Environment and Natural Resources Journal

Volume 25
Issue X
2027

Barriers to Transitioning from Chemical-Input-Dependent Production Practices to Microbial Pesticide Use in GI Pineapple Production: Evidence from Tha Uthen Pineapple Farmers in Thailand

Hassadin Hunsuwannakul and Sasipim Poompimol*

Department of Agricultural Extension and Development, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand

ARTICLE INFO

Received: 19 Apr 2026
Received in revised: 22 Aug 2026
Accepted: 25 Aug 2026
Published online: 30 Oct 2026
DOI: 10.32526/ennrj/25/20260157

Keywords:
Microbial pesticides/ Chemical-input dependence/ Geographical indication/ Pineapple production/ Transition barriers/ Agricultural extension

*** Corresponding author:**
E-mail: sasipim@kku.ac.th

ABSTRACT

Microbial pesticides are promoted as alternatives to conventional pest-control inputs, yet their use may remain limited in chemically intensive production systems. This study examined chemical-input use, microbial pesticide use, extension exposure, and reported constraints related to the transition to microbial pesticides in geographical indication (GI) pineapple production among Tha Uthen pineapple farmers in Nakhon Phanom Province, Thailand. A cross-sectional survey using structured interviews was conducted between February and April 2024 with 134 farmers selected from the registered large-scale farming system (Plang Yai) pineapple groups. Descriptive statistics were used to summarize farmer characteristics, chemical-input dependence, microbial pesticide use, extension exposure, and reported constraints, and a descriptive subgroup profile was provided to characterize farmers with and without microbial pesticide use experience. The results showed that pineapple production remained strongly dependent on chemical-related inputs. Positive annual expenditure on herbicides, ethephon, and chemical fertilizers was reported by 94.0%, 95.5%, and 98.5% of farmers, respectively. Current microbial pesticide use was limited to 2.2% of respondents, while 3.7% had current or former use experience. Nevertheless, 64.9% had received training, and 66.4% had received information on microbial pesticide use. Among the five farmers with use experience, the most frequently reported constraints concerned practical use and product quality or performance, followed by knowledge- and price-related constraints. These findings highlight the need for implementation-oriented support addressing practical application, storage, and product quality or field performance alongside information provision.

HIGHLIGHTS

- GI pineapple production remained strongly dependent on chemical-related inputs.
- Current microbial pesticide use was limited to 2.2% of surveyed farmers.
- Training and information reached 64.9% and 66.4% of farmers, respectively.
- Practical-use and product-performance constraints were most frequently reported.
- Findings support implementation-oriented extension beyond information provision.

1. INTRODUCTION

Agricultural intensification has increased reliance on synthetic pesticides in many cropping systems, raising concerns about environmental contamination, effects on non-target organisms, and human health risks. After application, pesticide residues may move beyond the target area through runoff, leaching, spray drift, and accumulation in soil and water. These processes can affect aquatic organisms, beneficial insects, pollinators, soil microbial communities, and other non-target species that contribute to agroecosystem functioning. Repeated use of chemical pesticides may therefore create environmental burdens that extend beyond short-term pest suppression, particularly in production systems where chemical inputs become embedded in routine farm management (UNEP, 2021).

Citation: Hunsuwannakul H, Poompimol S. Barriers to transitioning from chemical-input-dependent production practices to microbial pesticide use in GI pineapple production: Evidence from Tha Uthen pineapple farmers in Thailand. Environ. Nat. Resour. J. 2027;25(X):xx-xx.

In response, sustainable crop protection has increasingly emphasized integrated pest management (IPM), which seeks to reduce excessive chemical inputs through more ecologically grounded strategies. Biological and microbial methods are often considered important components of IPM because they can suppress pests while potentially reducing environmental risks associated with repeated chemical pesticide use (Chandler et al., 2011; Srinivasan et al., 2022; Zhou et al., 2024). Microbial pesticides, including products based on fungi, bacteria, and viruses, are generally valued for their target specificity, biodegradability, and lower persistence compared with many conventional synthetic pesticides. However, their environmental promise does not automatically translate into practical adoption. Their effectiveness depends on proper handling, appropriate storage, timely application, and farmers' confidence in their field performance (Marrone, 2007; Glare et al., 2012; Ayilara et al., 2023; Verma et al., 2024; Cai and Dimopoulos, 2025).

Microbial pesticides are therefore widely discussed as promising tools for sustainable agriculture and IPM, but their uptake remains uneven in practice. Previous studies suggest that farmers' decisions to use microbial products are shaped not only by awareness of environmental benefits, but also by concerns about efficacy, usability, trust in field performance, and the operational fit of the technology with existing farm routines (Tensi et al., 2022; Kernecker et al., 2021). Reviews of the biopesticide sector further indicate that short shelf life, delayed action, storage requirements, application complexity, and relatively high costs continue to limit wider use under real farm conditions (Marrone, 2007; Ayilara et al., 2023; Verma et al., 2024; Cai and Dimopoulos, 2025).

International experience suggests that microbial pesticides can be incorporated into crop protection systems, but a successful transition usually depends on supportive institutional, technical, and advisory conditions. In Europe, evidence from Dutch and German arable farms shows that trust in microbial applications, access to knowledge, and support matter for adoption, indicating that farmers are more likely to use microbial pesticides when they trust their performance and receive adequate technical guidance (Tensi et al., 2022). In broader IPM experiences across developing regions, biological and microbial options have been promoted as part of efforts to reduce reliance on chemical pesticides, but their wider use has depended on product availability, affordability, extension support, and compatibility with farmers' production practices (Chandler et al., 2011; Srinivasan et al., 2022). These international cases indicate that farmers do not adopt microbial pesticides simply because they are environmentally preferable. Instead, the transition requires a support system that links environmental benefits to practical field performance, product reliability, and farmer decision-making.

In Thailand, this transition challenge is particularly relevant because biopesticides are being promoted nationally, yet conventional pesticides remain the dominant method of crop protection for many farmers. Policy-level promotion and extension activities may increase awareness of biological alternatives. However, international evidence suggests that awareness alone is unlikely to lead to sustained use unless farmers also receive practical support for application, storage, timing, and assessment of field performance. More broadly, evidence from agricultural extension research suggests that training and information exposure do not necessarily translate into broader adoption when usability, local conditions, and limited diffusion beyond initial contact points constrain implementation (Kondylis et al., 2017; Praneetvatakul et al., 2024; Anzum et al., 2023).

These transition challenges may be especially important in high-value place-based production systems, such as geographical indication (GI) crops, where product reputation depends not only on origin and quality but increasingly on the sustainability of production practices. Tha Uthen pineapple is officially recognized as a GI product of Nakhon Phanom Province, with government sources linking the designation to a specific production area and distinctive product characteristics associated with the local agroecological context (FAO, 2019; Vandecandelaere et al., 2018; Department of Intellectual Property, 2013; Ministry of Agriculture and Cooperatives, 2026). In the study area, pineapple production also faces practical constraints, including climatic variability and weed pressure, which may reinforce dependence on conventional chemical inputs. These characteristics make Tha Uthen pineapple a relevant setting for examining the transition toward microbial pest management. As a registered GI crop produced in the Tha Uthen and Phon Sawan districts, it represents a place-based production system in which agricultural extension has promoted microbial pesticide use. At the same time,

conventional pest-management practices remain important in local production.

Existing literature has provided useful insights into biopesticide promotion in Thailand at policy and multi-crop levels (Praneetvatakul et al., 2024) and has identified communication, usability, and adoption-related considerations in sustainable agricultural technologies (Anzum et al., 2023; Kondylis et al., 2017; Tensi et al., 2022). Evidence remains limited, however, on how chemical-input use, extension exposure, microbial pesticide use experience, and reported implementation constraints coexist within a specific GI production system. This study therefore focuses on the observed pattern of input use and microbial pesticide experience among Tha Uthen pineapple farmers.

Therefore, this study aimed to characterize the conditions relevant to the limited establishment of microbial pesticide use in the GI pineapple production system among Tha Uthen pineapple farmers in Nakhon Phanom Province, Thailand. Specifically, the study examined (1) current chemical-input use and expenditure, (2) current and former microbial pesticide use, (3) exposure to training and information, and (4) constraints reported by farmers with microbial pesticide use experience.

2. METHODOLOGY

2.1 Study area and research design

This study was conducted in Nakhon Phanom Province, northeastern Thailand. Tha Uthen pineapple is registered as a Thai geographical indication (GI No. 57100066), with its production area extending across Tha Uthen and Phon Sawan districts (Department of Intellectual Property, 2013). A cross-sectional survey using structured face-to-face interviews was conducted between February and April 2024. The location of Nakhon Phanom Province and the two study districts is shown in Figure 1.

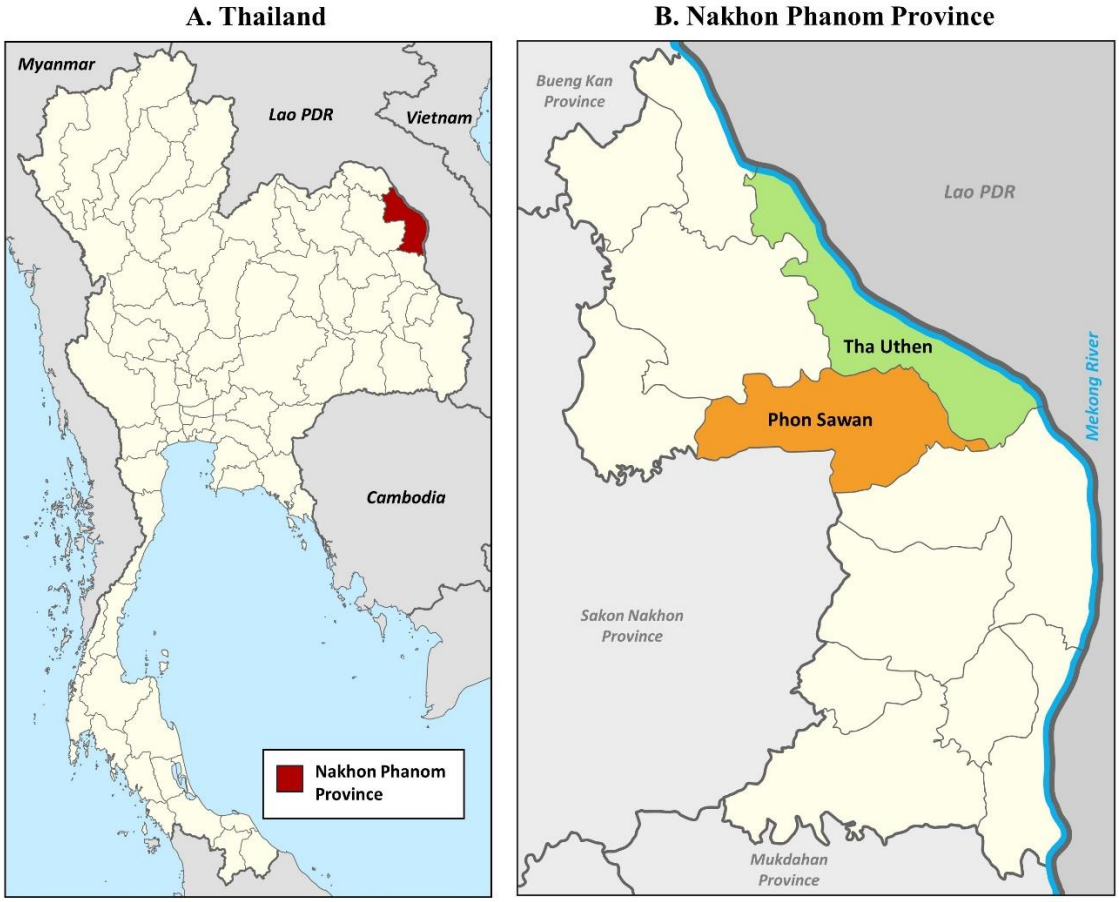


Figure 1. Location of Nakhon Phanom Province in Thailand and the study districts of Tha Uthen and Phon Sawan

2.2 Population and sample

The target population comprised 200 farmers registered in two Large-Scale Farming System (Plang Yai) pineapple groups in Tha Uthen and Phon Sawan districts. Membership records in the Department of Agricultural Extension's Large-Scale Farming

Information System were verified with the relevant agricultural extension offices before data collection in 2024, comprising 85 farmers in Tha Uthen and 115 in Phon Sawan (Department of Agricultural Extension, 2025). The corresponding registered farmer lists served as the sampling frame.

The two districts were treated as sampling strata. The required sample size was calculated using Yamane's formula with a 5% margin of error (Yamane, 1967), yielding a total of 134 farmers. Proportional allocation produced samples of 57 farmers from Tha Uthen and 77 from Phon Sawan. Within each district, respondents were selected by simple random sampling from the registered-farmer list. If a selected farmer was unavailable, could not be contacted, or declined participation, a replacement was selected from the same district sampling list until the allocated sample size was reached.

2.3 Research instrument and data collection

A structured interview schedule comprising closed- and open-ended questions was used to collect data on farmer and farm characteristics, production practices and costs, chemical and non-chemical pest management inputs, microbial pesticide use, reported constraints, and exposure to training and information. Three experts evaluated content validity using the Index of Item-Objective Congruence (IOC), with item-level values ranging from 0.67 to 1.00 (Rovinelli and Hambleton, 1977; Turner and Carlson, 2003).

The interview schedule was pretested with 30 farmers from a comparable Large-Scale Farming group who were not included in the study sample to assess its clarity and suitability for field administration. The variables analyzed in this article consisted of factual, binary, continuous, and multiple-response checklist items rather than multi-item psychometric scales; therefore, we did not report internal-consistency coefficients such as Cronbach's alpha for these variables.

Field data were collected through face-to-face interviews between February and April 2024.

2.4 Variables and operational definitions

The variables analyzed in this article were organized into five domains: farmer and farm characteristics, chemical-related input use and expenditure, microbial pesticide use experience, extension exposure, and reported constraints. For interpretation, we used variables from the full sample to characterize the production and extension context, whereas we summarized reported constraints only for farmers with current or former microbial pesticide use experience. Product-related constraints refer only to the measured checklist items; we did not assess broader supply-chain conditions.

2.4.1 Farmer and farm characteristics

Farmer and farm characteristics included gender, age, education, household labor, hired labor, pineapple income, agricultural income, non-agricultural income, household debt, pineapple farming experience, land ownership, land rental, and selected indicators of social and group participation. These variables were retained in their original survey formats and used to describe the sample and to support a descriptive subgroup profile by microbial pesticide use experience.

2.4.2 Chemical-related input use and expenditure

Respondents reported annual chemical-related input expenditure (baht/year) for four production inputs: herbicides, disease-control chemicals, ethephon used for flower induction, and chemical fertilizers. Each expenditure amount was retained as a continuous variable. For descriptive use indicators, each input category was coded as 1 when annual expenditure was greater than zero and 0 when expenditure was zero.

A chemical-input category count was calculated as the number of categories with positive annual expenditure, with a possible range of 0-4. Combined annual chemical-input cost was calculated as the sum of expenditure across the four categories.

2.4.3 Microbial pesticide use experience

Microbial pesticide use was recorded for *Beauveria bassiana*, *Metarhizium anisopliae*, *Trichoderma* spp., *Bacillus thuringiensis*, *Bacillus subtilis*, nucleopolyhedrovirus, and other microbial products. Farmers were classified into three mutually exclusive respondent-level categories: current use, former use only, and no reported use experience. Current use was defined as the current use of at least one microbial product, whereas former use only referred to previous use with no reported current use. A separate indicator identified any current or former microbial pesticide use experience. Product-specific responses were treated as multiple responses and were therefore not additive across unique farmers.

2.4.4 Extension exposure

Extension exposure was measured using two binary indicators: whether the farmer had ever participated in training on microbial pesticide use (yes/no) and whether the farmer had ever received information about microbial pesticide use (yes/no). For descriptive analysis, the two indicators were combined into three categories: no exposure, when neither training nor information was reported; partial exposure, when either training or information was reported but not both; and both forms of exposure, when both training and information were reported.

2.4.5 Reported constraints

Reported constraints were elicited using a multiple-response checklist organized into four domains. Practical-use constraints comprised three sub-items: short shelf life or declining efficacy during storage, complexity or limitations in use, and lack of suitable storage space. Knowledge-related constraints comprised three sub-items: lack of knowledge about the benefits of different microbial products, correct application, and correct storage. Price-related constraints comprised one sub-item concerning the high price of microbial starter culture. Product quality/performance constraints comprised three sub-items: slower action than alternative control methods, the need for repeated or regular application, and perceived ineffectiveness against pests encountered in pineapple production.

A constraint domain was coded as present when a farmer reported at least one sub-item within that domain. In this article, constraint summaries were calculated for the five farmers with current or former microbial pesticide use experience.

2.5 Data analysis

Categorical variables were summarized using frequencies and percentages, while continuous variables were summarized using means, standard deviations, minimums, and maximums. Medians and interquartile ranges were used for subgroup comparisons and for markedly skewed variables where appropriate.

Three constructed descriptive indicators were used in the analysis: (1) a chemical-input category count, defined as the number of the four selected chemical-related input categories with positive annual expenditure (0-4); (2) microbial pesticide use status, classified as current use, former use only, or no reported use experience, with a separate indicator for any current or former use experience; and (3) extension exposure, classified as no exposure, partial exposure, or both training and information exposure. Product-specific microbial pesticide use and reported constraints were treated as multiple-response items.

Because only five farmers reported current or former microbial pesticide use experience, subgroup comparisons were descriptive. Continuous variables were summarized using medians and interquartile ranges and categorical variables were summarized using frequencies and percentages. Inferential subgroup tests were not conducted because of the small subgroup size. Data management and analyses were performed using IBM SPSS Statistics version 29.

2.6 Ethical considerations

The Human Research Ethics Committee of Khon Kaen University approved the research protocol on 30 January 2024 (Approval No. HE663420). Participation was voluntary, informed consent was obtained before each interview, and respondent information was kept confidential and reported only in aggregate form.

3. RESULTS AND DISCUSSION

3.1 Respondents and production characteristics

A total of 134 Tha Uthen pineapple farmers participated in the study. Most respondents were female (75.4%), while 24.6% were male. The mean age was 51.71 years (SD=8.88), with ages ranging from 31 to 74 years. In terms of educational attainment, 64.2% had education below the lower secondary level, whereas 35.8% had a lower secondary education or higher. The average pineapple farming experience was 14.12 years (SD=6.28), with a median of 12.50 years (IQR=10.00-15.00 years) (Table 1).

The high proportion of female respondents is consistent with women's substantial participation in agriculture in northeastern Thailand. The 2023 Agricultural Census reported that women accounted for 59.2% of agricultural holders in the northeastern region (National Statistical Office, 2024). Previous research has also shown that women in Thailand play an active role in agricultural groups (Akter et al., 2017). The higher female representation in the present sample may therefore reflect, at least partly, the region's broader gender composition in agriculture and women's participation in group-based agricultural activities.

Concerning farm and economic characteristics, the mean annual pineapple income was 133,776.12

baht (SD=120,514.85; median=100,000 baht, IQR=50,000-195,000), and the mean annual household debt for the 2023 production cycle was 144,881.49 baht (SD=157,942.32; median=95,000 baht, IQR=20,000-200,000). Median owned and rented land areas were 2.25 rai (IQR=1.00-4.19) and 0.00 rai (IQR=0.00-2.75), respectively.

Farmers also reported several production constraints. The most frequently reported constraint was drought or natural disaster (81.3%), followed by high production costs (71.6%). Other reported constraints included pest outbreaks (12.7%), low output prices (10.4%), marketing problems (3.7%), sweetness below standard (3.0%), health concerns from chemicals (2.2%), and other problems such as degraded soil (1.5%).

Table 1. Respondent and production characteristics of Tha Uthen pineapple farmers (n=134)

Variable	n (%) or mean ± SD [range]	Median [IQR]
Panel A. Respondent characteristics		
Male	33 (24.6)	-
Female	101 (75.4)	-
Age (years)	51.71±8.88 [31-74]	51.00 [45.00-57.00]
Education: below lower secondary	86 (64.2)	-
Education: lower secondary or higher	48 (35.8)	-
Pineapple farming experience (years)	14.12±6.28 [7-45]	12.50 [10.00-15.00]
Panel B. Production and economic characteristics		
Pineapple income (baht/year)	133,776.12±120,514.85	100,000 [50,000-195,000]
Household debt (baht/year)	144,881.49±157,942.32	95,000 [20,000-200,000]
Owned land area (rai)	3.21±3.01 [0-15]	2.25 [1.00-4.19]
Rented land area (rai)	2.47±4.94 [0-30]	0.00 [0.00-2.75]
Panel C. Reported production constraints*		
Drought/natural disaster	109 (81.3)	-
High production costs	96 (71.6)	-
Pest outbreaks	17 (12.7)	-
Low output prices	14 (10.4)	-
Marketing problems	5 (3.7)	-
Sweetness below standard	4 (3.0)	-
Health concerns from chemicals	3 (2.2)	-
Other (e.g., degraded soil)	2 (1.5)	-

Note: Values are presented as n (%) or mean±SD [range], or median [IQR], as appropriate. *Multiple-response items

3.2 Current pest and weed problems

All respondents reported weed infestation. Chemical control was used for weed management by 121 farmers (90.3%), while 98 (73.1%) reported non-chemical cultural or manual practices such as cutting, pulling, and manual removal. The most frequently reported reasons for selecting existing control methods were perceived effectiveness against pests encountered in the field (91.0%), convenience and rapid effects (79.1%), and cost saving or cost reduction (16.4%) (Table 2).

Farmers also frequently reported plant diseases, including root and stem rot (56.7%), fruit core disease (85.1%), and wilt (51.5%). For these three disease-specific management items, farmers predominantly reported either no specific control or cultural practices such as cutting or removing affected plants; no respondent selected chemical control for these specific disease items.

3.3 Current chemical-input use and expenditure

The results showed a high reliance on chemical inputs in pineapple production. A total of 94.0% of farmers reported annual expenditure on herbicides, 95.5% on ethephon for flower induction, and 98.5% on chemical fertilizers. In contrast, only 0.7% of respondents reported expenditure on disease-control chemicals. The mean annual expenditure was 2,307.01 baht (SD=3,922.21) for herbicides, 2,335.37 baht (SD=3,326.63) for ethephon, and 9,137.24 baht (SD=11,057.78) for chemical fertilizers. The

combined annual chemical-input cost averaged 13,781.87 baht (SD=15,603.71).

When considering the number of chemical-input categories, 0.7% of farmers reported positive expenditure in one category, 9.7% in two categories, and 89.6% in three categories. In contrast, no farmer reported positive expenditure across all four categories included in the analysis (Table 3, Panel A).

Table 2. Selected pest-management methods and reasons for method selection among Tha Uthen pineapple farmers

Panel / Indicator	n	%
Panel A. Reported weed-management routines		
Farmers reporting weed infestation	134	100.0
Use of chemical control for weed management	121	90.3
Use of non-chemical cultural/manual weed-control practices, such as cutting, pulling, and manual removal	98	73.1
Panel B. Reasons for selecting existing control methods		
Perceived effectiveness against pests encountered in the field	122	91.0
Convenience and rapid effects	106	79.1
Cost saving or cost reduction	22	16.4

Note: Multiple responses were allowed for control methods and reasons.

3.4 Training and information exposure

Regarding extension exposure, 87 farmers (64.9%) had previously received training on microbial pesticide use, and 89 farmers (66.4%) had received information on microbial pesticides. When these two forms of exposure were combined, 43 farmers (32.1%) had no exposure, 6 farmers (4.5%) had partial exposure, and 85 farmers (63.4%) had exposure to both training and information (Table 3, Panel B).

3.5 Current and former microbial pesticide use

Three farmers (2.2%) reported current use of at least one microbial pesticide. Two additional farmers (1.5%) reported former use only, bringing the total to five farmers (3.7%) with any current or former microbial pesticide use experience. At the product level, two farmers (1.5%) currently used *Trichoderma* spp., two (1.5%) reported former use of *Trichoderma* spp., and three (2.2%) currently used other microbial products. Product-specific responses overlapped because the two current *Trichoderma* users also reported current use of other microbial products. No current or former use was reported for *Beauveria bassiana*, *Metarhizium anisopliae*, *Bacillus thuringiensis*, *Bacillus subtilis*, or nucleopoly-hedrovirus (Table 3, Panel C).

Table 3. Chemical-related input use and expenditure, extension exposure, and microbial pesticide use among Tha Uthen pineapple farmers (n=134)

Panel	Variable	n (%)	Mean annual cost±SD (baht)
A. Chemical-input dependence	Positive expenditure on herbicides	126 (94.0)	2,307.01±3,922.21
	Positive expenditure on disease-control chemicals	1 (0.7)	2.24±25.92
	Positive expenditure on ethephon for flower induction	128 (95.5)	2,335.37±3,326.63
	Positive expenditure on chemical fertilizers	132 (98.5)	9,137.24±11,057.78
	Combined chemical-input cost	-	13,781.87±15,603.71
	Farmers using 1 chemical-input category	1 (0.7)	-
	Farmers using 2 chemical-input categories	13 (9.7)	-
	Farmers using 3 chemical-input categories	120 (89.6)	-
	Farmers using 4 chemical-input categories	0 (0.0)	-
B. Extension exposure	Ever received training	87 (64.9)	-
	Ever received information on microbial pesticide use	89 (66.4)	-
	No exposure	43 (32.1)	-
	Partial exposure (training or information only)	6 (4.5)	-
	Exposure to both training and information	85 (63.4)	-

Table 3. Chemical-related input use and expenditure, extension exposure, and microbial pesticide use among Tha Uthen pineapple farmers (n=134) (cont.)

Panel	Variable	n (%)	Mean annual cost±SD (baht)
C. Microbial pesticide use	Current microbial pesticide use, any type	3 (2.2)	-
	Former microbial pesticide use only	2 (1.5)	-
	Any current or former use experience	5 (3.7)	-
	Current use of *Trichoderma* spp.	2 (1.5)	-
	Former use of *Trichoderma* spp.	2 (1.5)	-
	Current use of other microbial products	3 (2.2)	-
	Current/former use of *Beauveria bassiana*	0 (0.0)	-
	Current/former use of *Metarhizium anisopliae*	0 (0.0)	-
	Current/former use of *Bacillus thuringiensis*	0 (0.0)	-
	Current/former use of *Bacillus subtilis*	0 (0.0)	-
	Current/former use of nucleopolyhedrovirus	0 (0.0)	-

3.6 Reported constraints among farmers with microbial pesticide use experience

Constraint analysis was restricted to the five farmers with current or former microbial pesticide use experience. Practical-use constraints and product quality or performance constraints were each reported by four farmers (80.0%), knowledge-related constraints by three (60.0%), and price-related constraints by one (20.0%) (Table 4).

Table 4. Reported constraint domains among farmers with microbial pesticide use experience (n=5)

Constraint domain	Farmers reporting at least one problem, n (%)
Practical use constraints	4 (80.0)
Knowledge-related constraints	3 (60.0)
Price-related constraints	1 (20.0)
Product quality/performance constraints	4 (80.0)

Note: Percentages are calculated among the five farmers with current or former microbial pesticide use experience. These are the same five farmers identified in Table 3, Panel C and profiled in Table 5. Multiple constraints could be reported.

3.7 Descriptive profile by microbial pesticide use experience

Table 5 presents the descriptive profile of the five farmers with current or former microbial pesticide use experience and the 129 farmers with no reported use experience. The experienced subgroup had a lower median age (47.00 vs 51.00 years) and shorter median pineapple-farming experience (10.00 vs 13.00 years). The experienced subgroup had higher median pineapple income, agricultural income, household debt, hired labor, rented land area, and combined chemical-input cost, whereas it had lower median owned land area. Several distributions overlapped between the two groups, including age and pineapple income, indicating substantial within-group variability.

Three of the five farmers with use experience (60.0%) had lower secondary education or above, compared with 34.9% of farmers with no reported use experience. All five had received both training and information on microbial pesticide use, compared with 62.0% of farmers with no reported use experience. Given the small experienced subgroup, these patterns are presented as descriptive characteristics rather than evidence of group differences.

3.8 Interpretation of transition barriers in GI pineapple production

3.8.1 Chemical-input use alongside limited microbial pesticide use

This study identified a pronounced asymmetry in current production practice. Most respondents reported spending on herbicides, ethephon, and chemical fertilizers, whereas only three farmers (2.2%) reported current use of at least one microbial pesticide. Two additional farmers (1.5%) reported former use only, bringing the total to five farmers (3.7%) with any current or former use experience. These findings indicate that microbial pesticide use was present but remained uncommon within the sampled farming groups.

Farmers also commonly reported weed infestation and chemical weed control, and they frequently selected control methods based on their perceived effectiveness, convenience, and rapid effect. These patterns align with IPM literature emphasizing that alternative control options must be workable within existing production routines (Zhou et al., 2024; Gaillard et al., 2025).

Two findings provide additional context for farmers' reported considerations. Although 71.6% reported high production costs as a general production constraint, only 16.4% cited cost saving or cost reduction as a reason for selecting pest-management methods. Perceived effectiveness (91.0%) and convenience or rapid effect (79.1%) were cited much more frequently, suggesting that cost saving was considered less often in reported method selection than effectiveness or convenience, even though high production costs were commonly reported as a broader production constraint. Only 2.2% of farmers identified chemical-related health concerns as a production constraint. Thus, chemical-related health concerns were infrequently reported within the production-constraint checklist, despite broader evidence that pesticide use can pose environmental and human-health risks (UNEP, 2021).

Table 5. Descriptive profile of farmers by microbial pesticide use experience

Variable	No reported use experience (n=129)	Current or former use experience (n=5)
Age (years)	51.00 [45.00-57.00]	47.00 [42.00-56.00]
Household labor (persons)	2.00 [2.00-3.00]	2.00 [2.00-2.00]
Hired labor (persons)	2.00 [0.00-4.00]	4.00 [2.00-5.00]
Pineapple income (baht/year), median [IQR]	100,000.00 [50,000.00-180,000.00]	150,000.00 [120,000.00-220,000.00]
Agricultural income (baht/year)	60,000 [25,000-170,000]	150,000 [100,000-150,000]
Non-agricultural income (baht/year)	10,000 [0-40,000]	0 [0-50,000]
Household debt (baht/year; 2023 production cycle)	90,000 [20,000-200,000]	300,000 [300,000-400,000]
Pineapple farming experience (years)	13.00 [10.00-15.00]	10.00 [10.00-11.00]
Owned land area (rai)	2.75 [1.00-4.25]	0.00 [0.00-2.00]
Rented land area (rai), median [IQR]	0.00 [0.00-2.00]	10.00 [3.00-20.00]
Combined chemical-input cost (baht/year), median [IQR]	7,850.00 [4,700.00-15,600.00]	17,000.00 [16,700.00-49,000.00]
Education: lower secondary or higher, n (%)	45 (34.9)	3 (60.0)
Ever received training, n (%)	82 (63.6)	5 (100.0)
Ever received information, n (%)	84 (65.1)	5 (100.0)
Exposure to both training and information, n (%)	80 (62.0)	5 (100.0)

Note: Continuous variables are presented as median [IQR], and categorical variables as n (%). The five farmers with current or former microbial pesticide use experience are the same subgroup identified in Table 3, Panel C and Table 4. Subgroup comparisons are descriptive.

The very low reported expenditure on disease-control chemicals (0.7%) should be considered alongside farmers' reported disease-management patterns. Although plant diseases were common, farmers predominantly reported cultural practices such as cutting or removing affected plants, or no specific control, rather than chemical disease management. Thus, the low expenditure does not indicate an absence of disease occurrence, but rather reflects the management pattern reported in this production context.

We interpret the combination of universal weed pressure and the disease- or insect-oriented functions of the microbial products included in the survey as suggesting a possible product-problem misalignment. This issue warrants closer attention when selecting microbial products for extension activities in the study area.

3.8.2 Extension exposure alongside limited current microbial pesticide use

Training and information exposure were relatively common: 64.9% of respondents had received training, and 66.4% had received information on microbial pesticides. At the time of the survey, however, only three farmers (2.2%) reported current use. This contrast suggests that exposure to information alone does not capture the implementation conditions surrounding actual use.

Prior research similarly indicates that practical guidance, credible technical support, and context-specific applicability can influence the implementation of agricultural innovations after farmers have been introduced to them (Kondylis et al., 2017; Tensi et al., 2022; Praneetvatakul et al., 2024).

Constraint data from the five farmers with current or former use experience indicate implementation issues that may arise after initial exposure. Practical-use and product quality or performance constraints were the most frequently reported, suggesting that extension support may need to address conditions encountered during actual product use in addition to providing training and information.

3.8.3 Constraints reported by farmers with microbial pesticide use experience

Among the five farmers with current or former microbial pesticide use experience, four reported at least one practical-use constraint and four reported at least one product quality or performance constraint; three reported knowledge-related constraints and one reported a price-related constraint. Practical-use constraints concerned shelf life, storage, and use limitations, whereas product quality or performance constraints concerned slower action, repeated application, and perceived ineffectiveness. Knowledge-related constraints concerned product benefits, correct application, and storage, while the price-related constraint concerned the cost of microbial starter culture. Taken together, the reported constraints extended beyond knowledge-related issues to practical-use and perceived product-performance issues. Verma et al. (2024) similarly emphasized the importance of maintaining microbial activity during storage and application, while Fenibo and Matambo (2025) identified slow action, instability, and cost-related limitations as continuing challenges for biopesticide use. Marrone (2007) discussed these concerns within the broader challenge of achieving wider adoption of microbial and biochemical pesticides.

This pattern aligns with IPM literature that treats biopesticides as components to be integrated into pest-management systems rather than simple substitutes for synthetic pesticides. Chandler et al. (2011) examined factors affecting the development and use of biopesticides within IPM systems, while Ferreyra-Suarez et al. (2024) highlighted the sustainability potential of fungal-based bioproducts alongside their still-limited market presence relative to conventional chemical products. The constraints observed in this study are therefore consistent with literature emphasizing the importance of considering product characteristics and their fit with pest-management practices.

3.8.4 Limited use experience and discontinuation among former users

Only five farmers reported any current or former microbial pesticide use experience, comprising three current users and two former users. Compared with the 129 farmers with no reported use experience, this subgroup had a higher median rented land area, combined chemical-input cost, and pineapple income, as well as a lower median age and a higher proportion of farmers with at least lower-secondary education. Taken together, these characteristics suggest a somewhat different production and socioeconomic profile, particularly in land rental, chemical-input expenditure, income, and educational attainment. Previous Thai research has also reported a positive association between education and biopesticide use (Praneetvatakul et al., 2024).

All five farmers with use experience had also received both training and information on microbial pesticides. This suggests that extension exposure was common among farmers with microbial pesticide use experience, although it cannot be interpreted as a determinant of use. Previous studies have similarly highlighted the role of agricultural extension advice and professional support in farmers' engagement with IPM and microbial applications (Kondylis et al., 2017; Tensi et al., 2022; Praneetvatakul et al., 2024). The subgroup patterns observed here should therefore be regarded as descriptive characteristics rather than evidence of factors influencing initial or continued use.

The survey also recorded reasons for discontinuation among the two former *Trichoderma* users. One farmer reported that the product was ineffective, while the other reported storage difficulties and a limited usable period. These responses describe the discontinuation experiences of the two former users. The reported reasons correspond to the product-performance and practical-use constraint domains identified in the subgroup analysis.

3.8.5 Implications for extension and program design

The constraint pattern reported by the five farmers with current or former microbial pesticide use experience provides a basis for prioritizing several areas of extension support. Because practical-use and product quality or performance constraints were the most frequently reported domains, the most directly supported areas for extension are practical guidance on application and storage and locally relevant

demonstrations or product trials that allow farmers to assess product performance under pineapple production conditions. Knowledge-related constraints also support targeted guidance on product selection, correct application, and storage. Only one farmer reported a price-related constraint; therefore, the present data provide a weaker basis for prioritizing cost-related support.

These priorities are consistent with evidence from Thailand showing positive associations between agricultural extension advice, IPM practices, and biopesticide use, while also identifying constraints related to farmers' knowledge, methods of use, and the availability of suitable products (Praneetvatakul et al., 2024). Tensi et al. (2022) similarly identified a lack of knowledge and professional support as barriers to adopting microbial applications, supporting the relevance of technical guidance alongside information provision.

Training and information exposure were already relatively common in the study population, while current microbial pesticide use remained limited. A relevant next step for extension programs is therefore to evaluate whether existing training and information activities could be complemented by practical support during product trial and use, particularly in the priority areas identified above. More broadly, evidence from agricultural extension experiments suggests that direct extension contact can support technology uptake, while diffusion through information networks may be limited (Kondylis et al., 2017). These recommendations are based on the observed constraint pattern and were not interventions tested in this study. Future program implementation could assess other measures, such as improving supply reliability, cost-sharing, or farmer-to-farmer learning, if subsequent monitoring identifies these issues as relevant constraints in the local context.

3.8.6 Implications for GI production

The widespread use of chemical-related inputs observed among the registered Tha Uthen pineapple farmers provides baseline information relevant to sustainability-oriented assessment of this GI production context. Previous studies have suggested that GI systems can contribute to sustainable food systems when place-based product quality, local knowledge, production practices, and environmental management are considered together (FAO, 2019; FAO, 2023; Vandecandelaere et al., 2018). Falasco et al. (2024) further showed that the environmental contribution of GI products depends on how sustainability practices are implemented, while Guareschi et al. (2023) emphasized the potential role of collective management in supporting broader sustainability objectives.

In this context, the present findings suggest that sustainability-oriented development of Tha Uthen pineapple production should consider actual production practices alongside the place-based qualities represented by the GI designation. The observed patterns of chemical-related input use and microbial pesticide use provide baseline indicators that could be monitored over time to assess changes in production practices relevant to sustainability-oriented development.

3.8.7 Limitations of the study

This study has several limitations. First, the cross-sectional design limits interpretation of temporal and causal relationships between extension exposure and microbial pesticide use. Second, the sampling frame was restricted to farmers registered under the Large-Scale Farming System in Tha Uthen and Phon Sawan districts; therefore, the findings apply to this registered farming population rather than to all Tha Uthen pineapple growers in Nakhon Phanom Province. Third, only five farmers reported current or former microbial pesticide use experience, limiting subgroup analysis to descriptive comparisons. The study did not directly elicit reasons for non-use from the 129 farmers with no reported microbial pesticide use experience; therefore, the reported constraint data characterize only the five farmers with current or former use experience. Fourth, the study did not include direct environmental measurements such as pesticide residues, soil quality, water contamination, or biodiversity indicators. Reasons for discontinuation were available for only two former users.

4. CONCLUSION

This study characterized four aspects of microbial pesticide use in the GI pineapple production context among 134 registered Tha Uthen pineapple farmers. First, expenditure on chemical-related production inputs was widespread, particularly for herbicides, ethephon, and chemical fertilizers, whereas expenditure on disease-control chemicals was uncommon. Second, three farmers (2.2%) reported current microbial pesticide use, while two additional farmers (1.5%) reported former use only; overall, five farmers (3.7%) had current or former use experience.

Third, extension exposure was relatively common, with 64.9% having received training and 66.4% of farmers having received information on microbial pesticide use. Fourth, among the five farmers with use experience, the most frequently reported constraints concerned practical use and product quality or performance, followed by knowledge and price.

Among the two former users, one reported ineffectiveness, and one reported difficulty with storage and a limited usable period as reasons for discontinuation. The constraint pattern reported by the five farmers with use experience identifies practical application, storage, and product quality or field performance as priority areas for extension and program design, with targeted technical guidance also relevant to knowledge-related constraints. The possible misalignment between predominant weed-management needs and the functions of the microbial products included in the survey warrants further assessment when selecting products for local promotion.

Longitudinal research should examine the sequence between extension exposure, initial use, continued use, and discontinuation. Studies with larger numbers of microbial pesticide users, direct investigation of reasons for non-use among farmers without previous experience, and field assessment of product performance under local pineapple-production conditions would provide a stronger basis for understanding the conditions associated with microbial pesticide use.

ACKNOWLEDGEMENTS

This research received no external funding. The authors gratefully acknowledge the Department of Agricultural Extension and Khon Kaen University for their academic cooperation in supporting professional development, teaching, research, and agricultural extension. The authors also thank the Nakhon Phanom Provincial Agricultural Extension Office, the Phon Sawan District Agricultural Extension Office, and the leaders of the GI pineapple large-scale farming groups in Tha Uthen and Phon Sawan districts for facilitating field coordination and data collection. The authors also thank Asst. Prof. Arunee Promkhambut and Asst. Prof. Sukanlaya Choenkwan for their valuable advice during the preparation of this manuscript. We extend our sincere appreciation to all participating farmers for their time and cooperation.

AUTHOR CONTRIBUTIONS

Conceptualization, H.H. and S.P.; Methodology, S.P.; Validation, S.P.; Formal analysis, H.H. and S.P.; Investigation, H.H.; Data curation, H.H.; Writing - original draft, H.H.; Writing-review and editing, S.P.; Visualization, S.P.; Resources, H.H.; Supervision, S.P.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Akter S, Rutsaert P, Luis J, Htwe NM, San SS, Raharjo B, et al. Women's empowerment and gender equity in agriculture: A different perspective from Southeast Asia. Food Policy 2017;69:270-9.

Anzum HMN, Chakraborty TK, Bosu H. Farmer's perception and factors influencing adoption of adaptation measures to cope with climate change: an evidence from coastal Bangladesh. Environment and Natural Resources Journal 2023;21(2): 113-26.

Ayilara MS, Adeleke BS, Akinola SA, Fayose CA, Adeyemi UT, Gbadegesin LA, et al. Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. Frontiers in Microbiology 2023;14:Article No. 1040901.

Cai P, Dimopoulos G. Microbial biopesticides: A one health perspective on benefits and risks. One Health 2025;20: Article No. 100962.

Chandler D, Bailey AS, Tatchell GM, Davidson G, Greaves J, Grant WP. The development, regulation and use of biopesticides for integrated pest management. Philosophical Transactions of the Royal Society B: Biological Sciences 2011;366(1573):1987-98.

Department of Agricultural Extension. Large-Scale Farming Information System: Provincial Large-Scale Farming Summary [Internet]. 2025 [cited 2025 Feb 6]. Available from: https://co-farm.doae.go.th/graph/Report4smry.php?cmd= resetdrilldown.

Department of Intellectual Property. Tha Uthen Pineapple. Nonthaburi, Thailand: Department of Intellectual Property; 2014 (in Thai).

Falasco S, Caputo P, Garrone P. Can Geographical Indications promote environmental sustainability in food supply chains? Insights from a systematic literature review. Journal of Cleaner Production 2024;444:Article No. 141100.

Fenibo EO, Matambo T. Biopesticides for sustainable agriculture: feasible options for adopting cost-effective strategies. Frontiers in Sustainable Food Systems 2025;9:Article No. 1657000.

Ferreyra-Suarez D, García-Depraect O, Castro-Muñoz R. A review on fungal-based biopesticides and biofertilizers production. Ecotoxicology and Environmental Safety 2024; 283:Article No. 116945.

Food and Agriculture Organization of the United Nations (FAO). Geographical Indications for Sustainable Food Systems. Rome: Food and Agriculture Organization of the United Nations; 2019.

Food and Agriculture Organization of the United Nations (FAO). Using Geographical Indications to Improve Sustainability: Lessons Learned from 15 Years of FAO Work on Geographical Indications. Rome: FAO; 2023.

Gaillard B, Turnheim B, Belmin R, Loconto AM. Socio-technical lock-in as alignment process: tracing the joint development of pesticide dependency and vegetable production in Senegal

(1900-2024). Environmental Innovation and Societal Transitions 2025;56:Article No. 100997.

Glare TR, Caradus JR, Gelernter WD, Jackson TA, Keyhani NO, Köhl J, et al. Have biopesticides come of age? Trends in Biotechnology 2012;30(5):250-8.

Guareschi M, Mancini MC, Arfini F. Geographical indications, public goods and sustainable development goals: A methodological proposal. Journal of Rural Studies 2023; 103:Article No. 103122.

Kernecker M, Seufert V, Chapman M. Farmer-centered ecological intensification: Using innovation characteristics to identify barriers and opportunities for a transition of agroecosystems towards sustainability. Agricultural Systems 2021;191:Article No. 103142.

Kondylis F, Mueller V, Zhu J. Seeing is believing? Evidence from an extension network experiment. Journal of Development Economics 2017;125:1-20.

Marrone PG. Barriers to adoption of biological control agents and biological pesticides. CABI Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 2007;2(051):1-12.

Ministry of Agriculture and Cooperatives. Tha Uthen Pineapple, Nakhon Phanom Province [Internet]. 2026 [cited 2026 Apr 19]. Available from: https://www.opsmoac.go.th/sustainable_agri-dwl-preview-481991791824.

National Statistical Office (NSO). 2023 Agricultural Census: Northeastern Region. Bangkok: NSO; 2024 (in Thai).

Praneetvatakul S, Schreinemachers P, Vijitsrikamol K, Potchanasin C. Policy options for promoting wider use of biopesticides in Thai agriculture. Heliyon 2024;10(2):e24486.

Rovinelli RJ, Hambleton RK. On the use of content specialists in the assessment of criterion-referenced test item validity. Dutch Journal of Educational Research 1977;2:49-60.

Srinivasan R, Tamò M, Subramanian S. The case for integrated pest management in Africa: Transition from a pesticide-based approach. Current Opinion in Insect Science 2022;54:Article No. 100970.

Tensi AF, Ang F, van Der Fels-Klerx HJ. Behavioural drivers and barriers for adopting microbial applications in arable farms: Evidence from the Netherlands and Germany. Technological Forecasting and Social Change 2022;182:Article No. 121825.

Turner RC, Carlson L. Indexes of item-objective congruence for multidimensional items. International Journal of Testing 2003;3(2):163-71.

United Nations Environment Programme (UNEP). Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them. Nairobi: UNEP; 2021.

Vandecandelaere E, Teyssier C, Barjolle D, Jeanneaux P, Fournier S, Beucherie O. Strengthening sustainable food systems through geographical indications: An analysis of economic impacts. Rome: Food and Agriculture Organization of the United Nations; 2018.

Verma ML, Kumar A, Chintagunta AD, Samudrala PJK, Bardin M, Lichtfouse E. Microbial production of biopesticides for sustainable agriculture. Sustainability 2024;16(17):Article No. 7496.

Yamane T. Statistics: An Introductory Analysis. 2nd ed. New York: Harper and Row; 1967.

Zhou W, Arcot Y, Medina RF, Bernal J, Cisneros-Zevallos L, Akbulut MES. Integrated pest management: An update on the sustainability approach to crop protection. ACS Omega 2024;9(40):41130-47.