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Comparing conventional practices and good agricultural practices: Socio-economic impacts on smallholder vegetable farmers in Cambodia

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ABSTRACT
Vegetable production is essential in Cambodia's agricultural sector, contributing to sustainable rural livelihoods, domestic demand, and the economy. However, the quality of vegetables remains limited, largely due to improper application of cultivation techniques. In this regard, good agricultural practices (GAP) have been introduced in the country to address this issue. The aim of the study was to determine the factors influencing GAP adoption and income in vegetable farming systems, explore challenges and perceptions related to the CamGAP standard, and compare the economic performance of GAP and non-GAP farmers. The study was conducted in six provinces between January and June 2024, involving interviews with 85 GAP and 60 non-GAP leafy vegetable farmers. A two-sample t-test was used to compare household characteristics and economic outcomes between the two groups. Likert scale surveys evaluated potentials and constraints to vegetable production, while LASSO regression models identified factors influencing GAP adoption. Results indicate that age, GAP application, and total production costs significantly affected farmers' income. GAP application is notably associated with membership in agricultural cooperatives. The average income was 346.7 USD per 0.1 hectare for GAP farmers and 170.7 USD per 0.1 hectare for non-GAP farmers. GAP application increased incomes and resulted in higher-quality products due to reduced chemical use during cultivation. Strengthening and expanding agricultural cooperatives are essential for promoting wider GAP adoption, increasing rural incomes, and reducing environmental impacts in vegetable production.

Contribution/Originality: This study contributes to the promotion of CamGAP adoption among smallholder vegetable farmers in Cambodia. It identifies socio-economic factors of GAP adoption and its income effects, highlighting the crucial role of agricultural cooperatives in promoting sustainable agricultural production in Cambodia.

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1. INTRODUCTION

Cambodia's agriculture sector employs most of the population and accounts for 16.6% of the GDP (World Bank, 2024). Rice is the primary crop, followed by cassava, maize, mung bean, and soybean. The Cambodian government promotes investment and diversification of agricultural products, while it is self-sufficient in rice and exports various fruits and agricultural products. About 75% of its population resides in rural areas, and around 36.6% of the total workforce was directly engaged in the agriculture sector in 2022 (World Vegetable Center, 2024).

Cambodia is considered one of the most vulnerable countries to climate change. Climate change is causing increased droughts in Cambodia, which significantly impact the Tonlé Sap and Mekong deltas. These water systems are essential for water supply, agriculture, and fishing in the country (Fagerland & Sandvik, 2009). Smallholder farmers in Cambodia face a range of problems related to climate change. Poor infrastructure, particularly limited irrigation and rural roads, and inadequate access to technology and extension services are the major challenges that Cambodian farmers currently face (Food and Agriculture Organization of the United Nations, 2017). The diversity of Cambodia's produce including rice, poultry, fish, and vegetables, means that climate change can affect every farmer differently (Food and Agriculture Organization of the United Nations, 2018). Cambodia's food safety is crucial due to pesticide and pollution contamination in both imported and local foods. Bacteria, including those resistant to antibiotics, are common in animal-based foods. Maintaining food safety requires collaboration from all stakeholders, including the public, private, and consumers (Thompson, Vipham, Hok, & Ebner, 2021). Cambodian farmers are adopting safe vegetable value chains, using new seeds, compost, and pest management technologies. They collaborate with stakeholders, receive training, and access packing centers, boosting their income and food security (General Directorate of Agriculture, 2020).

Cambodia's Ministry of Agriculture, Forestry and Fisheries (MAFF) approved the National GAP standard through Ministerial Proclamation No. 099 MAFF on 10 March 2010. The proclamation outlines the responsibilities of the General Directorate of Agriculture in implementing GAP management and issuing compliance certificates (General Directorate of Agriculture, 2020). GAP encompasses many agricultural practices designed for water saving, reduced input use, safe chemical application, and energy-efficient technology. Farmers can utilize drip irrigation for vegetables and fruit, as well as water-saving technology such as alternative wet and dry irrigation for rice. Applying inputs such as fertilizers and pesticides according to the established standards can result in significant savings. Using certified seeds and growing them in net-houses for vegetables can ensure high germination rates and effective protection against erratic weather. Lower input use means lower production costs, while decreased water consumption leads to less energy usage for irrigation. All these practices contribute to reducing greenhouse emissions, while ensuring that food is produced safely for both farmers and consumers at higher prices (Eliseu, Lima, & Gaspar, 2024; Kharel, Dahal, & Raut, 2022).

Applying for the CamGAP certification involves several steps. First, farmers should understand the CamGAP standards, which cover food safety, environmental management, worker health, and produce quality. Then, they need to prepare their farms by implementing necessary practices, such as maintaining proper hygiene, using chemicals safely, and keeping farm records. Afterward, they can submit the application to the Provincial Department of Agriculture, Forestry and Fisheries (PDAFF) or the General Directorate of Agriculture (GDA). These institutions will review the submitted documents to verify their completeness and compliance, followed by an on-site farm inspection by qualified inspectors who assess field sanitation, input usage, and record-keeping practices. An inspection report is then prepared, and any identified non-compliances must be addressed within a specified timeframe. The Certification Committee at the GDA makes the final decision based on the inspection report and corrective actions taken. If approved, the farm receives the CamGAP certificate, allowing the use of the CamGAP logo to signify adherence to good agricultural practices (Ol, 2021).

Particularly, GAP has an essential role in ensuring sustainability, including maximizing social, economic, and environmental benefits and impacts of agriculture now and in the future. GAP adoption provides significant benefits to farmers, consumers, and the environment. Farms that implement GAP experience enhanced produce quality and safety, leading to higher marketability and access to premium markets. Studies show that compliance with GAP standards increases soil organic matter (SOM) by 3.3%-3.7% (Ministry of Industry Science Technology & Innovation (MISTI), 2024) and reduces pesticide residues by up to 31%, mitigating health risks for consumers (Schreinemachers et al., 2012). GAP can improve soil management and efficient water use, enhancing crop yields by an average of 36% (Ministry of Industry Science Technology & Innovation (MISTI), 2024). The environmental benefits include reduced agrochemical runoff, contributing to healthier ecosystems and water sources. Due to the benefits of GAP adoption in Cambodia, the number of CamGAP certificates has increased constantly, from 51 in 2019 to 250 certified farms, orchards, and plantations in 2021 (National Institute of Statistics (NIS), 2021; Open Development Cambodia, 2024).

Smallholder farmers in Cambodia need help in adopting safe vegetable production practices due to low trust levels among value chain actors. This lack of social capital impacts the sustainability of the safe vegetable value chain, which relies on strong working relationships between partners (General Directorate of Agriculture, 2020). Another challenge is the current capacity of Cambodian farmers. GAP adoption can be challenging for them. A feasible strategy for Cambodia's vegetable subsector is to focus on what can be done better than either Vietnam or Thailand by augmenting the import substitution potential. Ensuring the safety of local vegetables along with sufficient supply can increase domestic demand (Hin et al., 2024). The study aims to (1) determine factors affecting income and GAP adoption in vegetable farming systems, (2) identify potentials and challenges farmers face in applying and complying with the CamGAP Standard, (3) assess farmers' perceptions of GAP and non-GAP practices on vegetable products, and (4) perform an economic comparison between GAP and non-GAP farmers.

2. RESEARCH METHODOLOGY

The study was conducted between January and June 2024 to explore the characteristics of vegetable cultivation techniques in Cambodia. Six provinces were selected for the study site: four in the northwest (including Battambang, Banteay Meanchey, Pailin, and Siem Reap), one in the central region (Kandal), and another in the south (Takeo). The study focused on specific major vegetable-growing practices, particularly leafy vegetables, and included cost-benefit analysis. The leafy vegetable growers were categorized into two groups based on their applications: (1) Cambodia Good Agricultural Practice (GAP) and (2) conventional vegetable production system (non-GAP). This classification aimed to identify the impact of GAP adoption on vegetable production performance.

2.1. Sampling Method

We aimed to interview 15 GAP-leaf vegetable farmers in each province, each randomly sampled. Unfortunately, responses from GAP farmers were found to be invalid and, therefore, were removed. The final analysis included 15 interviewees from Battambang, Pailin, Siem Reap, Kandal, and Takeo provinces, while those from Banteay Meanchey numbered 10. In contrast, 10 non-GAP farmers from each targeted province were interviewed. Therefore, the total number of GAP and non-GAP farmers was 85 and 65 persons, respectively (Table 1). A well-structured questionnaire is designed and used to gather information from the two farmer groups. It is categorized into household information, vegetable farming characteristics, GAP adoption and training, cost-benefit analysis, and potential constraints to GAP adoption. To ensure the quality and reliability of the questionnaire, first, a pre-test will be carried out to verify the questions, and then modifications will be made to finalize the questionnaire for the real survey.

Table 1. Sample sizes for each farmer group in the six provinces.

Province	GAP farmers	Non-GAP farmers	Total
Banteay Meanchey	10	10	20
Battambang	15	10	25
Pailin	15	10	25
Siem Reap	15	10	25
Kandal	15	10	25
Takeo	15	10	25
Total	85	60	145

2.2. Data Collection and Analysis

The data to be collected will be entered, cleaned, and manipulated in MS Excel and then analyzed using R Program version 4.4.0 and RStudio 2024.04.1+748. Descriptive statistics are used for data analysis. Data on household characteristics, vegetable practices, and GAP adoption are analyzed using an independent two-sample t-test for comparison between the GAP and non-GAP groups. This statistical test is carried out with an error level of 5% (95% confidence level). Before the test is performed, assumptions of normality and homogeneity are checked and verified. In case homogeneity is unfulfilled, Welch's test is employed instead to ensure the reliability of the test. The statistical packages called "rstatix" will be used to perform the independent two-sample t-test and paired-sample t-test, while all graphs are plotted using the "ggplot2" package (Kassambara, 2023; Wickham, 2016; Wickham et al., 2023).

2.2.1. Two-Sample t-Test

The two-sample t-test is used to compare means between two independent groups, and in this study, the test is used to compare the means of numeric data between the GAP group and the non-GAP group (Delacre, Lakens, & Leys, 2017; Fagerland & Sandvik, 2009). Prior to the test, assumptions of normality and no outliers are checked and verified, and then the test is conducted with an error level of 5% (95% confidence level).

2.2.2. Likert Scale Analysis

The Likert scale analysis is applied to evaluate perceptions related to potentials and constraints in vegetable production between two groups based on land use, vegetable farming characteristics, yield, financing, markets, weather, training on vegetable farming, and supporting policies. A five-point scoring system is used: 1 (strongly disagree), 2 (disagree), 3 (moderately agree), 4 (agree), and 5 (strongly agree). An independent two-sample t-test was also employed to compare mean scores for each issue rated by the groups at an error level of 5% (95% confidence level). All assumptions must be checked and verified before performing the test (Joshi, Kale, Chandel, & Pal, 2015; Willits, Theodori, & Luloff, 2016).

2.2.3. LASSO Regression

To further understand the economic conditions and to determine which factors affect the income generated by leafy vegetable production in the studied locations, a multiple linear regression model is applied, considering the income earned per ton of vegetables as a dependent variable (Table 2). Meanwhile, predictor variables that may influence income include age, educational level, all available labor, including household and hired labor, years of farming experience, the chance of attending training related to vegetable farming, GAP adoption, and total production cost. If any predictor variables are statistically significant, this indicates that they affect income.

To avoid both multicollinearity among the predictor variables and the assumptions of normality and homoscedasticity, the least absolute shrinkage and selection operator (LASSO) regression was applied. The use of this regression is that any predictors without a presented coefficient are considered not influential in the income (Andriopoulos & Kornaros, 2023; Saperas-Riera, Mateu-Figueras, & Martin-Fernandez, 2023).

The multiple linear regression model is presented below.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\dots\dots\dots\dots. + \beta_n X_n + \varepsilon \quad (1)$$

Table 2. Description of all variables used for performing the LASSO regression with the total income as a dependent variable.

No.	Variable	Description	*Letters*
	Dependent variable		
1	Income (USD/T vegetables)		Y
	Predictor variables		
1	Age (year)		X_1
2	Educational level (year)		X_2
3	Available labor (person)		X_3
4	farming experience (year)		X_4
5	Chance of attending training related to vegetable farming	0 = Never attend training 1= Used to attend training	X_5
6	Current GAP adoption	0 = Traditional farming 1= GAP adoption	X_6
7	Total production costs (USD/T vegetables)		X_7
8	β_i	The slope of individual predictor variables	
9	ε	Error	

The study also emphasizes the importance of GAP adoption in vegetable farming systems; therefore, a multiple logistic regression is applied, considering GAP adoption as a dependent variable (traditional farming = 0; GAP adoption = 1) as shown in Table 3. The predictor variables that may influence the decision of GAP adoption include age, educational level, all available labor, including household and hired labor, years of farming experience, the chance of attending training related to vegetable farming, GAP adoption, total production cost, and yield. Similarly, the LASSO regression was also applied to the multiple logistic regression, identifying only factors that may influence the decision to adopt Cam-GAP. The fundamental use of the LASSO regression is to determine the factors that affect the decision to choose GAP or non-GAP adoption.

The multiple logistic regression model is presented below.

$$ln(Y - Y_0) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots\dots\dots\dots\dots. + \beta_n X_n \quad (2)$$

Table 3. Description of all variables used for performing the LASSO regression with the decision to adopt GAP as a dependent variable.

No.	Variable	Description	*Letters*
	Dependent variable		
1	GAP adoption	0 = No adoption 1 = Adoption	Y
	Predictor variables		
1	Age (year)		X_1
2	Educational level (year)		X_2
3	Available labor (person)		X_3
4	farming experience (year)		X_4
5	Chance of attending training related to vegetable farming	0 = Never attend training 1= Used to attend training	X_5
6	Current GAP adoption	0 = Traditional farming 1= GAP adoption	X_6
7	Total production costs (USD/T vegetables)		X_7
8	Yield		X_8
9	β_i	The slope of individual predictor variables	

2.2.3. Cost-Benefit Analysis

The Likert scale analysis is used to evaluate perceptions related to potentials and constraints in vegetable production between the two groups. To compare the economic aspects of the two farmer groups and assess profitability across the horizontal line, value added is calculated accordingly Food and Agriculture Organization of the United Nations (FAO) (2006) and Food and Agriculture Organization of the United Nations (FAO) (2013) based on total variable costs (TVC), or immediate inputs (II); total fixed costs (TFC), or consumption of fixed capital; total costs (TC); total revenues (TR); gross value added (GVA); net value added (NVA); total profits (TP); and economic efficiency (EE); and per capita profit. To simplify the comparison between the two groups and determine the correct value added, the focus will be on the production of only one vegetable type, which is the main income source for each province. The unit for comparison is based on one ton of each main vegetable produced in the provinces (Edwards, 2015; Pindyck & Rubinfeld, 2013).

Normally, IIs are calculated based on the purchase of inputs, seeds, and supporting materials for one production cycle, while TFC is the sum of all depreciated costs (DC) needed to operate dried fish production. DC was calculated from tools/equipment, trailers, and truck use for transportation, depending on their lifespans. In this study, TR is calculated based on one ton of sold vegetables multiplied by the selling prices. There are two prices, either retail or wholesale, but in this study, the wholesale prices were used to calculate TR because it is more common for the two farmer groups. Wages (W) paid for labor costs, interest rates (I) for micro-financial institutions, rental cost (R) for farmland, and taxes paid to the government are also included for the study to identify the generation of value added for different stakeholders. Economic efficiency (EE) is also a good indicator used to determine return on investment for vegetable production, while per capita profits are also calculated and compared among the groups.

The formulas of cost-benefit analysis, value added, and economic efficiency.

$$TC = TVC + TFC \quad (3)$$

$$TR = P\,x\,Q \quad (4)$$

$$TP = TR - TC \quad (5)$$

$$\mathrm{EE} = \frac{\mathrm{TR}}{\mathrm{TC}} \quad (6)$$

Where;

- DC = Depreciation costs (USD/0.1 ha).
- PV = Present value (USD).
- SV = Salvage value (USD).
- TC = Total cost (USD/0.1 ha).
- TVC = Total variable costs (USD/0.1 ha).
- TFC = Total fixed costs (USD/0.1 ha).
- TR = Total revenue (USD/0.1 ha).
- P = Vegetable Price (USD/kg).
- Q = Yield or Quantity of vegetables per year (Ton).
- TP = Total profit (USD/0.1 ha).
- EE = Economic efficiency.

3. RESULTS

3.1. Household Characteristics

The household characteristics of both farmer groups focused on sex, age, educational level, household numbers, years of farming experience, membership of agricultural cooperatives, and main jobs. As illustrated in Table 4, the respondents of both groups have a similar sex ratio. The age distribution of the non-GAP group was slightly older than that of the GAP group. However, on average, both groups were older than 40 years. The educational level of the GAP group was approximately 1.5 years higher than that of the non-GAP group, but the education levels for both groups are still considered very low. Respondents from the non-GAP group had a higher percentage of being household heads (69%), while about 23% were observed in the GAP group.

The household members of both groups are similar (around five persons). While four people live together, the GAP groups have more females in the families. Regarding farm labor, two people in the households worked on the farms to support the family. All respondents have at least 10 years of experience in farming, and only 67% of the non-GAP group have an agricultural cooperative membership compared to the GAP group. The primary income is from agricultural production, particularly vegetable production, while a few worked as government officers, middlemen, or grocery sellers. This indicates that they did not sell labor for extra money to support the family. This means that they can make a living from their farming practices. Usually, farmers who are members of agricultural cooperatives have a greater chance of receiving various training related to farming.

Table 4. Illustration of household characteristics of non-GAP and GAP farmers.

Variable	Non-GAP	GAP
Sex		
Male	33 (49%)	26 (54%)
Female	34 (51%)	22 (46%)
Age (Year)	48.9 ± 1.5	44.1 ± 1.3
Education (Year)	4.9 ± 0.4	6.5 ± 0.5
Household head		
Yes	46 (69%)	11 (23%)
No	21 (31%)	37 (77%)
Household number (Person)	5.0 ± 0.2	5.0 ± 0.4
People living together (Person)	4.3 ± 0.2	4.5 ± 0.2
Number of Females (Person)	2.0 ± 0.1	2.7 ± 0.2
Total farm labor (Person)	2.0 ± 0.1	2.3 ± 0.1
Farming experience (Year)	10 ± 1.2	14 ± 1.7

Variable	Non-GAP	GAP
Agricultural cooperative membership		
Yes	45 (67%)	47 (98%)
No	22 (23%)	1 (2%)
Main job		
Farming	67 (100%)	48 (100%)
Second job		
Government officer	2 (3%)	6 (13%)
Middleman	2 (3%)	1 (2%)
Grocery	2 (3%)	3 (6%)
Migrant worker	-	-

3.2. Main Vegetable Crops

Figure 1 illustrates the types of vegetables cultivated in site studies. Curly cabbage was the most commonly grown, accounting for about 80% of the GAP group and about 50% of the other group. Kale ranks second in preference for the GAP group (47%), while the non-GAP group preferred Chinese greens after curly cabbage. Other crops, such as mustard greens, morning glory, and cucumber, were also cultivated, but the percentage of farmers growing them is small. The findings indicate that farmers from both groups prefer to grow short-lived leafy vegetables because the economic return is faster.

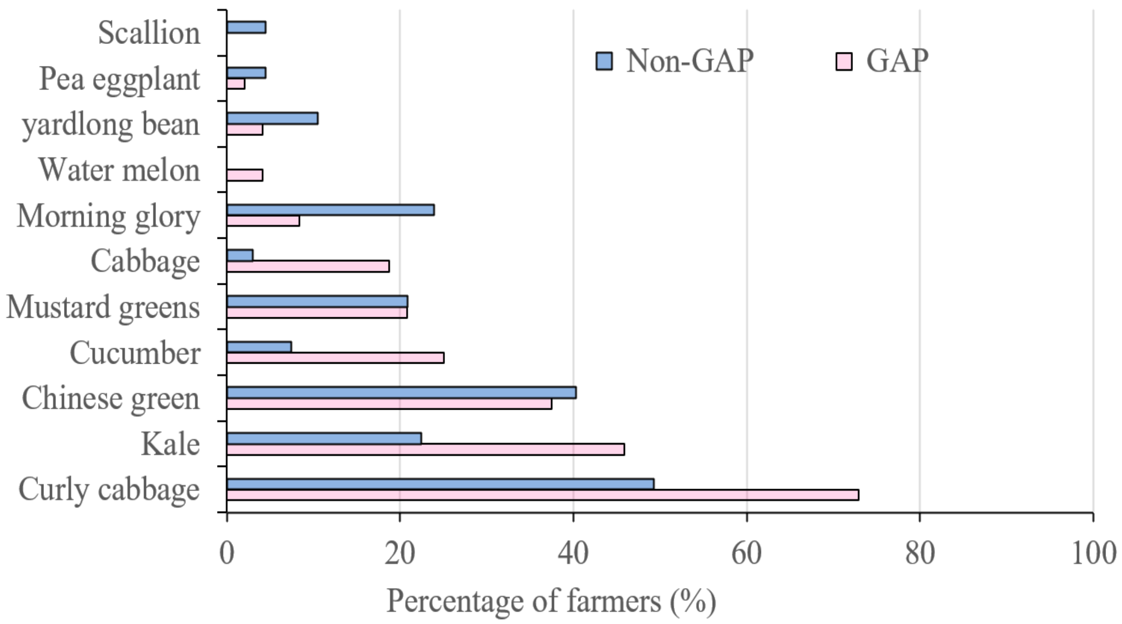

Figure 1. Comparing important vegetable crops between the GAP and non-GAP groups.

3.3. GAP Application Process

The process of GAP certification consists of several steps, including application submission, document review, on-site inspection, laboratory testing, evaluation report, certification decision, issuing of the certificate, and regular audits. The life cycle of the GAP certificate is one year, renewable. In this study, the process was simplified to five stages, assuming that the interviewed farmers are practicing GAP, so we only wanted to know about this simplified process. Therefore, the process of applying for GAP certificates was evaluated based on these steps: finding the application form, filling in the form, submitting the form, waiting for the results, and various payments during the process (Table 5). For this question, only farmers from the GAP group were asked, based on a five-point score, because they had applied experience.

The findings indicate that the score assigned to each step of the process was high, suggesting that the application process is not difficult from start to finish. As a result, farmers who applied were mostly members of agricultural cooperatives, which provided them with technical support and advice during the process. This implies that farmers seeking to apply only require some guidance, after which they can easily obtain GAP certificates without concern. However, the results for the GAP application process were based on the assumption that farmers are already familiar with GAP through dissemination by local authorities or training within their cooperatives, and that they have begun practicing farming in accordance with GAP standards. These farmers then decide to apply for a CamGAP certificate, making the process straightforward. Conversely, farmers who have not yet adopted GAP practices will face a longer application process, involving a series of mandatory activities such as initial training, application submission, actual implementation, on-site inspection, and final evaluation before they can receive the certificates.

Table 5. Evaluation of scores given to the GAP application process.

GAP application process	Score	Remark
Finding the application form	4.0	Easy
Filling the form	4.0	Easy
Submit the form	4.1	Easy
Waiting for the results	3.6	Simple to easy
Spending	4.1	Easy
Other	3.9	Easy

Note: The given score is in the range of 1 to 5, and higher values represent more ease.

3.4. Factors Affecting Income

To determine factors affecting income derived from vegetable farming, the LASSO regression was applied, considering age, labor, education, farming experience, cooperative membership, GAP adoption, GAP training, farmland, and TC as predictor variables (Table 6).

The results indicate that the age of farmers (38-50), GAP adoption, and total costs influenced income, while other variables had no effect at all. The findings suggest that farmers who had more years in farming were likely to earn higher incomes. If they spent more on input costs, the likelihood of earning more is also high. The most important thing is that if farmers adopt GAP, the likelihood of earning income is about two times higher than the non-GAP group.

3.5. Factors Affecting GAP Adoption

The decision to adopt GAP in vegetable production was assessed using the LASSO regression, considering the factors: age, labor, education, farming experience, cooperative membership, GAP training, total costs, and total revenue (Table 7). The results indicate that only one factor influences the decision to adopt GAP in vegetable farming, which is membership in an agricultural cooperative. Farmers who possess membership are 50% more likely to adopt GAP in their farming. Although they might not apply it yet, the findings suggest they may apply it later on. In contrast, other factors such as age, labor, or education did not influence the decision-making process to apply GAP.

Table 6. Determination of factors affecting the income earned from vegetable production.

No.	Predictor variables	Coefficient	Remark
	Intercept	770.88	
1	Age	8.92	Sig.
2	Labor	-	
3	Education	-	
4	Farming experience	-	
5	Cooperative membership	-	
6	GAP Adoption	1.9	Sig.
7	GAP training	-	
8	Land size	-	
9	Total costs	0.02	Sig.

Note: The "-" sign indicates non-significant factors, while "Sig." represents significance for the LASSO regression.

Table 7. Determination of factors affecting the decision to adopt GAP.

No.	Predictor variables	Odd ratios	Remark
	Intercept	0.4	
1	Age	-	
2	Labor	-	
3	Education	-	
4	Farming experience	-	
5	Cooperative membership	1.5	Sig.
6	GAP training	-	
7	Total costs	-	
8	Total revenue	-	
	Pseudo-R^2	0.34	

Note: the "-" sign indicates non-significant factors, while "Sig." represents significance for the LASSO regression.

3.6. Potentials of GAP Adoption

Potentials of GAP adoption were evaluated based on five-point scoring systems (Table 8). The respondents from both groups were asked the same questions that focused on GAP practices, farmland size, available labor, vegetable yield and price, investment budget, external support and training, external factors, and future prospects for GAP. It is clear that farmers from the GAP group were more familiar with GAP practices compared to the non-GAP group.

The GAP group was aware of GAP, noting that the application process is quick and the fees are acceptable. The overall Cam-GAP principles are easy to follow when prior guidance is provided. Those who practice GAP continue their farming practices, although the selling price is not different. The reason is that customers know, or will know, the importance of GAP practices.

When asked about the scores of sufficient land size, farmers from both groups mentioned that they did not have enough land for vegetable production. However, they were reluctant to rent more land to increase their production. In terms of available farm labor, they mentioned that the level of sufficiency is moderate, so they may or may not hire labor to support the farming production. There is a trade-off between the two options.

3.7. Constraints to GAP Adoption

Constraints to GAP adoption are presented in Table 9. There are some key challenges to GAP adoption, and those include a lack of awareness, financial constraints for the implementation of GAP, a lack of technical support and incentives, traditional practices, market access, and a lack of tools to cope with climatic factors. Farmers need to start up GAP adoption; an initial budget is necessary for infrastructure, such as the construction of net-houses for vegetable production.

When asked about the necessary budget for vegetable production, farmers from both groups stated that the level of their available investment is moderate. However, they may not see the necessity to borrow money from local lenders. With respect to technical support from the government and NGOs, farmers from the GAP group expressed more satisfaction compared to the non-GAP group because they had more experience with various training programs such as Cam-GAP, composting, drought-resilient farming, or water-saving techniques.

When asked about drought frequency and adaptability to drought through cultivating resistant crops, their perceptions are considered moderate. Therefore, more training may be needed to cope with these issues. When asked about the future prospects of GAP adoption, farmers from the GAP group express their strong support for continuity in strict application, compared to the non-GAP group, who are uncertain about adopting GAP. The GAP group is also willing to introduce Cam-GAP to other farmers seeking to improve their vegetable farming.

Table 8. Potentials and challenges were evaluated for farmers with and without Cam-GAP.

Factor	GAP	Non-GAP	Remark
GAP practice			
Know about GAP	4.1	2.4	***
Application fees are acceptable	4.0	2.2	***
Applying for Cam-GAP standards is quick	3.9	2.7	***
Cam-GAP principles are easy to follow	4.0	2.4	***
Continue to adopt Cam-GAP, although vegetable prices are not different	3.9	2.3	***
Customers know Cam-GAP importance	3.8	2.3	***
Land size			
Enough land for vegetable production	2.8	2.4	ns
Rend more land for vegetable production	2.7	2.6	
Labor			
Enough labor	3.3	3.1	ns
Hire labor	3.0	3.2	ns
Yield			
Satisfied with the yield	2.8	2.6	ns
Sell vegetables by yourselves	3.1	3.4	ns
Price			
Satisfied with vegetable prices	3.1	2.9	ns
Prices of Cam-GAP vegetables are higher	3.2	2.6	*
Budget			
Enough budget for production	3.2	2.9	ns
Prefer local lenders to MFIs	3.3	2.8	ns
Support			
Receive technical support from NGOs	3.5	2.5	**
Receive technical support from the government	3.8	2.2	***
Training			
Enough training on Cam-GAP	3.7	2.5	***
Enough training on composting	3.4	2.4	**
Enough training on drought resilience	3.5	2.7	*
Enough training on fertilizer application	3.3	2.3	**
Enough training on safe pesticide application	3.4	2.3	***
Enough training on water-saving	3.5	2.7	*
External factor			
Frequent drought	3.2	3.2	ns
Grow drought-resistant crops	3.0	3.1	ns
Adaptable to drought	3.0	3.0	ns
Future prospects			
Strictly adopt Cam-GAP for production	3.9	2.3	***
Introduce Cam-GAP to other farmers	4	2.3	ns

Note: Asterisks "*", "**", and "***" denote statistical significance at 0.05, 0.01, and 0.001, respectively.

3.8. Cost-Benefit Analysis

A cost-benefit analysis was performed to compare costs and profits between the two groups (Table 9). The results indicate that the average farming land size was not different, being about 0.20 ha. For vegetable production, farmers from the GAP group tend to spend more on variable costs and total costs compared to the non-GAP group, while the comparison ratios were 1.8 and 1.4 times the costs spent by the non-GAP group. However, fixed costs were not different between the two groups, amounting to 100 USD/0.1 ha. Despite that, farmers from the GAP tend to spend more on net-house construction, which is 6.6 times the construction costs spent by the non-GAP group. Anyway, only a few non-GAP farmers built a net-house for vegetable production. The average net-house construction cost is 1,500 USD, so GAP farmers have to depreciate about 45.8 USD/year after construction.

Although the GAP group had higher total costs, the cost of fertilizer and pesticide use was 20% less than that of the non-GAP group. This clearly demonstrates that the adoption of GAP can reduce dependency on chemicals. Additionally, the GAP group earned more total revenue (about 575 USD/0.1 ha), which is approximately twice the revenue earned by the non-GAP group. Similarly, the total profit for the GAP group was also twice that of the non-GAP group. However, economic efficiency was good but indifferent between the two groups. It can be said that any dollar spent on vegetable production can produce 1.4-1.9 dollars in return.

Table 9. Cost-benefit analysis between GAP and non-GAP farmers based on 0.1 ha of land.

Parameter	GAP	Non-GAP	Ratio [(1)]	Note
Land size (ha)	0.23	0.20	1.16	ns
variable cost (USD/0.1 ha)	206.6	117.6	1.8	*
Land preparation	15.8	5.3	3.0	*
Seed	9.9	9.5	1.0	ns
Care	72.5	9.4	7.7	*
Power	8.4	6.9	1.2	ns
Manure	13.9	18.4	0.8	ns
Fertilizer	28.7	38.0	0.8	ns
Pesticide	11.3	14.8	0.8	ns
Harvest	45.9	15.3	3.0	**
Fixed cost (USD/0.1 ha)	98.0	100.0	1.0	ns
Irrigation system	52.2	93.1	0.6	ns
Net-house	45.8	6.9	6.6	*
Total cost (USD/0.1 ha)	304.6	217.7	1.4	*
Total revenue (USD/0.1 ha)	575.2	309.9	1.9	***
Price (USD)	0.5	0.5	1.0	ns
Yield (Ton)	1.2	0.6	1.9	*
Total profit (USD/0.1 ha)	346.7	170.7	2.0	**
Economic efficiency	1.9	1.4	1.3	ns

Note: [(1)] denotes the division of values in GAP by the values in non-GAP, while asterisks "*", "**", "***" mean significant differences at 0.05, 0.01, and 0.001, respectively. Meanwhile, "ns" means non-significance.

4. DISCUSSION

This study reveals convincing evidence of the positive economic impacts of GAP adoption among Cambodian vegetable farmers. Farmers who adopt GAP achieve significantly higher income, yields, and profits compared to those practicing conventional farming, although their total production costs are higher. These results validate findings by Zeweld, Van Huylenbroeck, Tesfay, Azadi, and Speelman (2020), who indicated that GAP improves soil organic matter and productivity, and Bocquet-Appel, Naji, Vander Linden, and Kozlowski (2012), who demonstrated that GAP adoption reduces pesticide residues by 31%, thus reducing production costs while enhancing food safety and marketability. The study also confirms that GAP adoption enhances both environmental and economic efficiency. GAP farmers used fewer chemical fertilizers and pesticides (approximately 20% less), but they achieved higher yields and profits per 0.1 ha of land compared to non-GAP farmers. These findings are consistent with Kharel et al. (2022), who found that GAP adoption increased crop yield by 36%, and Incoom et al. (2025), who emphasized that GAP can support sustainability and improve profitability.

Furthermore, regression analyses show that income from vegetable farming is significantly influenced by three key factors: farmer age, total production costs, and GAP adoption. The positive influence of age may be due to accumulated experience, while higher input costs—when allocated to quality and efficiency—correlate with greater returns. This echoes findings from Kosari-Moghaddam et al. (2025), who emphasized that strategic input use under GAP contributes to both resilience and profitability in Chinese agriculture. The decision to adopt GAP is significantly influenced by membership in agricultural cooperatives, a finding that aligns with the UCDAVIS report, which highlighted the importance of strong social capital and collaborative networks in the safe vegetable value chain (Dawson, 2019). Cooperative members often receive training, technical support, and market linkage opportunities, which reduce perceived risks associated with GAP implementation (Open Development Cambodia, 2024).

However, the study also identified major barriers to GAP adoption, particularly among non-GAP farmers. These include limited awareness of GAP principles, financial constraints for infrastructure investment, insufficient access to training, and market uncertainty. Similar constraints were observed in studies by Kosari-Moghaddam et al. (2025) and Thompson et al. (2021), which indicated that weak extension services and infrastructure gaps limit adoption among smallholder farmers in Southeast Asia. In terms of cost-benefit analysis, it shows that GAP farmers incur higher total costs, but their gross and net returns are significantly higher, similar to previous findings that indicated that GAP adoption leads to sustainability and profitability (Ministry of Agriculture Forestry and Fisheries (MAFF), 2020).

5. CONCLUSION

The study compares household characteristics, production types, factors affecting income and decision-making, cost-benefit analyses, potentials, and constraints related to GAP adoption between the two groups of farmers, GAP and non-GAP, as well as other stakeholders.

The results indicate that the adoption of GAP can lead to a reduction in chemical inputs such as chemical fertilizer and pesticides and an increase in income and profit. Besides that, income earned from vegetable production is mainly influenced by the farmers' age, GAP adoption, and total production costs. In terms of the decision to adopt CamGAP, the only factor found in this study is being a cooperative member.

This suggests that farmers who are part of the agricultural cooperative have a higher likelihood of accepting GAP for their vegetable production. For the cost-benefit analysis, farmers from the GAP group tend to earn twice the income and profit of the non-GAP group on the same size of farmland, although total costs are higher. In terms of Cam-GAP application processes, each step is not difficult if farmers are given prior instruction and support.

The findings also indicate that farmers from the non-GAP group have no idea about CamGAP practices at all; the primary results are due to financial constraints and lack of awareness, as new adoption requires both time, effort, and investment. Thus, making them interested in adoption, continuous training, and financial and technical support is strongly required so that crops can be produced for high profitability and safe consumption.

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Institutional Review Board Statement: The Ethical Committee of the National Meanchey University, Cambodia has granted approval for this study on 13 December 2023.
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