of plastic barriers was studied through 40 individual farm surveys (questionnaires) in the village of Ñuñunhuayo. Most of the farmers of this village were involved and could gain experiences with this technology over several years, in which this technology was tested on-farm. The survey comprised questions to learn about traditional potato crop management and farmers opinions about the use of plastic barriers as a new alternative control tool for Andean potato weevil.

Statistical analysis

Data for potato tuber infestation and tuber yield were subjected to analysis of variance (ANOVA). The Kruskal-Wallis test was applied to analyze statistical differences in potato tuber losses (SAS Institute 2003). For the calculation of the insecticide application costs per hectare we collected information throughout the cropping season on the quantity of product used per knapsack sprayer and area as well as on the number of applications. Plastic barriers' cost calculations are based on the price of the plastic per meter and the wooden sticks to fix the barriers. For the estimation of net profits we followed the methodology described by Ortiz *et al.* (1996).

Results

Large-scale validation of the plastic barrier technology

Efficacy of plastic barriers versus insecticide applications. In the 20 plastic barrier fields in Ñuñunhuayo, tuber infestation ranged from 0 to 27% with an average infestation of 6.7%. In contrast, farmers´ insecticide-treated fields showed a tuber infestation between 1.8 to 51.26% with an average of 19.6% (Table 1). These fields were treated 2-5 times with the hazardous insecticides Furadan, Carbofuran or Regent. Likewise, in Aymara, tuber damage at harvest ranged from 0.5% to 16% in the 20 plastic barrier fields with an average infestation of 5.5%. Here, farmers' insecticide-treated fields received 1-5 times insecticide applications and tuber damage ranged from 0.45 to 44.8% with an average of 18%.

Table 1. Mean potato tuber infestation by Andean potato weevil (*Premnotrypes suturicallus)*, total tuber yield, Andean potato weevil caused tuber loss and cost for insecticides and plastic barriers in plastic barrier and insecticide-treated farmers plots in the villages Ñuñunhuayo and Aymara, 2007 (N=20 for each treatment at each location).

Parameters	Ñuñunhuayo		Aymara	
	Plastic barrier	Insecticide-treated	Plastic barrier	Insecticide-treated
Mean proportion of infested tubers (%)[1]	6.66a (1.74)*[a]	19.61b (2.87)	5.48a (1.15)	18.03b (3.38)
Mean total tuber yield of (kg/ha)[1]	9,650.60a (763.37)	9,813.63a (639.21)	20,885.03a (2,896.15)	18,002.33[a] (2,926.80)
Mean proportion of damaged tuber weight (kg/ha)[1]	676.34 (200.46) a	1,850.31 (300.59) b	1,027.83 (270.31) a	3,813.21 (1,312.78) b
Mean technology costs (US$)	57.00	101.58 (6.42)	57	96.51 (8.17)

[1]Means followed by different letters within a row are significant different according to the LSD or Kruskal-Wallis test at P • 0.05. *Figures in brackets indicate Standard errors.

Tuber yield in plastic barrier **versus** ***insecticide-treated plots**.* In the 20 plastic barrier fields in Ñuñunhuayo tuber yields varied from 4,950 kg to 17,033 kg/ha, with an average of 9,651 kg/ha. Losses caused by the Andean potato weevil through tuber damage ranged between 0 and 1,800 kg with an average damage of 676.34 kg/ha (Table 1).Yields in farmers' insecticide-treated plots ranged from 4,793 kg to 17,476 kg/ha, with an average tuber loss of 9,814 kg/ha. Here, tuber losses ranged between 320 to 5430 kg with an average of 1,850 kg/ha. In this community mainly bitter native potato varieties are planted, which are processed to freeze-dried potatoes called "chuño". Likewise, in Aymara, tuber yield in plastic barrier fields varied from 7,243 kg to 51,720 kg/ha, with an average of 20,885 kg/ha. Here, losses caused by Andean potato weevil ranged between 32.12 and 1,943.88 kg/ha with an average tuber loss of 1,027 kg/ha. In insecticide-treated fields, yield ranged from 7,130 kg to 57,880 kg, with an average of 18,002 kg/ha. The tuber yield loss caused by Andean potato weevil ranged in these fields between 44 and 25,108 kg/ha, with an average tuber loss of 3,813 kg/ha. In this village, commercial as well as native potato varieties are cultivated.

***Efficacy of the plastic barriers in different potato agroecologies**.* Preliminary on-farm experiments in different potato agroecologies in Peru (Puno and Huancavelica), Bolivia and Ecuador confirmed that plastic barriers also control other Andean potato weevil species like *P. solaniperda* in Puno*, P. latithorax* in Bolivia or *P. vorax* in Ecuador (Table 2).

Table 2. Potato tuber infestation (%) caused by different Andean potato weevil species (*Premnotrypes* ssp.) in plastic barrier and insecticide-treated fields in different potato agroecologies of Peru, Ecuador and Bolivia, 2008

Treatments	Peru		Bolivia	Ecuador
	Puno	Huancavelica	Cochabamba	Carchi
Species	*P. solaniperda*	*P. suturicallus*	*P. latithorax*	*P. vorax*
Plastic barrier	3.98	20.01	5.0	5.0
Insecticide-treated	10.9	40.86	18.0	5.0
Control	15.35	55.40	-	-

Economic benefits of plastic barriers versus insecticides

***Input costs for insecticides and plastic barriers**.* For farmers in Ñuñunhuayo costs for insecticide treatments varied from US$65 to US$162.5/ha, with an average of US$ 101.58/ha (Table 1). In Aymara, costs for insecticides ranged between US$65 to US$162.5/ha, with an average of US$96.50/ha. In contrast, the costs of plastic barriers (including wooden sticks) were US$57/ha.

***Net benefits for plastic barriers* versus *insecticide-treated plots*.** A net benefit for the use of plastic barriers of US$147.63/ha and US$807.31/ha was estimated for the potato production systems of Ñuñunhuayo and Aymara, respectively, based on mean tuber yield, mean tuber infestation at harvest, potato price with and without damage, proportion of damaged tuber weight, costs for plastic barriers and insecticide applications (Table 3).

Table 3. Estimated net benefits for plastic barriers and insecticide treatments to control Andean potato weevil (*Premnotrypes suturicallus*) in the villages Ñuñunhuayo and Aymara, Peru. Means derived from 20 on-farm experiments in each of the villages

Parameters	Ñuñunhuayo		Aymara	
	Plastic barrier	Insecticide-treated	Plastic barrier	Insecticide-treated
Mean total tuber yield of (kg/ha)	9,651	9,814	20,885	18,002
Mean proportion of infested tubers (%)	6.65	19.61	5.49	18.03
Price of healthy tubers (US$/kg)*	0.16	0.16	0.16	0.16
Price of infested tubers (US$/kg)**	0.05	0.05	0.05	0.05
Mean proportion of damaged tuber weight (kg/ha)	676	1,850	1,027.83	3,813
Mean technology costs (US$)	57.00	101.57	57.00	96.50
Total value of healthy tubers (US$/ha)	544.16	1,570.24	3,341.60	2,880.32
Total value of infested tubers (US$/ha)	33.80	92.50	51.39	190.65
Total weight of healthy tubers (kg/ha)	8,975	7,964	19,858	14,189
Value of healthy tubers (US$/ha)	1,436	1,274.24	3,177.28	2,270.24
Value of healthy and infested tubers (US$/ha)	1,469.80	1,366.74	3,228.67	2,460.86
Net production benefits (US$/ha)	1412.80	1,265.17	3,171.67	2,364.36
Net benefits from plastic barrier (US$/ha)	147.63		807.31	

*Considers a potato price of S/.0.50 (1$=3.10); **Considers a loss of value of infested tubers by 67% (Ortiz et al. 1996).

Environmental Impact of plastic barriers and insecticide applications

The Environmental Impact Quotient (EIQ) for the use of insecticides ranged between 32.4 and 486.4 with a mean of 144.8 per ha (Tables 4). Farmers used fungicides more frequently and hence also the EIQ for fungicides was higher in the insecticide-treated fields compared to the plastic barrier fields.

Table 4. Environmental Impact Quotient (EIQ/ha) for insecticide-treated and plastic barrier fields to control Andean potato weevil control. Ñuñunhuayo, 2007.

Treatments	EIQ for insecticides	EIQ for fungicides	EIQ: Total
Insecticide-treated	144.81 (24.48)* 32.43 – 486.43**	46.72 (3.72) 15.66 – 125.28	191.50 (30.10) 52.14 – 344.09
Plastic barrier	0	32.88 (2.42) 20.88 – 62.64	32.88 (2.42) 20.88 – 62.64

* Standard error; **minimum and maximum range

Adoption potential of plastic barriers

According to 97.5% of the farmers interviewed in Ñuñunhuayo, the Andean potato weevil is the main pest problem in potato production. Farmers (75%) are practicing fallow with periods of more than five years; a typical rotation (90% of farmers) is fallow-potato-oat (*Avena fatua* L.)-fallow. Almost all farmers apply highly toxic insecticides to control Andean potato weevil like carbofuran (92.5 %) with an average of three applications during the potato cropping period. Most farmers (95%) valued plastic barriers as useful to reduce Andean potato weevil caused tuber damage (Table 5). Farmers (100%) consider installing barriers as easy and state that barriers do not interfere with cultural practices in potato (90%). Among main constraints plastic barriers may be affected by rain, sunlight, wind and animals. According to 82% of the farmers plastic is easy to find, but they would prefer to buy it in their own village. Ninety percent of farmers would accept a price of US$0.16/m and 65% of farmers would recommend this technology to other farmers.

Table 5. Farmers' opinion about the use and constraints of plastic barriers, Ñuñunhuayo (N=40)

Questions	Acceptation	%
What is your opinion about plastic barrier?	Useful; reduces Andean potato weevil damage	95
Any problem with the installation?	Easy to install	100
Any interference with cultural practices?	No	90
Any other constraints?	Rain, sunlight, wind and animals	30
Is it easy to find/buy plastic?	Yes	82
How much are you willing to pay for plastic?	Until US$ 0.16/m	90

Discussion

Large-scale validation of the plastic barrier technology

The large scale validation confirmed previous results that plastic barriers control Andean potato weevils effectively (Kroschel et al. 2009), and moreover clearly demonstrated its higher efficacy compared to the use and application of insecticides. In both villages Ñuñunhuayo and Aymará, plastic barriers reduced mean tuber infestation by 65% to 70% compared to insecticide applications directed by farmers. In this experiment, no control fields without any control could be set up; however, Ewell *et al.* (1990) for example reported a mean tuber infestation of 70% at harvest in 51 fields evaluated in the Rio Mantaro valley. According to Ortiz *et al.* (1996) an Andean potato weevil infestation of 10% already causes significant economic losses for a commercial potato producer. The preliminary evaluation of the plastic barrier technology in other potato agroecologies of Peru and the Andes (Bolivia, Ecuador) also successfully demonstrated the efficacy of barriers to hinder migration and reduce infestation of other Andean potato weevil species like *P. solaniperda* in Puno*, P. latithorax* in Bolivia or *P. vorax* in Ecuador (Belmont 2007).

Economic benefits of plastic barriers versus insecticides

The higher tuber infestation in insecticide-treated fields caused higher tuber yield losses compared to the use of plastic barriers. Further, the costs for insecticides were almost double as high as for the materials used to prepare the plastic barriers. We didn't consider labor costs for the insecticide applications, which also would include the transport of water, or the time for the installation and/or maintenance of the plastic barrier. The cost of insecticides also varied greatly with regard to the type of insecticide and the number of applications. However, high net benefits of US$147.63/ha and US$807.31/ha were estimated for the two villages Ñuñunhuayo and Aymará, when using plastic barriers.

Ecological assessment

Environmental Impact Quotient (EIQ). High EIQ values of a mean of 144.87/ha were determined for farmer's practice of using highly toxic insecticides to control Andean potato weevil. EIQ values are classified as low (0-20), medium (20.1-40) and high (more than 40) (Mazlan and Mumford 2005). The insecticides used by farmers in this study belong to the group of Carbamates (carbofuran) and Phenylpyrazole (fipronil), which have EIQ values of 50.7 and 90.92, respectively. Carbofuran is classified as a highly hazardous Ib pesticide, and fipronil belongs to class II, moderately hazardous pesticides (WHO 2005). The application of other highly hazardous insecticides to control Andean potato weevil is very common in the study region. Orozco *et al.* (2009) reported that farmers often also use metamidophos (Class Ib) in the Mantaro valley, which has an EIQ value of 36.8 (http://nysipm.cornell.edu/publications/eiq/files/EIQ_values.xls).

Adoption potential of plastic barriers. In the study village Andean potato weevils are the main biotic constraint in potato production to which farmers' response by using highly hazardous insecticides. Farmers interviewed in the village Ñuñunhuayo generally had an overall good opinion about the use of plastic barriers, but first the following years will show and prove if they will adopt and continue using this technology on their own.

Conclusions

The application of insecticides is the only direct control method for Andean potato weevils that is employed by farmers. Earlier, integrated pest management recommendations suggested the use of various cultural practices (crop rotation, use of chicken after harvest to reduce the larvae population in soil, etc.) or baiting weevils with potato leaves treated with insecticides but which methods all do not reduce tuber damage in the short-term and hence are difficult for farmers to adopt. Based on an enhanced knowledge about the weevil migration and behavior, the plastic barrier technology was developed and successfully tested in two Andean villages over a period of fours years in more than 60 individual field experiments. The technology has shown not only to be more reliable than several insecticide applications but also to be more cost effective and environmental friendly. At present, the technology is being taken up by the national agricultural institutes in Peru, who will further distribute and promote the use of plastic barriers.

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