ASEAN
Journal of Scientific and Technological Reports
Online ISSN:2773-8752

Research article

Sustainable Organic Vegetable Production in Low-Cost Greenhouses and Post-Harvest Safety: A Community-Based Approach in Phatthalung Province, Thailand

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Citation:
Buakong, W.; Juthong, T.; Sermsin, N.; Yooyen, T. Sustainable organic vegetable production in low-cost greenhouses and post-harvest safety: A community-based approach in Phatthalung Province, Thailand. *ASEAN J. Sci. Tech. Report.* **2026**, *29*(1), e259596. https://doi.org/10.55164/ajstr.v29i1.259596.

Article history:
Received: June 22, 2025
Revised: October 2, 2025
Accepted: October 16, 2025
Available online: December 14, 2025

Abstract: This participatory action research assessed a community model for organic vegetable production. The study evaluated organic vegetable production efficiency and microbial safety using low-cost greenhouse systems among 20 households in Khok Muang Sub-district, Phatthalung Province, Thailand. The research involved three parts: 1) evaluating organic vegetable production in low-cost greenhouses, 2) detecting fecal coliform and *Escherichia coli* contamination in fresh vegetable produce, and 3) analyzing contamination of parasites in fresh vegetables. The results demonstrated successful knowledge transfer. The participating households reduce monthly vegetable expenses by 55.60 USD while generating a monthly income of 88.60 USD through the cultivation of seven vegetable types annually. Microbiological analysis revealed coliform contamination in unwashed vegetables at 4.87, 4.55, and 4.18 log CFU/g for kale (*Brassica oleracea* L.), green oak lettuce (*Lactuca sativa* L.), and Chinese cabbage (*Brassica sativa* var. *crispa* L.), respectively, with *E. coli* detected only in green oak lettuce (1.24 log CFU/g). Post-washing, coliform levels decreased to 3.71, 3.58, and 3.06 log CFU/g, respectively, with no detectable *E. coli*. Vinegar (100 ppm) treatment significantly reduced coliform levels by 35.60%. An examination of parasites in three vegetable kinds across seven greenhouses revealed that 37.50% of 24 samples were affected with at least one agricultural pest species, with green oak lettuce exhibiting the greatest contamination rates. The community approach effectively enhanced household food security and income, emphasising the significance of appropriate post-harvest handling procedures to comply with Thai public health regulations for the commercialisation of fresh produce.

Keywords: Participatory action research; parasite contamination analysis; microbiological safety; coliform bacteria; *Escherichia coli*

1. Introduction

Sustainable agriculture has become an essential strategy for rural development in Thailand, particularly in Phatthalung Province, where agricultural activities are important to the local economy. Phatthalung ranks 13th out of 14 southern provinces in terms of economic prosperity, with an agrarian production structure accounting for 31.08% of economic activity but a low per capita income of only 2,033.70 USD annually [1]. The province has established an agricultural and cooperative development plan for 2023-2027 that prioritises sustainable agriculture and organic farming expansion [1]. The plan is consistent with the Sufficiency Economy Philosophy, which prioritises balanced development by taking into account economic, social, cultural, and environmental concerns. However, economic disparities highlight the urgent need to adopt innovative agricultural approaches to alleviate poverty while promoting sustainability. Despite Phatthalung's varied agricultural environment, in rice cultivation, rubber plantations, orchards, and animals, the region continues to have considerable economic difficulties. Khok Muang Sub-district in Khao Chaison District is a small example of these challenges. Initially mainly planted with rice, this area has been increasingly converted to monoculture rubber plantations. The producers of the market are experiencing fluctuations. As noted by the Economic Research Division of the Rubber Authority of Thailand [2], when rubber prices drop to 0.97-1.38 USD per kg against production costs of 1.74 USD per kg, farmers face significant financial strain with annual incomes of approximately 2,080.5 USD per hectare. This economic instability is exacerbated by seasonal challenges, including the 4-5-month rainy and dry seasons during which rubber plants lose their leaves, thereby diminishing income-generating prospects. In addition to economic risks, farmers in Khok Muang also face health and environmental problems. Chemical-intensive farming practices have resulted in concerning health effects, with 90% of a sample of 100 farmers exhibiting chemical contamination in their blood during a 2019 evaluation. Furthermore, water scarcity during dry seasons also presents a persistent challenge for agricultural diversification [3]. This indicates a need to understand the various perceptions of organic vegetable production efficiency and microbial safety using low-cost greenhouse systems, which impact household food security and income. In this research, the study employed participatory action research (PAR) to address these interconnected challenges by developing and implementing a sustainable organic vegetable production model using low-cost greenhouse systems.

The research has three objectives: (1) to evaluate organic vegetable production in low-cost greenhouses as an alternative income source for rubber farmers; (2) to detect and mitigate fecal coliform and *E. coli* contamination in fresh vegetable produce; and (3) to analyze parasite contamination in fresh vegetables. Through this community-based approach, knowledge transfer mechanisms focused on four key areas: low-cost greenhouse construction, bio-organic fertilizer production, precise organic vegetable cultivation techniques, and compliance with Organic Thailand farming standards. Muhie et al. [4] emphasize that such integrated approaches are essential for developing sustainable agricultural systems that balance economic benefits with food safety concerns. This research aims to develop a model household for organic vegetable production to enhance farmers' quality of life and comply with public health regulations for the commercialisation of fresh produce, implementing production and post-harvest safety.

2. Materials and Methods

2.1 Site description

Khok Muang Subdistrict, Khao Chai Son District, Phatthalung Province, has a terrain of hills and flat plains scattered throughout with an area of approximately 68 square kilometers, or approximately 6,800 hectares, and is divided into 5,091 males and 5,310 females, 3,698 households, and 15 villages (Figure 1). Most people in Khok Muang Sub-district work in agriculture, which covers 6,183 hectares. The agricultural region is categorised by significant crop varieties as follows: rubber covers 5,528 hectares, accounting for 89.41%; oil palm 233.28 hectares (3.77%); fruit trees 63.36 hectares (1.02%); vegetables 8.16 hectares (0.13%); field crops 7.36 hectares (0.12%); and other agricultural areas such as fishing 33.92 hectares (0.55%), livestock 30.24 hectares (0.49%), and rice 142.88 hectares (2.31%).

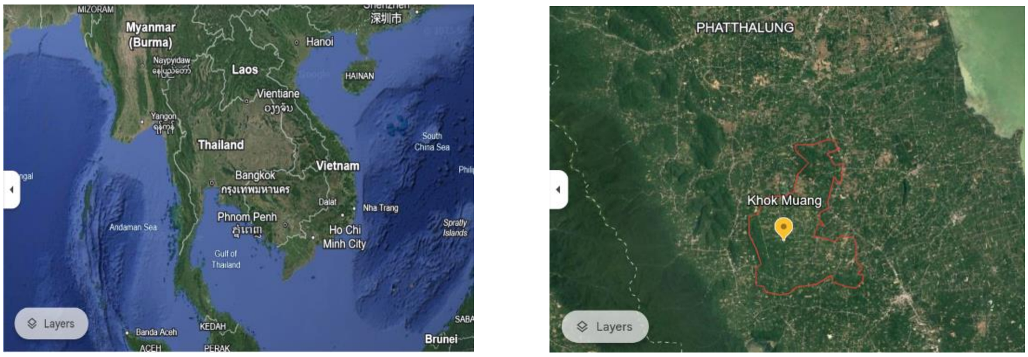

Figure 1. Site sampling location in the study areas in Khok Muang Sub-districts, Phatthalung Province, Southern Thailand.

2.2 Organic Vegetable Production in Greenhouse Systems

2.2.1 Community Context Analysis

This study employed a participatory action research (PAR) mixed-methods design to understand the farmer context in Khok Muang Sub-district, Khao Chaison District, Phatthalung Province, Thailand, and to co-develop and implement an organic vegetable production model using low-cost greenhouse systems [5-6]. The first part focused on context analysis, utilizing two primary data sources: 1) comprehensively understanding the local agricultural landscape. The research team conducted the focus group with key informants, including community leaders, the mayor of Khok Muang Sub-district, and the district agricultural office. These interviews explored the general agriculture context, farmers' knowledge and practices related to organic vegetable production, their perceived capacity and interest in adopting low-cost greenhouse technology for enhancing household food security based on sufficiency economy principles, and the availability of relevant local agricultural infrastructure and support systems. 2) Purposive sampling was used to lead farmers from the Khok Muang community, selected from 85 individuals. These sessions facilitated the sharing of their farming knowledge and practical experiences, and the identification of prevalent problems and obstacles encountered in their current agricultural practices. Data was taken during these conversations, and the transcribed qualitative data were analysed to identify key characteristics.

2.2.2 Development and Transfer of Organic Vegetable Production Technology

Following the standard of production, processing, and labelling of organic agriculture products, this research aimed to develop an organic vegetable production standard system and disseminate the system to participating households. The multifaceted approach was evaluated, encompassing compliance assessment, production yield, income analysis, and satisfaction evaluation. The research team conducted systematic observations to assess farmers' compliance with the training and technology transfer. Participating households received comprehensive training on the organic vegetable production standard system developed. The sessions were recorded to establish a comparative baseline for the application of the transferred knowledge. The researchers evaluated the farmers' potential for organic vegetable production; researchers assessed the farmers' potential for organic vegetable production. The level of compliance with training and the observed potential were quantified using percentage calculations. The efficiency of the technology transfer was analysed in 85 participating farmers using a focus group to collect and summarize the results of low-cost greenhouse organic vegetable production systems. The satisfaction data collected were analysed. Farmers involved in the study completed a satisfaction questionnaire on a rating scale to assess their perception of the effectiveness and utility of the technology transfer. The overall satisfaction level was determined by interpreting these average scores using a predefined rating scale with Best [7].

2.2.3 Evaluation of Farmer Compliance and Production Yields

In this research, 20 selected model households demonstrated the following key characteristics: 1) the ability to apply knowledge gained from technology transfer within their households. 2) Patience and commitment to practicing agriculture within the organic farming system. 3) Availability of space to carry out agricultural operations. 4) The potential to share and transfer knowledge to others in the community. Model households were selected through a collaborative process involving meetings with Khok Muang Sub-district Municipality and the local community. This included conducting surveys and exchanging ideas to identify suitable candidates. The selection process involved a consultation between members of the community enterprise group and agricultural experts from the Khok Muang Sub-district municipality. As a result, 20 households from Khok Muang Sub-district were selected as model households. We collected the organic vegetable production, yields, and costs from farmers' records of produce delivered to the market. To assess the impact of implementing the organic production standard, we compared the production yields and income data collected before and after the farmers' participation in the research. The pathway outlines a structured process for improving rubber farmers' livelihoods through sustainable organic vegetable production, emphasizing capacity building, economic diversification, certification, and long-term rural development (Figure 2).

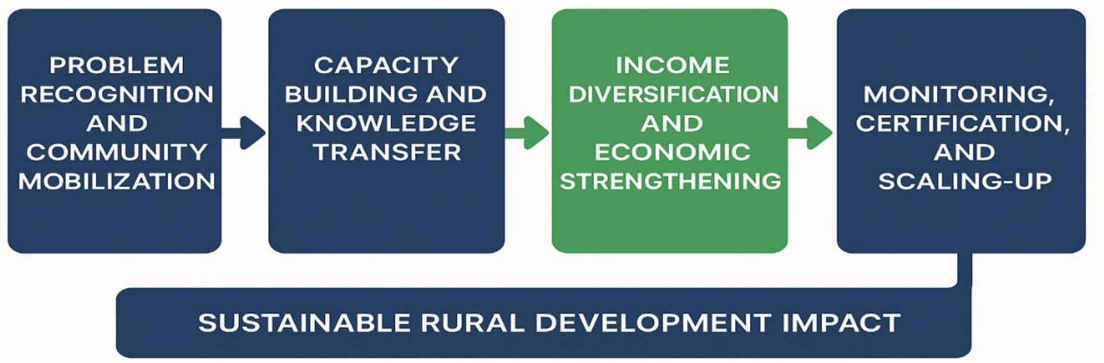

Figure 2. Driving pathway for enhancing rubber farmers' livelihoods through sustainable low-cost greenhouse organic vegetables production

2.3 Microbiological Safety Assessment

2.3.1 Sample Collection of Vegetables

The sample of three leafy green vegetables—green oak lettuce, Chinese cabbage, and kale (100 g each)—was collected from community-based organic farming operations in Khok Muang, Phatthalung Province, in August 2024 (Figure 3). All samples were harvested using aseptic techniques to prevent cross-contamination during collection. These vegetables were selected based on their popularity as raw consumption items, making their microbiological safety particularly important for consumer health.

2.3.2 Washing Methods Evaluation

The study compared unwashed vegetables with those processed using the community group's standard washing protocol. The three types of vegetable leaves (green oak lettuce, Chinese cabbage, and kale) were compared between unwashed and washed to verify the community group's washing method. The washing method followed the protocol of the farming community group involved soaking vegetables in three water basins for 30 seconds in each basin (Figure 4). Then, the samples were tested for coliform and *E. coli* levels. The experiments of washing methods evaluation were duplicated for each vegetable sample.

2.3.3 Vinegar Solution Efficacy Testing

Green oak lettuce, which showed both coliform and *E. coli* contamination in its unwashed state, was selected for vinegar solution efficacy testing. The unwashed green oak leaves were used as a control. Fresh green oak leaves were examined after being washed with vinegar at different solution levels to assess the reduction of coliform bacteria and *E. coli* contamination. The vinegar used for washing vegetables was prepared from vinegar (5% acetic acid) and converted into ppm units of acetic acid. The concentrations were 0, 6.25, 25, and 100 ppm and were applied in the second basin of washing steps.

2.3.4 Coliform and E. coli Analysis

Microbiological analysis was conducted using standardized methods. 10-fold dilutions of each vegetable sample were prepared in 0.85% NaCl solution. 10 g of each vegetable leaf was put in a stomacher bag, and 90 mL of 0.85% NaCl solution was added. Then, the samples were homogenized using a stomacher for 60 seconds. Subsequently, the solution was further diluted to a 1:100 fold. Then, 1 ml aliquots of 1:10 and 1:100 dilution samples were placed in duplicate onto 3M™ Petrifilm™ (3M Petrifilm™ Rapid *E. coli* / Coliform Count Plate) and incubated at 35±2°C for 24±2 hrs. After incubation, *E. coli* and total coliform were enumerated. The *E. coli* colony count is indicated by a blue colony, and the total coliform is indicated by a red colony with gas production (Bird et al., 2020). The bacterial colonies were quantified and expressed as logarithmic values of CFU/g of vegetables (log CFU/g).

(a) (b) (c)

Figure 3. Appearance of (a) Green oak lettuce, (b) Chinese cabbage, and (c) Kale leaves

(a) (b) (c)

Figure 4. Steps of vegetables washing (a) 1st washing basin, (b) 2nd washing basin, and (c) 3rd washing basin

2.4 Pest Contamination Analysis

2.4.1 Sampling Methods

The pest contamination analysis was conducted on 24 vegetable samples collected from seven low-cost greenhouse operations in the Khok Muang community. Three types of vegetables (green oak lettuce, 9 samples; Chinese kale, 9 samples; and Chinese cabbage, 6 samples) were randomly selected to represent different cultivation cycles and environmental conditions within each greenhouse. For each vegetable type, 50 g samples were collected using sterile equipment. Care was taken to include both inner and outer leaves to assess potential differences in contamination patterns. In addition, 100 g soil samples were collected from each greenhouse to examine the relationship between soil and vegetable contamination.

2.4.2 Detection Techniques for Pests in Vegetables

Vegetables were assessed through sedimentation techniques following standardized protocols. The samples were individually washed with distilled water (250 mL) in a beaker container, which was sanitized after each procedure in saline solution (0.85% NaCl). Washing liquid was filtered through sterile gauze in a sedimentation glass. After 12 h, the upper layer was discarded, and 30 mL of the wash liquid was transferred to plastic tubes and centrifuged (2,000 rpm for 5 minutes). Subsequently, the supernatant was carefully removed, and 100 µL of the pellet was transferred to five glass slides, mixed with Lugol's iodine solution, and analysed under an optical microscope with 100x and 400x magnification.

2.5 Statistical analysis

A paired t-test (dependent t-test) was performed to determine statistically significant differences in vegetable production yield before and after research participation. Using the IBM SPSS Statistics-25 program, we conducted a one-way analysis of variance (ANOVA) with statistical distinctions across multiple treatment groups with 95% confidence. The mean production yield for both periods was calculated. Bacteria count (log CFU/g) was determined using means and standard deviations.

3. Results and Discussion

3.1 Community context

This research comprehensively analysed the agricultural context in Khok Muang Sub-district through focus group discussions with key informants, including community leaders, the mayor, and district agricultural officials. The discussions reveal that a community relies heavily on rubber plantations, replacing traditional rice cultivation. Purposive sampling identified 85 lead farmers who engaged in knowledge-sharing sessions that underscored various challenges: economic vulnerability stemming from volatile rubber prices, seasonal income disparities during the 4–5-month rainy season and dry periods, chemical contamination impacting farmer health (90% of tested farmers exhibited chemical exposure), water resource constraints during dry seasons, and insufficient knowledge of agricultural diversification. These initial assessments identified the need for sustainable farming alternatives that could provide year-round income supplementation while addressing health and environmental concerns [8, 9].

Based on community needs, the research team developed a comprehensive knowledge transfer program focused on four key technological components: low-cost greenhouse construction (six designs evaluated, costs from 1.38-4.74 USD for a square meter structure, with wood-framed greenhouses with PVC or wood roofing proving most cost-effective at 1.52 USD and 1.38 USD respectively) (Table 1); bio-organic fertilizer production techniques using locally available materials to replace chemical fertilizers; precise organic vegetable cultivation methods for selecting crop varieties, planning planting schedules, and implementing organic pest management; and Organic Thailand farming standards training on certification requirements and compliance procedures to enhance market opportunities. For technology transfer using participatory training methods, where researchers systematically observe throughout the process to assess the level of adoption, collaboration with local farmer groups makes this tool effective in resource-limited communities [10].

3.2 Greenhouse system implementation outcomes

Implementing participatory action research methods significantly improved farmers' knowledge of organic vegetable production technologies. The pre-training assessment showed baseline knowledge at 3.81±0.08 on a 5-point scale, which increased to 4.45 ± 0.08 post-training, representing a 16.8% improvement. Knowledge of bio-organic fertilizer production showed the highest post-training score (4.55 ± 0.51), while greenhouse construction presented the most challenging learning curve (4.36 ± 0.65). These findings align with Rahman et al. [15], who observed that participatory knowledge transfer approaches significantly enhance agricultural technology adoption. Implementation capacity assessment revealed high practical application ability (4.72 ± 0.30), indicating effective knowledge transfer beyond theoretical understanding (Table 2). This high implementation rate suggests the technologies were appropriately adapted to local contexts, a factor Bukchin and Kerret [11] identified as critical for successful agricultural innovation adoption.

Cost analysis of six greenhouse designs revealed that wood-framed structures with wood roofing provided the most economical option at 83.05 USD per 6×10 m greenhouse. Steel pipe constructions offered more excellent durability but substantially higher costs (237.22-284.44 USD) (Table 1). The wood-PVC hybrid design (91.38 USD) emerged as the preferred option, balancing cost-effectiveness with moderate durability, like the findings by Wiseansart [12], who identified hybrid structures as optimal for smallholder farmers. Payback period calculations indicated that even the most expensive greenhouse design would be recovered within 16 months based on average vegetable yields and current market prices. This rapid return on investment encouraged adoption among participating households, with 85% selecting the wood-PVC hybrid design. These findings support Ma et al.'s [13] conclusion that initial investment barriers can be overcome when farmers perceive economic returns within short timeframes.

The greenhouse system yielded seven vegetable varieties, with Chinese kale showing the highest production (61.9 ± 9.61 kg/greenhouse/year). Other successful crops included green oak lettuce (59.25 ± 6.88 kg/greenhouse/year), frillice iceberg lettuce (58.9 ± 5.92 kg/greenhouse/year), and mustard greens (58.95 ± 5.42 kg/greenhouse/year) (Table 3). The wide standard deviation in red oak lettuce yields indicates variable production success among participating households, potentially reflecting different skill levels or microenvironmental factors within greenhouses. The economic analysis revealed two benefits: monthly savings of 55.60 USD in household vegetable spending and an additional income of 88.60 USD per month. This results in a total economic benefit of 144.20 USD monthly, a significant extra income for rubber farmers' households. Alin, along with Touch et al. [14], emphasized that such additional income is crucial in enhancing smallholder farmers' resilience to market volatility. These economic benefits could translate into an annual revenue of approximately 3,962.40 USD combined with the average primary household income of 186.11 USD per month; the total income surpasses the average per capita income in Phatthalung Province (2,033.70 USD). It effectively doubles household revenue [1]. The food supply chain operates in two distinct ways:1) Direct supply from farmers to consumers – consumers purchase food straight from farmers, ensuring freshness and often reducing costs. This approach is common in farmers' markets, direct farm sales, and community-supported agriculture programs, fostering closer connections between producers and buyers. 2) Supply through distributors – food moves from farmers to distributors before reaching consumers. Distributors play a vital role in handling transportation, storage, and processing, ensuring steady availability in grocery stores, restaurants, and food services. This system enhances accessibility and convenience but involves a longer supply chain. The findings indicate that the integration of organic production with low-cost greenhouse technology can markedly enhance vegetable yields, facilitate crop diversification, and elevate the livelihoods of rubber farming communities. Subsequent research should concentrate on comprehensive economic evaluations, pest and disease interactions, and farmer acceptance to further substantiate and expand this paradigm across analogous agroecological regions.

Table 1. Cost comparison of greenhouse types

Greenhouse type	Pillar material	Roof material	Cost (USD/m^2)
Type 1	PVC	PVC	1.57
Type 2	Wood	PVC	1.52
Type 3	Wood	Wood	1.38
Type 4	Cement	PVC	2.59
Type 5	Steel pipe	Steel pipe and PVC	3.95
Type 6	Steel pipe	steel pipe	4.74

Table 2. Knowledge transfer effectiveness (pre and post training)

Knowledge component	Pre-training score	Post-training score	Improvement (%)	Meaning
Low-cost greenhouse construction	3.72 ± 0.98	4.36 ± 0.65	17.2	Very satisfied
Bio-organic fertilizer production	3.91 ± 0.92	4.55 ± 0.51	16.4	Extremely satisfied
Organic vegetable cultivation	3.81 ± 0.95	4.45 ± 0.51	16.8	Very satisfied
Overall average	3.81 ± 0.08	4.45 ± 0.08	16.8	Very satisfied

Remarks: 4.51 - 5.00 = Extremely satisfied, 3.51-4.50 = Very satisfied, 2.51 - 3.50 = Moderately satisfied, 1.51 - 2.50 = Slightly satisfied, 1.00 - 1.51, The most slightly satisfied

(a) (b) (c)

Figure 5. Vegetable products (a) Chinese kale, (b) mustard green, and (c) green oak were produced in the low-cost greenhouse.

3.2 Microbiological safety findings

Microbiological analysis revealed significant contamination in unwashed organic vegetables. Coliform levels were highest in kale (4.87 log CFU/g), followed by green oak lettuce (4.55 log CFU/g) and Chinese cabbage (4.18 log CFU/g). *E. coli* was detected only in unwashed green oak lettuce samples (1.24 log CFU/g). The three-basin washing protocol effectively reduced coliform levels to 3.71, 3.58, and 3.06 log CFU/g for green oak lettuce, Chinese cabbage, and kale, respectively, representing reductions of 18.46%, 14.35%, and 37.17%. No *E. coli* was detected in any washed samples, indicating complete removal through the washing process (Table 4). These contamination patterns align with findings from Rahman et al. [15], who reported coliform levels of 3.8-5.2 log CFU/g in unwashed leafy vegetables. The higher contamination in kale is attributed to its textured leaf surface providing more significant microbial attachment sites, as described by Alegbeleye et al. [16]. Vinegar washing experiments with green oak lettuce demonstrated a concentration-dependent reduction in coliform levels. Unwashed samples showed contamination of 3.23 log CFU/g, which decreased to 2.80, 2.49, 2.31, and 2.08 log CFU/g after treatment with 0, 6.25, 25, and 100 ppm vinegar solutions, respectively. The 100-ppm concentration achieved the highest efficacy, with a 35.60% reduction compared to unwashed samples and a 25.71% improvement over standard water washing (Table 5). These results are consistent with those of Nascimento et al. [17], who reported that vinegar solutions reduced coliform counts in lettuce by 48.60-68.00%, depending on concentration. The antimicrobial effect observed is attributed to acetic acid's ability to disrupt bacterial cell membranes and intracellular pH, as Alreshoodi et al. [18] explained.

Based on these findings, a three-step washing protocol incorporating vinegar treatment is recommended for optimal microbial reduction. This includes (1) an initial rinse with clean water to remove soil and debris, (2) a 30-second soak in 100 ppm vinegar solution, and (3) a final rinse with clean water to remove vinegar residue. This protocol balances efficacy with practicality, as higher vinegar concentrations tested by Atter et al. [19] and Traore et al. [20] achieved more significant reductions but may negatively impact sensory qualities. Although this approach can significantly reduce contamination, it does not guarantee the complete elimination of pathogens, and therefore, additional technologies such as appropriate cold storage (≤4°C) should be implemented as recommended by Srisamran et al. [21]. For commercial applications, the Thai Public Health standards for fresh vegetables require coliform levels below 3 log CFU/g and no *E. coli*. The recommended protocol brings products within these compliance thresholds, supporting market access while utilizing low-cost, accessible materials suitable for smallholder farmers.

Table 3. Vegetable production yields and economic impact

Type of organic vegetables	Before	After	t-test	*p*-value	% increase in the yields of vegetable production	Income greenhouse /year
	yields (kg/greenhouse /year)	yields (kg/greenhouse /year)				
1. Green oak (*Lactuca sativavar. crispa* L.)	No crop	59.25 ± 6.88	-	-	New introduction	246.88
2. Red oak (*Lactuca sativa*)	No crop	57.4 ± 9.90	-	-	New introduction	239.20
3. Frillice iceberg Lettuce (*Lactuca sativa* L.)	No crop	58.9 ± 5.92	-	-	New introduction	245.42
4. Mustard greens (*Brassica juncea*)	45.63 ± 15.56	58.95 ± 5.42	1.49	0.145^{ns}	29.20	81.88
5. Chinese kale (*Brassica alboglabra* L.H. Bailey)	30.67 ± 20.32	61.9 ± 9.61	4.43	0.00**	101.70	171.94
6. Kale (*Brassica oleracea*) L. var *acephala* DC.)	No crop	48 ± 7.89	-	-	New introduction	400.00
7. Chinese cabbage (*Brassica sativa* var. *crispa* L.)	28.54 ± 13.21	56.25 ± 4.98	7.34	0.00**	97.10	78.13
Total	**104.84**	**400.65**	**-**	**-**	**289.30**	**1,463.40**

N = Number of samples = 20, SD = standard deviation, **$p < 0.01$.

Table 4. Coliform and *E. coli* contamination before and after washing

Vegetable type	Coliform (log CFU/g)		*E. coli* (log CFU/g)		Coliform reduction (%)
	Unwashed	Washed	Unwashed	Washed	
Green oak lettuce	4.55 ± 0.02	3.71 ± 0.81	1.24 ± 0.24	ND	18.46
Chinese cabbage	4.18 ± 0.04	3.58 ± 0.96	ND	ND	14.35
Kale	4.87 ± 0.02	3.06 ± 0.01	ND	ND	37.17

*ND = Not detected

Table 5. Effect of vinegar concentration on Coliform levels in green oak lettuce

Treatment	Vinegar concentration (ppm)	Coliform (log CFU/g)	Reduction vs. Unwashed (%)	Reduction vs. Water washing (%)
Unwashed	0	3.23 ± 0.03^{e}	-	-
1	0	2.80 ± 0.06^{d}	13.31	-
2	6.25	2.49 ± 0.01^{c}	22.91	11.07
3	25	2.31 ± 0.04^{b}	28.48	17.50
4	100	2.08 ± 0.05^{a}	35.60	25.71

Different letters within treatment indicate significant differences at the $p < 0.05$ level, according to Duncan's multiple range test method.

3.3 Agricultural pest contamination results

Agricultural pest analysis of 24 vegetable samples revealed significant contamination rates in all examined vegetable varieties. In total, 37.5% (9/24) of the samples contained at least one parasite, with Chinese cabbage having the highest contamination rate (50.0%, 3/6). Green oak lettuce and Chinese kale had similar contamination rates of 33.3% (3/9) (Table 6). These findings are in line with Laoraksawong et al. [22], who reported contamination rates of 35–58% in green leafy vegetables from organic farming systems (Table 7). The higher contamination rates in Chinese cabbage may be due to its distinctive leaf morphology, which provides numerous cavities for parasite attachment and protection from conventional washing methods. This morphological influence on the contamination pattern supports the observation by Dokmaikaw et al. [23], who observed that complex leaf structures harbored significantly more agricultural pests than smooth-surfaced vegetables. Two main types of agricultural pests were found in the vegetable samples: aphids (plant lice) and vegetable mites in various stages (Figure 6). The prevalence of arthropod parasites underscores the difficulties faced by organic farming systems that depend more on biological pest control than on chemical pesticides, as observed by Ounis et al. [24]. These results highlight the complex balance between chemical reduction and management of potential biological contaminants. The presence of ticks, usually linked to host animals, signifies possible cross-contamination from adjacent livestock or wildlife, a phenomenon noted by Zahid et al. [25], prevalent in mixed farming systems. Distribution patterns vary among vegetable types, with green oak lettuce having the most diverse parasite profiles. This suggests that targeted washing protocols should be developed for specific vegetable types rather than applying a uniform approach to the entire produce, as suggested by Nahhas et al. [26].

Figure 6 Microscopic images of common vegetable pests. The top row shows aphids (plant lice), which are soft-bodied insects that feed on plant sap and can transmit plant viruses. The bottom row displays various views of vegetable mites, tiny arachnids that damage plant tissue by piercing and sucking out cell contents.

Table 6. Prevalence of agricultural pests in different vegetable types

Vegetable type	Samples tested	Contaminated samples	Contamination rate (%)
Green oak lettuce	9	3	33.30
Chinese kale	9	3	33.30
Chinese cabbage	6	3	50.00
Total	24	9	37.50

Table 7. Distribution of agricultural pest species across vegetable types

Agricultural pest type	Green oak lettuce	Chinese kale	Chinese cabbage	Total prevalence (%)
Aphids (Plant lice)	17	16	7	90.91%
Vegetable mites	-	-	4	9.09%

4. Conclusions

This participatory action research demonstrated the effectiveness of low-cost greenhouse systems for organic vegetable production in Khok Muang, Phatthalung Province. Knowledge transfer led to a 16.80% enhancement in farmer competency, with bio-organic fertiliser production achieving the highest post-training score of 4.55 out of 5.00. The wood-PVC hybrid greenhouse design (91.38 USD) emerged as the optimal balance of cost-effectiveness and durability. Chinese kale yielded the highest production (61.9 ± 9.61 kg/greenhouse/year), while microbiological analysis revealed significant contamination reduction through proper washing protocols. Standard washing reduced coliform levels by 14.35-37.17%, while 100 ppm vinegar treatment achieved a 35.60% reduction. Parasite contamination was found in 37.5% of vegetable samples, with Chinese cabbage showing the highest rate (50%). Aphids were the most common agricultural pest (90.91%), indicating a need for effective pest control, especially against aphids, in vegetable production. There are substantial economic benefits, with participating households saving 55.60 USD monthly on vegetable expenses while earning 88.60 USD in additional income. The monthly economic impact of 144.20 USD constitutes a substantial augmentation to conventional rubber farming revenues, mitigating the economic vulnerability highlighted in the community context analysis. Beyond financial gains, the organic production methods reduced chemical exposure for producers and consumers, directly addressing the 90% chemical contamination rate previously documented among farmers. The enhanced post-harvest handling techniques effectively diminished microbial contamination to levels that meet Thai Public Health requirements, facilitating market access beyond local consumption.

5. Acknowledgements

The author would like to thank rubber smallholder farmers in Phatthalung province, Thailand, for participating in this research. This research was supported by the Research Council of Thailand (NRCT) (grant no. N71B650095), the Faculty of Agro- and Bio-Industry, and the Faculty of Science and Digital Innovation Thaksin University, Phatthalung Province, Thailand. The authors declare no conflict of interest between themselves and any other individual or organization

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