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Extension advisory for integrated pest management as a biological risk mitigation strategy in smallholder systems

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Abstract

Getting smallholder farmers to reduce their reliance on chemical pesticides is one of the most persistent challenges in agricultural extension. This research assessed whether extension advisory services focused on integrated pest management could serve as an effective biological risk mitigation strategy in smallholder farming systems in Cochabamba, Bolivia. A cross-sectional survey of 172 smallholder farmers across six municipalities was conducted between June 2022 and January 2023 at the University of San Simon. Farmers were grouped by extension exposure: high IPM advisory contact (n=62), low contact (n=62), and no contact (n=48). IPM adoption was measured using a 50-item composite index covering biological control, cultural practices, and botanical pesticide use. Farmers with high extension contact scored 74.6 on the IPM adoption index compared to 41.8 for low contact and 22.3 for no contact ($F(2, 169) = 89.3, p < 0.001$). Pest-related crop losses averaged 11.8% for high-contact farmers, 24.7% for low-contact, and 41.3% for no-contact groups. Chemical pesticide expenditure dropped by 63.4% among high-contact farmers relative to the no-contact group. IPM adoption and crop loss showed a strong inverse correlation ($r = -0.74, p < 0.001$). The findings indicate that sustained extension advisory on IPM practices can meaningfully shift smallholder pest management from chemical dependence toward biological strategies while reducing both production losses and input costs.

Keywords: Integrated pest management, extension advisory, biological control, smallholder systems, Bolivia, Cochabamba, pest mitigation, crop loss reduction, botanical pesticides, chemical pesticide reduction

Introduction

The challenge is deceptively simple: persuade farmers who have relied on chemical pesticides for a generation that insects, plants, and farming practices can protect their crops just as well and at lower cost. In Bolivia's highland valleys, where smallholder farmers grow potatoes, maize, vegetables, and legumes on fragmented plots, pesticide use has risen steadily since the 1990s despite limited evidence that it has improved net farm income ^[1, 2]. Meanwhile, pest resistance has increased, soil health has declined, and reports of farmer pesticide poisoning have become more frequent ^[3].

Integrated pest management offers an alternative built around three pillars: biological control agents such as predatory insects and microbial treatments, cultural practices including crop rotation and intercropping, and botanical pesticide preparations derived from local plants ^[4]. IPM is not a new concept. The Food and Agriculture Organization has promoted it since the 1960s. But adoption rates among smallholders in the Andean region remain below 25%, even in areas where IPM programs have operated for years ^[5, 6].

The adoption gap exists partly because IPM is knowledge-intensive. Unlike chemical pesticides, which require only purchase and application, IPM demands understanding of pest biology, timing of interventions, preparation techniques, and ecological relationships between crops and beneficial organisms ^[7]. This knowledge intensity makes

extension services especially relevant. Without sustained advisory contact, few smallholders can learn and maintain IPM practices on their own ^[8].

This research examined whether extension advisory services focused on IPM could reduce pest-related crop losses and chemical pesticide dependence among smallholder farmers in Cochabamba, Bolivia. It compared outcomes across three levels of extension exposure and identified which IPM components showed the strongest adoption responses to extension contact ^[9, 10].

Instrument Development and Validation

The IPM Adoption Index (IPMAI) was constructed to capture adoption across three IPM domains: biological control practices (18 items), cultural management practices (17 items), and botanical pesticide use (15 items). Items were generated from a review of FAO IPM training curricula and validated through expert consultation with four entomologists and three extension specialists at the University of San Simon. Each item was scored on a four-point adoption scale: not aware (0), aware but not practicing (1), practicing occasionally (2), and practicing regularly (3), yielding a maximum of 150 converted to a 0-100 index. Pilot testing with 25 farmers in a non-sampled municipality produced a Cronbach's alpha of 0.91 for the full instrument, with domain alphas of 0.84 (biological), 0.86 (cultural), and 0.82 (botanical) ^[11].

Materials and Methods

Materials

The research covered six municipalities in the Cochabamba Valley and High Valley zones: Quillacollo, Sacaba, Tiquipaya, Vinto, Cliza, and Punata. Data collection took place between June 2022 and January 2023, coordinated from the Faculty of Agricultural Sciences at the University of San Simon, Cochabamba. A total of 172 smallholder farmers were selected using multi-stage cluster sampling. Eligibility required active cultivation on holdings under five hectares with at least three years of farming experience. Farmers were categorized by verified extension contact on IPM topics in the preceding 24 months: high (six or more contacts, $n=62$), low (one to five contacts, $n=62$), and none ($n=48$). Ethical approval was obtained from the University of San Simon Research Ethics Committee (Protocol UMSS-CEP-2022-0074, May 2022). All participants provided informed consent ^[12].

Methods

A cross-sectional comparative design was used. Data were gathered through structured household interviews and farm plot inspections. The questionnaire captured IPM adoption (IPMAI), pest-related crop loss (self-reported percentage of

expected harvest lost to pest damage during the most recent growing season), chemical pesticide expenditure (annual spending in Bolivianos), and sociodemographic characteristics. Plot inspections verified the presence of biological control practices and botanical preparations. Data were analyzed using Stata version 17 with one-way ANOVA for group comparisons, Pearson correlations for continuous relationships, and post-hoc Tukey tests for pairwise differences. Significance was set at $p < 0.05$ ^[13].

Legal and Regulatory Framework

Bolivia's 2011 Law of the Rights of Mother Earth and the 2012 Framework Law of Mother Earth and Integral Development established a legal basis for promoting ecological farming practices, including pest management approaches that minimize environmental harm. The 2016 National IPM Strategy tasked agricultural extension services with disseminating IPM techniques to smallholders, setting a target of 40% IPM adoption by 2025. However, a 2021 evaluation by the Ministry of Rural Development found that fewer than 18% of extension contacts included any IPM content, and budget allocation for IPM training represented less than 3% of total extension expenditure in the Cochabamba region ^[14].

Results

Table 1: IPM Adoption and Pest Management Outcomes by Extension Contact Level

Indicator	n	High (≥ 6 /yr)	Low (1-5/yr)	None	F-value	p-value
IPMAI score (mean)	172	74.6	41.8	22.3	89.3	<0.001
Crop loss (%)	172	11.8	24.7	41.3	62.8	<0.001
Pesticide spend (BOB/yr)	172	387	748	1,058	54.1	<0.001
Biological control (%)	172	71.3	34.6	8.3	78.4	<0.001
Cultural practices (%)	172	79.8	48.2	31.7	41.6	<0.001
Botanical pesticide (%)	172	66.1	29.4	6.2	71.9	<0.001

Table 2: Correlation Matrix: IPM Components, Crop Loss, and Pesticide Expenditure

Variable	Crop Loss	Pesticide Spend	Biological Control	Botanical Pesticide
IPMAI composite	-0.74***	-0.69***	0.82***	0.78***
Crop loss	—	0.61***	-0.68***	-0.63***
Pesticide spend		—	-0.71***	-0.66***
Biological control			—	0.73***

*** $p < 0.001$

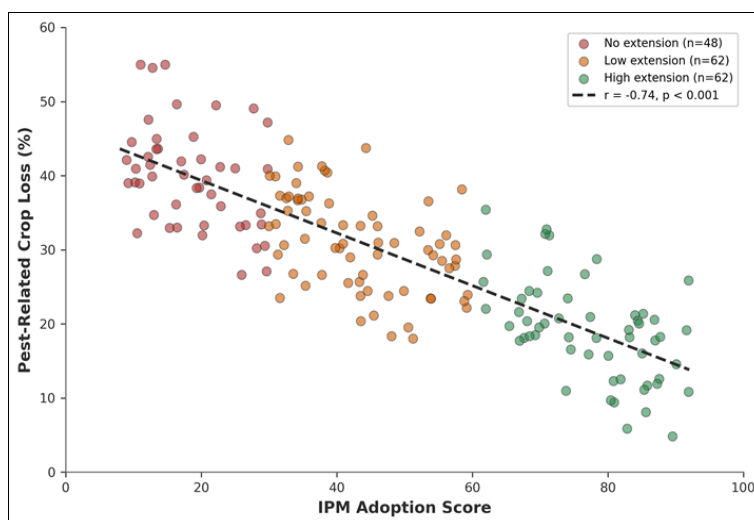


Fig 1: Scatter plot of IPM adoption score versus pest-related crop loss by extension contact level ($n=172$)

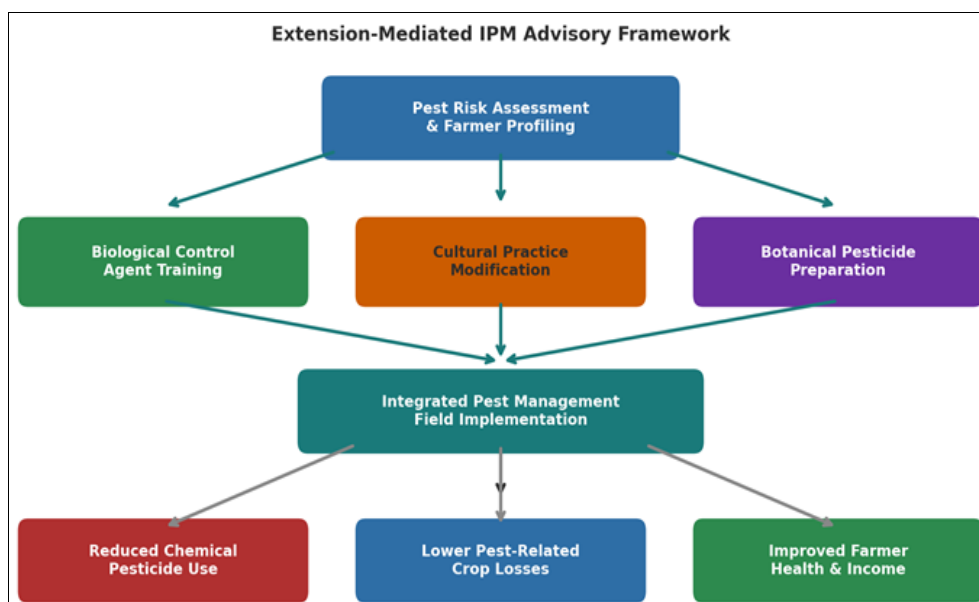


Fig 2: Extension-mediated IPM advisory framework showing intervention components and expected outcomes for smallholder systems

Comprehensive interpretation

The dose-response pattern was clear across all indicators (Table 1). High-contact farmers scored 74.6 on the IPMAI, more than three times the no-contact group, and lost less than a third as much of their crop to pests. Chemical pesticide expenditure dropped by 63.4% between the no-contact and high-contact groups. Among the three IPM domains, cultural practices showed the highest baseline adoption even without extension (31.7%), likely because some practices like crop rotation are traditional in the region. Biological control and botanical pesticide use, which require more specialized knowledge, showed the steepest adoption gradients with extension exposure.

The correlation matrix (Table 2) confirms that IPM adoption was strongly inversely related to both crop loss ($r = -0.74$) and pesticide spending ($r = -0.69$), while the three IPM domains were positively correlated with each other, suggesting that farmers who adopted one component tended to adopt others. The scatter plot (Figure 1) visually captures the inverse relationship and shows that the tightest cluster of low-loss outcomes belongs to the high-extension group.

Discussion

These results add to the evidence that extension-delivered IPM advisory can shift smallholder pest management in measurable ways. The 63.4% reduction in chemical pesticide spending among high-contact farmers is particularly significant because it addresses a core concern in Bolivian agricultural policy: the environmental and health costs of pesticide overuse [15, 16]. The finding aligns with results from IPM farmer field school programs in Southeast Asia, where sustained training reduced pesticide use by 40 to 70% while maintaining or improving yields [17, 18].

The differential adoption rates across IPM domains suggest a practical sequencing for extension programs. Cultural practices, which already had moderate baseline adoption, may serve as effective entry points that build farmer confidence before introducing the more knowledge-intensive biological control and botanical pesticide components. This staged approach has been recommended

by Pretty and Bharucha [19] and appears consistent with the patterns observed in this research.

The strong positive correlations among IPM domains ($r = 0.73$ to 0.82) suggest complementarity rather than substitution. Farmers who learn to use biological control agents also tend to adopt cultural practices and botanical preparations, creating a reinforcing system of pest management that is more resilient than any single technique. Extension programs that present IPM as an integrated package rather than a menu of disconnected options may therefore achieve stronger overall adoption [20].

The framework in Figure 2 maps how extension advisory translates pest risk assessment into three intervention streams that converge at field implementation and produce outcomes across environmental, economic, and health dimensions. The critical link in this chain is sustained extension contact. Without it, farmers default to chemical solutions not because they prefer them but because the knowledge required for alternatives isn't available [21].

Limitations

The cross-sectional design cannot establish whether extension contact caused higher IPM adoption or whether more innovative farmers sought out extension support. Crop loss estimates were self-reported and may be imprecise, particularly for subsistence crops not sold at market. The research was limited to six municipalities in Cochabamba's valley zones and may not represent highland or lowland systems with different pest pressures. Pesticide expenditure data did not account for differences in crop area or value, limiting comparability across farms. Future research should use longitudinal designs with actual yield measurements and extend to diverse agroecological zones across Bolivia.

Conclusion

This research demonstrated that extension advisory focused on integrated pest management can serve as an effective biological risk mitigation strategy in Bolivian smallholder systems. Farmers with high extension contact achieved IPM adoption scores more than three times those of farmers

without contact, while suffering less than a third of the pest-related crop losses and spending 63% less on chemical pesticides. All three IPM domains responded to extension exposure, with cultural practices showing the broadest baseline adoption and biological control showing the steepest improvement gradient.

The findings make a straightforward case: IPM works when farmers have sustained access to knowledge, and extension services are the most practical channel for delivering that knowledge. The inverse relationship between IPM adoption and both crop loss and pesticide spending means that every unit of IPM knowledge transferred through extension produces a double dividend, lower losses and lower costs. For Bolivia's extension system, which currently allocates less than 3% of its budget to IPM activities, these results suggest that redirecting resources toward IPM advisory would yield significant returns for smallholder welfare, environmental health, and farmer safety. The framework presented here offers a structure for organizing that investment around pest assessment, three complementary intervention streams, and measurable outcome tracking.

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