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Constraints in Adoption of Biopesticides and Biological Control Agents: An Extension Analysis

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ABSTRACT

Biopesticides and biological control agents (BCAs) are central to reducing chemical-pesticide dependence and advancing sustainable crop protection, yet their field-level adoption remains persistently low relative to their demonstrated technical potential. This review synthesises extension-oriented empirical literature — drawing on studies from India (Andhra Pradesh, Bihar), the Philippines, Iran, Kenya and Tanzania — to develop a typology of constraints spanning knowledge and awareness, technical performance, economic, institutional/extension, regulatory and socio-psychological dimensions. Reported adoption rates ranged from 25 percent (Andhra Pradesh BCAs) to 60.7 percent (South Cotabato rice BCAs), with biopesticides accounting for only about 4.2 percent of India's pesticide market against a global average of roughly 10 percent. Across the reviewed studies, knowledge and awareness gaps were the most frequently cited barrier, followed closely by weak institutional/extension support and doubts about product efficacy. The review situates these findings within diffusion-of-innovation, theory-of-planned-behaviour and health-belief-model frameworks and argues that a strengthened, better-resourced extension system — rather than product innovation alone — is the pivotal lever for closing the adoption gap. Recommendations for extension policy and practice are outlined.

INTRODUCTION

The intensification of chemical pesticide use since the Green Revolution has delivered substantial productivity gains but has also generated well-documented costs: acute pesticide poisoning, resistance development in target pests, and residue-driven barriers to trade. Biopesticides — microbial, botanical and biochemical formulations — and biological control agents (BCAs) such as parasitoids, predators and entomopathogens offer a technically viable, more sustainable alternative within an integrated pest management (IPM) framework. Yet across geographies as different as India, the Philippines, Iran, Kenya and Tanzania, farmer-level adoption of these technologies remains a fraction of their technical promise. Understanding why this adoption gap persists, and specifically the role that extension systems play in closing or perpetuating it, is the focus of this review.

This review synthesises recent empirical literature on the constraints to biopesticide and BCA adoption, with particular attention to extension-related variables — training, institutional support, and access to advisory services — as distinct from purely technical or product-level constraints. It draws on studies employing diverse methods (logistic regression, Garrett ranking, partial least squares structural equation modelling, and knowledge-attitude-practice surveys) to build a comparative, cross-country picture of what is holding back adoption and where extension intervention offers the greatest leverage.

GLOBAL AND INDIAN STATUS OF BIOPESTICIDES AND BIOLOGICAL CONTROL AGENTS

Despite decades of research investment, biopesticides remain a modest share of the overall crop-protection market. Table 1 summarises key quantitative indicators of the sector's current scale, drawing on the most recent peer-reviewed estimates available.

India has built a sizeable production infrastructure — 86 government-funded macrobial units and 141 microbial biopesticide production units — yet biopesticides capture only 4.2 percent of the domestic pesticide market, below the global average of roughly 10 percent. This gap between production capacity and market penetration is itself indicative of a demand-side, adoption-stage bottleneck rather than a supply-side shortfall, and motivates the extension-focused constraint analysis that follows

Table 1. Global and Indian biopesticide/biological control agent sector indicators.

Indicator	Value	Source (DOI)
Invertebrate biocontrol agent species commercially available worldwide	>440 species	10.1007/s10526-017-9801-4
Biopesticide formulations officially registered in India (Insecticide Act, 1968)	104 formulations, 19 types	10.18311/jbc/2024/46321
Government-funded macrobial (natural-enemy) production units in India	86 units	10.18311/jbc/2024/46321
Government/private microbial biopesticide production units in India	141 units	10.18311/jbc/2024/46321
Biopesticide share of India's total pesticide market	4.2%	10.3390/agriculture13030557
Biopesticide share of the global pesticide market	~10%	10.1017/S1742170525100070
Global biopesticide production volume (annual)	>3,000 tonnes, growing ~10%/yr	10.3390/agriculture13030557

THEORETICAL FRAMEWORK

Three complementary behavioural and diffusion frameworks recur across the reviewed literature. Rogers' diffusion-of-innovation theory frames adoption as a function of an innovation's relative advantage, compatibility, complexity, trialability and observability, and situates BCAs as inherently more complex and less observable than conventional pesticides — their effects are typically slower, less visually dramatic, and more sensitive to correct handling. The Theory of Planned Behaviour (TPB) explains adoption intention through attitude, subjective norms and perceived behavioural control, while the Health Belief Model (HBM) foregrounds farmers' perceived severity of pesticide-related risk and perceived benefits and barriers of the alternative. Studies applying an integrated TPB–HBM model in India found that perceived severity of chemical-pesticide harm most strongly shaped attitude, while subjective norms and government initiatives most strongly shaped adoption intention — underscoring that peer influence and policy visibility, both extension-mediated channels, are pivotal. Figure 1 organises the constraint categories identified across the reviewed studies around a common typology, with the extension system positioned as the primary mediating institution between constraint and adoption outcome.

TYPOLOGY OF CONSTRAINTS

Knowledge and Awareness Gaps

Across nearly every reviewed study, insufficient farmer knowledge of what biopesticides/BCAs are, how they work, and how to apply them correctly emerged as the most frequently cited barrier. In South Cotabato, Philippines, Garrett ranking explicitly identified lack of knowledge as the top-ranked constraint among rice farmers, ahead of market availability. In Kenya, farmers demonstrated general awareness of the concept of biological control but lacked the specific knowledge, experience and technical support needed to act on it. In Tanzania, knowledge gaps among both farmers and extension agents themselves were identified as the principal structural barrier to biological control uptake.

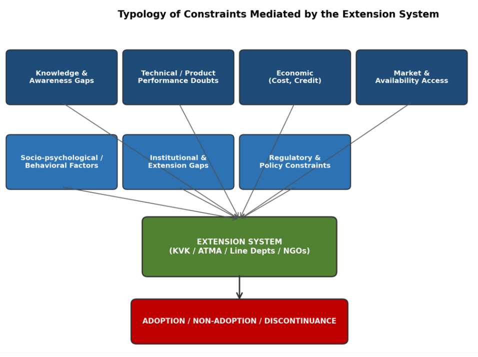

Figure 1. Typology of constraints to biopesticide/BCA adoption, mediated by the extension system.

Technical and Product Performance Doubts

Farmers frequently perceive biopesticides as slower-acting, less consistent, and less visibly effective than synthetic chemical alternatives. In Bihar, India, low perceived effectiveness and fear of reduced crop productivity were significant challenges to adoption identified through structural equation modelling. In Iran, low perceived self-efficacy in using biological control correctly — a technical-confidence rather than a pure product-efficacy issue — was a significant predictor of non-adoption.

Economic Constraints: Cost, Credit and Price Premiums

Biopesticides frequently carry a price premium over conventional pesticides, compounded by high production and registration costs on the supply side. In Andhra Pradesh, high cost and limited access to credit were identified as key barriers alongside a general lack of knowledge; annual income and farm size were significant positive predictors of adoption, indicating that BCA uptake is disproportionately concentrated among better-resourced farmers. In Bihar, premium price was explicitly named among the most significant challenges to adoption.

Institutional and Extension Service Gaps

Weak institutional support and limited extension contact recur as a distinct and often decisive constraint, separate from awareness per se. In South Cotabato, institutional support and extension services emerged as one of the strongest positive drivers of adoption where present, and their absence was correspondingly identified as a critical constraint; training access was a statistically significant predictor of adoption. In Kenya, farmers explicitly lacked technical support from extension agents or agro-dealers even where general awareness existed — illustrating that awareness without sustained technical backstopping is insufficient for adoption.

Market and Technical Access

Even motivated farmers can be constrained by limited local availability of quality-assured biopesticide/BCA products, unreliable supply chains, and the risk of spurious or adulterated formulations entering the market — a documented concern in India, where the proliferation of low-quality products has been reported to undermine confidence in genuine biocontrol products. Limited market and technical access was identified as a distinct adoption determinant in the South Cotabato study.

Table 2. Comparative summary of empirical studies on biopesticide/BCA adoption constraints.

Study location	Method	Adoption / awareness rate	Leading constraints identified
Kurnool, Andhra Pradesh, India (Vennelasree et al., 2025)	Stepwise logistic regression, n=120	25% adopted BCAs	Lack of knowledge, reliance on chemical fertilizer habits, high cost, limited access to credit
Patna/Bhagalpur/Purnea/Saharsa, Bihar, India (Kumar et al., 2025)	PLS-SEM, TPB + HBM, n=468	92.5% aware; 59.4% used biopesticides	Premium price, perceived low effectiveness, fear of reduced crop productivity
South Cotabato, Philippines (Pacol & Marcelino, 2026)	Garrett ranking, EFA, regression, n=244	60.7% adopted BCAs	Lack of knowledge and limited market availability (Garrett-ranked top two); weak market/technical access
Golestan Province, northern Iran (Abdollahzadeh et al., 2017)	Adoption/ discontinuance survey, n=415	Majority non-adopters; most early adopters discontinued	Low compatibility with existing practice, low perceived self-efficacy, lack of technical support
Four papaya counties, Kenya (Constantine et al., 2023)	KAP survey + KIIs, n=383 households	Awareness present but low technical uptake	Inadequate awareness, limited extension/ agro-dealer technical support, efficacy concerns
Northern Tanzania (Mkenda et al., 2020)	Knowledge-gap review/survey	Not separately quantified	Knowledge gaps among farmers and extension agents identified as the principal barrier

Regulatory and Policy Constraints

The registration process for new biopesticide active ingredients in India remains lengthy and costly, discouraging private-sector research and development investment and constraining the range of registered formulations to 104 across 19 types nationally. Streamlined, harmonised regulatory pathways have been specifically identified as a lever for broader adoption in comparative international reviews.

Socio-psychological and Behavioural Factors

Beyond structural constraints, farmers' compatibility perceptions — whether a new practice fits existing values, routines and risk tolerance — shape adoption independent of objective product performance. In Iran, farmers who derived high yields and income from conventional pesticide use, and who perceived greater benefit from pesticides generally, were less likely to adopt biological control, while most early adopters who did try it discontinued use soon afterward, reverting to chemical pesticides. This adoption–discontinuance pattern signals that first-trial experiences unsupported by follow-up extension contact can be actively counterproductive.

COMPARATIVE EVIDENCE ACROSS STUDIES

Table 2 draws together the adoption/awareness rates and top-ranked constraints reported across the principal empirical studies reviewed here, illustrating both the wide variation in observed adoption levels and the recurring centrality of knowledge and institutional-support gaps.

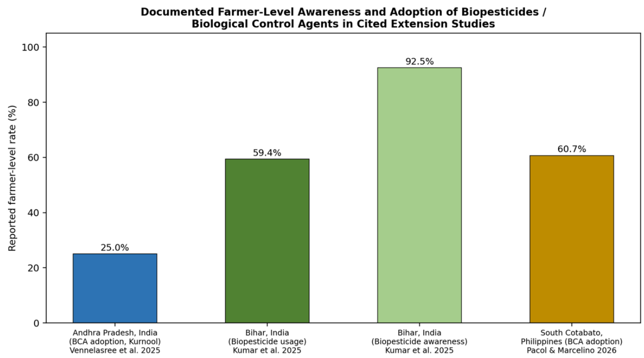

Figure 2. Documented farmer-level awareness and adoption rates of biopesticides/BCAs across three cited extension studies.

Figure 2 plots the reported adoption and awareness percentages from the three studies that provided directly comparable quantitative figures. Even where awareness is high — 92.5 percent in the Bihar sample — actual usage falls well short (59.4 percent), illustrating an awareness-to-adoption gap that knowledge transmission alone does not close.

To identify which constraint categories recur most consistently across the wider set of studies reviewed in Section 4, Figure 3 presents a simple synthesis count — the number of the eight reviewed studies/reviews in which each constraint category appears among the leading barriers discussed. This is a qualitative tally intended to indicate relative prominence in the literature reviewed, not a formal meta-analytic weight. Knowledge and awareness gaps appear as a leading constraint in the largest number of reviewed studies, followed by weak institutional/extension support and doubts about

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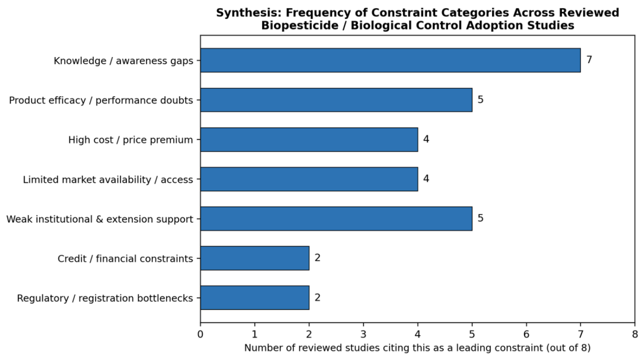

Figure 3. Synthesis of constraint-category frequency across the eight extension studies and reviews cited in this paper.

product efficacy. This ordering supports the core argument of this review: that extension system capacity — rather than biopesticide/BCA technical performance alone — is the most consistently identified lever for closing the adoption gap.

ROLE OF EXTENSION IN MEDIATING CONSTRAINTS

The comparative evidence indicates that extension contact operates on multiple constraint categories simultaneously rather than addressing awareness alone. Training access was a statistically significant positive predictor of BCA adoption in both the Andhra Pradesh and South Cotabato studies; in the latter, institutional support and extension services constituted the strongest factor loading among the five determinants identified through exploratory factor analysis. Government initiatives — policy visibility, subsidy programmes and organic-corridor schemes — had a significant direct positive effect on farmers' behavioural intention to adopt biopesticides in the Bihar study, operating through farmers' perception that the practice was socially endorsed and institutionally backed (subjective norms). Conversely, where extension and technical support were absent or thin — as documented in Kenya and Tanzania — general awareness of biological control failed to translate into confident, sustained use.

The Iranian evidence on adoption discontinuance further suggests that extension's role cannot end at the point of first trial: farmers who lacked follow-up technical support after initial adoption were more likely to revert to chemical pesticides, indicating that sustained post-adoption advisory contact is as important as pre-adoption promotion.

RECOMMENDATIONS FOR EXTENSION POLICY AND PRACTICE

- Prioritise sustained, hands-on training over one-off awareness campaigns, given that awareness levels already exceed usage levels in several study contexts (e.g., Bihar's 92.5% awareness vs. 59.4% usage).
- Pair frontline demonstrations of biopesticides/BCAs with visible, credible efficacy comparisons against farmers' existing chemical practice, addressing the perceived-efficacy constraint identified across multiple studies.
- Strengthen post-adoption follow-up and technical backstopping specifically to prevent early-adopter discontinuance, rather than concentrating resources solely on first-time promotion.
- Improve last-mile availability of quality-assured biopesticide/BCA products through coordinated production-unit and extension-agency planning, addressing the market-access constraint documented in the Philippines and India.
- Target credit and input-subsidy support toward smaller and lower-income farmers specifically, since income and farm size were significant positive predictors of adoption in the Andhra Pradesh study — indicating current uptake is skewed toward better-resourced farmers.
- Streamline biopesticide registration procedures to expand the range of locally available, regionally validated formulations beyond the current 104 registered products in India.
- Leverage social/peer networks and government-initiative visibility deliberately, given the strong, consistent role of subjective norms and government-initiative effects identified in the Indian behavioural-intention literature.

CONCLUSION

The persistent gap between the technical promise of biopesticides and biological control agents and their modest field-level adoption — 4.2 percent of India's pesticide market against 104 registered formulations and 227 production units — is best explained not by a single dominant constraint but by an interacting typology spanning knowledge, technical confidence, cost, institutional support, market access, regulation and behavioural compatibility. Across the comparative evidence reviewed here, from Andhra Pradesh's 25 percent adoption rate to South Cotabato's 60.7 percent, knowledge and awareness gaps and weak institutional/extension support recur as the most consistently cited barriers, ahead of product cost or regulatory constraints. This points to a clear policy implication: strengthening the density, technical depth, and post-adoption continuity of agricultural extension contact is likely to yield larger adoption gains than biopesticide product innovation alone, though the two are complementary rather than substitutable levers for sustainable pest management.

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