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RESEARCH ARTICLE

ECONOMIC ANALYSIS OF BANANA PRODUCTION IN *VALIKAMAM EAST* DS DIVISION, JAFFNA, SRI LANKA

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ABSTRACT

Banana, an ancient fruit, has evolved into one of the world's most widely cultivated, traded, and consumed fruits. In the Jaffna district, particularly in the *Valikamam East* DS division, banana cultivation is a key livelihood activity of many households, supporting both income and food security. Despite its local significance, recent research focusing on the economic dynamics of banana production in this area remains limited. This study aims to fill this gap by conducting a comprehensive economic analysis of banana production in the *Valikamam East* DS division. The study employed a simple random sampling method with 100 banana farmers for primary data collection. SPSS software was used for data analysis. Results revealed that all farmers cultivated on their own land, with an average farmer age of 55.77 years and an average family size of 4.5 members. Despite major challenges like climate hazards and high labour costs, the annual average cost of production, return, and net profit stood at Rs 281,390, Rs 671,066, and Rs 389,676 per acre, respectively, indicating profitability with a benefit:cost (B:C) ratio of 2.38. A significant correlation was observed between the farmers' experience, education and banana yield. Overall, this research provides valuable insights for banana farmers, policymakers, and researchers, paving the way for enhanced cultivation practices and informed decision-making.

Keywords: Extension, Production, Profitability, Socio-economic, Sri Lanka, Yield

INTRODUCTION

Bananas, famously nicknamed the "poor man's apple" and affectionately termed the "Apple of Paradise," are essential to tropical agriculture and thrive in nearly every humid tropical climate (Gowri & Shanmugam, 2015). As one of the world's most widely cultivated, traded, and consumed fruits, they play a vital role in global food systems (FAO, 2023). Bananas are not only a tasty delicacy but also a substantial energy source, providing 104 calories per 100 grams. They are rich in dietary fiber, potassium, vitamins B6 and C, along with beneficial antioxidants and phytonutrients. Their origins can be found in areas that include the Philippines, Indonesia, New Guinea, and the Malay Peninsula (Australian Banana Growers Council, 2017).

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In terms of cultivation, bananas are cultivated in more than 130 countries. Brazil, Ecuador, China, India, and the Philippines are notable producers in this field. On the other hand, the main importers of bananas are the Russian Federation, China, the EU, the USA, and Japan in terms of consumption. Worldwide banana production in 2021 was estimated to be over 125 million tons, grown on 5.3 million hectares of land (FAO, 2022). In addition to being a tasty fruit, bananas have useful applications for almost every component of them. The fruit itself is essential for creating frozen delights, desserts, and banana beer. The pseudo-stem produces strong fibres and starch, which are perfect for making hats, mats, and carpets. The plant's potash-rich ash is valued for fabric cleaning and dyeing, and its broad leaves make

excellent natural packing, eating mats, and even shelter. The fibrous nature also makes for nutrient-dense animal feed.

Sri Lanka is an island nation in South Asia whose economy and people's well-being primarily depend on agriculture. Banana is the most commonly grown and consumed fruit in Sri Lanka within this agricultural sector (Wasala et al., 2014). About 41,430 hectares are used for banana farming, and 745,085 tons were produced annually in 2021 (DOA, 2022). Although there are more than a thousand varieties of banana worldwide, Sri Lanka is home to 29 distinct cultivars and two indigenous wild species (Nadeeshani et al., 2018). Primary districts for banana farming include Kurunegala, Ratnapura, Hambantota, Monaragala, Ampara, and Jaffna (Ranathilaka et al., 2018). It is accounting more than 40% of the local fruit market (Ranathilaka *et al*., 2018).

The northern dry zone of Sri Lanka, more especially the Jaffna area in agroecological zones DL3 and DL4, provides ideal growing conditions for bananas. Notably, the *Valikamam East* Divisional Secretariat (DS) division stands out as an ideal area for banana farming due to its favourable climate and soil properties. Banana varieties such as Mysore, Silk, Bluggoe, and Watha Palu—known locally as *Kathali, Kappal, Sambal Mondan,* and *Etharai*—stand out strongly within this agrarian tapestry (Kalawathy & Theivendirarajah, 1990).

A large number of people in the *Valikamam East* DS division depend on growing banana as a crucial part of their lives. Improving banana cultivation yields is challenging for farmers as they encounter numerous obstacles and face significant problems in producing banana. Even though some studies are available in Sri Lanka, they do not adequately explore the current dynamics of banana production, as they are not recent. There is a noticeable gap in the literature and research on this important practice. Surprisingly, the economic assessment of banana production in the *Valikamam East* DS division of the Jaffna district has never been examined before. This fact emphasizes the value of undertaking this study to address the existing research gap.

This study was conducted to evaluate the economic performance of banana production in the *Valikamam East* DS Division of Jaffna, Sri Lanka. It assesses the profitability of banana cultivation by analyzing cost structures and returns. Furthermore, the study examines the factors influencing banana yield and evaluates their impact on production outcomes. It also analyzes the socio-economic characteristics of banana farmers to provide context on their demographic and livelihood conditions. In addition, the study explores the key constraints and challenges faced in banana cultivation. The findings aim to support policymakers in designing informed and targeted strategies to enhance the sustainability and economic well-being of banana farming communities in the region.

METHODOLOGY

The study was conducted in the *Valikamam East* DS division of the Jaffna district (Figure 1). The *Valikamam East* DS division comprises five AI ranges. Of these, two AI ranges, Urumpirai and Neervely, were selected due to the high number of banana farmers and extensive cultivation. According to the 2023 records obtained from the Agrarian Service Centre in Urumpirai, there were 565 registered banana farmers in Urumpirai and 551 in Neervely, resulting in a total sampling frame of 1,116 farmers. To ensure that each farmer had an equal and independent chance of being selected, a simple random sampling technique was employed. Each farmer was assigned a unique identification number. Microsoft Excel was used to generate a random number for each individual using the =RAND() function. The entire list was then sorted in ascending order based on these random values, and the first 100 farmers in the sorted list were selected as the sample for this study. This approach ensured unbiased selection and maintained the principles of probability sampling.

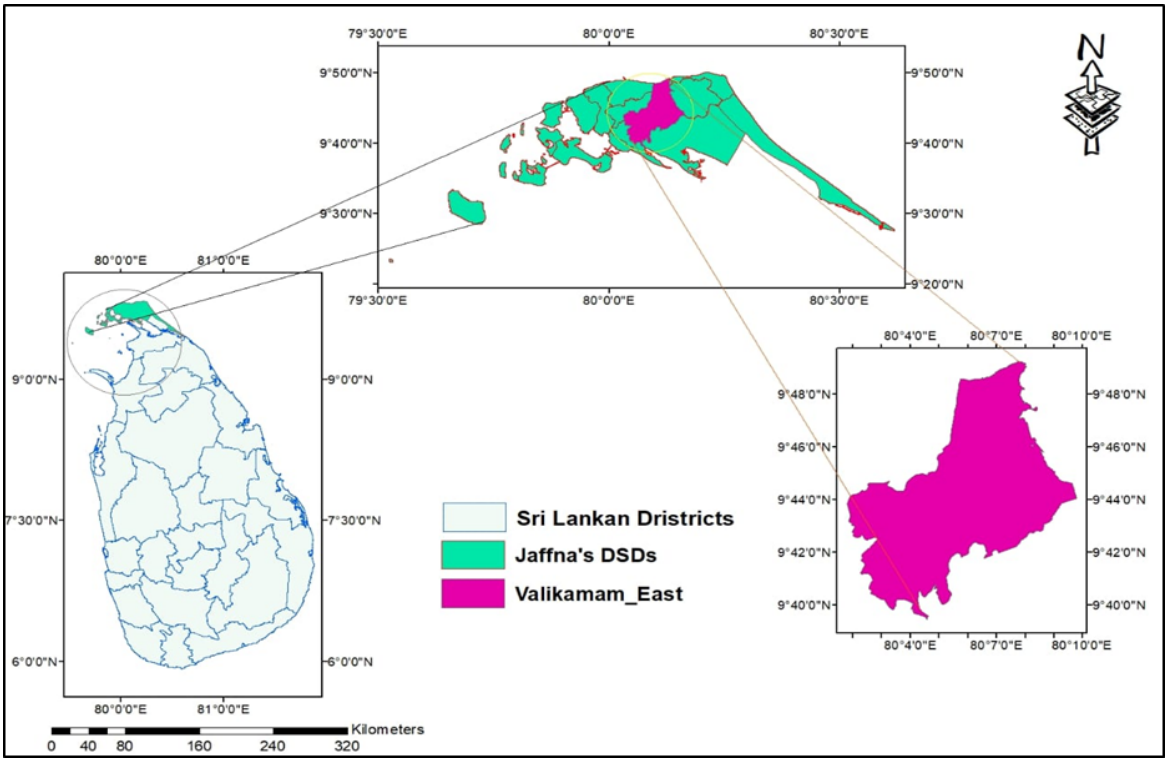


Figure 1. Location of the study area - *Valikamam East* DS Division
(Source: GIS Map, 2023)

The questionnaires were pretested with 10 banana farmers in the *Valikamam East* DS division prior to the main data collection to determine the suitability, clarity, and relevance of the questions. During the pretest, farmers were provided with a clear explanation of the study's objectives to ensure their understanding and cooperation. Feedback received from this pilot testing was used to refine and improve the questionnaire items. Furthermore, the questionnaire was reviewed by an agriculture inspector with expertise in local banana farming to confirm its content validity. These combined measures helped to enhance both the reliability and validity of the instrument for the study population.

Following pretesting and necessary refinements, a personally supervised structured questionnaire was administered to interview the selected banana growers in the study area to collect the primary data. In addition, past research articles, books, journals, periodicals, publications, and relevant websites were used to obtain secondary information.

The study was conducted in 2023 between August and November. The gathered data were appropriately organized in a Microsoft Excel 2016 spreadsheet. Then, the statistical software program SPSS version 29 was used to enter the organized data, and a database was formed for additional research. Descriptive statistics were used to analyze the socio-economic characteristics of the banana farmers, production costs, gross income, profit, availability of extension services, and major challenges and constraints in banana farming. The profitability of banana production in the study area was estimated by the benefit-cost ratio. The variables influencing banana production in the research area were identified using a multiple linear regression analysis.

The selection of independent variables for the regression analysis was aligned with the study's objective of identifying factors influencing banana yield. Four socio-economic variables, namely farmer experience, education level, family size, and farm size, were included based on their theoretical relevance, statistical suitability,

and continuous nature. Prior studies, such as Kashyap and Guleria (2015), have used socio-economic characteristics like age, experience, and education in similar yield-related analyses in apple growers in Mandi district of Himachal, which supports the inclusion of such variables. In this study, age was excluded due to multicollinearity with farmer experience. Categorical variables such as gender and marital status were also excluded to maintain model simplicity and because the focus was on continuous predictors. Although data were collected on input sufficiency, sources of marketing, and challenges in banana production, these were analyzed descriptively, as they were beyond the scope of the regression model. This approach ensured a focused analysis of how selected socio-economic characteristics influence banana yield, while also offering contextual insights into the farmers' livelihoods. A summary of the variables used in the multiple linear regression analysis, including their type and measurement units, is provided in a table (Table 1).

Based on the selected variables, the multiple linear regression model used in this study is expressed as follows:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + e$$

Where; Y: Banana yield (kg/acre), X_1: Experience of farmer (years), X_2: Education level of the farmer (years), X_3: Family size of the farmer, X_4: Farm size for banana cultivation (acre), β_0 is the intercept and, β_1, β_2, β_3, β_4 are the coefficients of independent variables, e: Random error term

The model was assessed using standard statistical measures. The significance of the relationships between the independent variables and banana yield was evaluated using p-values, the coefficient of determination (R^2), and standardized beta coefficients. These metrics helped to determine the overall explanatory power and reliability of the regression model.

Table 1: Summary of variables used in multiple linear regression analysis

Variable code	Variable name	Measurement unit	Type
Y	Banana yield	kg/acre	Dependent
X_1	Experience of farmer	Years	Independent
X_2	Education level of the farmer	Years of schooling	Independent
X_3	Family size	Number of members	Independent
X_4	Farm size for banana cultivation	Acres	Independent

(Source: Field Survey Data, 2023)

RESULTS AND DISCUSSION

Socio-economic characteristics of banana farmers

The results indicated that 88% of banana farmers are men, while only 12% are women, 85% of the respondents were married, and the rest were unmarried.

The socio-economic characteristics of the banana farmers are summarized in a table (Table 2). The data revealed that the average age of banana farmers was 55.8 years, with respondents ranging from 34 to 76 years. The data further revealed that the average family size was 4.5 members in the surveyed area. This finding is in accordance with the study by Athukorala and Karunarathna (2016), which reported an average family size of 5 among banana farmers in the districts of Ampara, Kurunegala, and Ratnapura, representing Sri Lanka's dry, intermediate, and wet climatic zones, respectively.

Table 2: Socio-economic characteristics of banana farmers

Characteristics	Range	Minimum	Maximum	Mean	Standard Deviation	Variance
Age	42	34	76	55.8	9.675	93.613
Family size	5	2	7	4.50	1.176	1.384
Experience	36	4	40	20.8	9.717	94.427

(Source: Field survey data, 2023)

The average farming experience of a farmer was 20.8 years. The findings also indicate the farmers' experience levels in banana cultivation range from 4 to 40 years. In contrast, Athukorala and Karunarathna's 2016 study on banana farmers reported a notably lower average farming experience of 11 years. Among surveyed farmers, 51% were engaged in banana production as a full-time occupation and 49% were involved as part-time.

According to the survey, the majority (55.0 %) had completed education up to the ordinary level (O/L), with 29.0% having completed education at the advanced level (A/L). Additionally, 11.0% and 5.0% of respondents finished the diploma and degree levels. It shows that among banana producers, a smaller number only have a higher level of education. Meanwhile, Ranathilaka et al. (2018) observed that 65% of participants had education levels below and up to O/L, with none having completed a degree or diploma. Additionally, Debebe & Dagne's 2018 study revealed that nearly 21% of banana farmers had no formal education, while 50% had completed primary education. These contrasting educational profiles underscore the diverse educational backgrounds within the banana farming community as identified by different research studies.

The predominant occupation among respondents is banana cultivation, with 51% primarily focused on this crop. Others, though involved in banana farming, report a range of primary occupations, including livestock rearing (9%), vegetable farming (11%), and paddy cultivation (9%). Additionally, 9% work in the government sector, balancing their public roles with agricultural pursuits.

The extent of the cultivated land area ranged from 0.25 acres to 3 acres, with an average extent of 1.27 acres.

Input sufficiency in banana production

Irrigation sufficiency among farmers was reported as 100% (Table 3). According to 94 % of farmers, planting material was adequate. According to 89% of farmers, fertilizer was enough. According to 62%, agrochemicals were adequate. Further, more than half (54%) of farmers claimed that labour was insufficient.

Table 3: Input sufficiency in banana production

Input	Sufficient (%)	Not sufficient (%)
Planting material	94	6
Fertilizer	89	11
Irrigation	100	0
Labour	46	54
Agrochemical	62	38

(Source: Field survey data, 2023)

Cost of production of banana

According to surveyed data, planting material costs an average of Rs. 13,863.64, agrochemical costs an average of Rs. 4,000, fertilizer costs an average of Rs. 121,400, and labour costs an average of Rs. 156,500. Each of these expenses was estimated annually per acre.

Total income and profit estimation

The estimated data showed that the average annual cost of production per acre for each farmer was Rs. 281,390, the average annual total return for each farmer was Rs. 671,066, and the average annual net profit per acre was Rs. 389,676 (Table 4).

Table 4: Total return and profit estimation

	Mean	Standard deviation
Total cost	281390.00	63969.989
Total return	671066.00	303003.712
Net profit	389676.00	309296.312

(Source: Field survey data, 2023)

Profitability of banana

A benefit-cost (B/C) analysis was done to assess the profitability of banana production in the study area. The Benefit-Cost (B/C) ratio was calculated as the total return divided by the total cost, which is Rs. 671,066 ÷ Rs. 281,390, resulting in a value of 2.38. As the computed B: C ratio of 2.38 is greater than 1, it can be decided that banana farming is profitable in the *Valikamam East* DS division.

In contrast, Ghimire et al. (2019) found a B:C ratio of 1.5, and Ranathilaka *et al*. (2018) revealed B:C ratios of 0.91 and 0.88 for two banana varieties, Kolikuttu and Ambun in Sri Lanka.

Banana yield

The average yearly yield of bananas was 7976 kg/acre (Table 5). In a year, the maximum and minimum yields of bananas per acre were 16,500 and 1,000 kg, respectively.

Sources of marketing

Among 100 farmers, 77% sold their bananas at a banana fair. About 16% of growers sold bananas to wholesalers, 3% sold to retailer stores, and the remaining 4% sold bananas in their own stores. Also, about 46% of banana growers sold their produce within the same village, while 45% sold it in neighbouring villages. Just 9% of farmers made sales in other districts.

Table 5: Banana yield per year (kg/acre)

Parameter	Mean	Minimum	Maximum	Standard deviation
Banana yield per year (kg/acre)	7976.60	1000	16500	3526.601
Farmgate price of banana (Rs/kg)	100.50	50	200	45.084

(Source: Field survey data, 2023)

Farmgate price

According to survey data, the average farmgate price of a kilogram of bananas was Rs. 100.50. Additionally, it can be seen that the lowest and highest farm gate prices for a kilogram of bananas were Rs. 50 and Rs. 200, respectively. Different farmgate prices can be seen throughout the year in different seasons (Table 5).

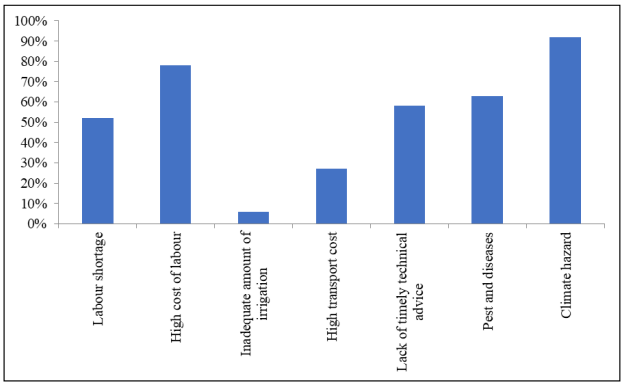
Availability of extension services

According to the survey, 44% of banana growers said there is enough extension availability. However, 56% said it was insufficient for the study region.

Constraints and challenges faced by farmers in banana cultivation

The various constraints and challenges faced by farmers in banana cultivation were summarized in this study (Figure 2). Most farmers (92%) who responded to the survey reported experiencing *"Kuruthadaithal"* problems due to climate hazards. *"Kuruthadaithal"* refers to the oozing of reddish sap from the banana pseudostem, often associated with bacterial or fungal infections triggered by unfavourable climatic conditions. As a result, the yield is significantly reduced. 52% of farmers reported shortages of labour, but 78% of farmers cited high labour costs. 63% of farmers reported having problems with pests and diseases. The absence of prompt technical assistance was mentioned by 58% of participants. Only 27% reported having expensive transportation costs. Only 6% of respondents mentioned irrigation shortages in the research area. Considering these specifics, climate hazards were ranked highest based on severity. High labour costs, pests and diseases are ranked second and third, respectively. Lack of timely technical advice was ranked fourth. Lack of labour and high transportation costs were in fifth and sixth place, respectively. Insufficient irrigation was placed seventh in terms of severity because only a few respondents said they had experienced it. Chaudhary & Khodifad (2017) study identified challenges in banana cultivation, ranking the non-availability of labour and high labour costs as the top two issues, while a lack of knowledge occupied the third position.

Figure 2. Constraints and challenges in banana production



(Source: Field survey data, 2023)

Factors affecting banana yield

Preliminary correlation analysis of independent variables

In exploring factors affecting banana yield in the *Valikamam East* DS division, a correlation analysis was conducted on key independent variables: experience, education, family size, farm size, and age (Table 6). These factors had subtle correlations, as indicated by the correlation coefficients. A number of relationships were determined to be statistically non-significant at the 0.05 level. Experience and education had a very slight negative correlation (-0.038; p=0.708); however, this link lacks statistical significance. Similarly, the correlations between experience and family size (0.10; p=0.290) and experience and farm size (0.040; p=0.692) were both non-significant, implying that these relationships may not be reliably present in the population.

Table 6: Preliminary correlation analysis of independent variables

Variable	Statistics	Experience	Education level	Family size	Farm size	Age
Experience	P	1	-.038	.107	.040	.464**
	α		.708	.290	.692	<.001
Education level	P	-.038	1	-.020	-.093	.056
	α	.708		.847	.359	.580
Family size	P	.107	-.020	1	.025	.154
	α	.290	.847		.806	.126
Farm size	P	.040	-.093	.025	1	.028
	α	.692	.359	.806		.786
Age	P	.464**	.056	.154	.028	1
	α	<.001	.580	.126	.786	

P: Pearson Correlation, α: 2-tail significant level, ** Correlation is significant at the 0.05 level (2-tailed), (Source: Field survey data, 2023)

The correlation between experience and age was moderately positive (r=0.464), significant at p=0.05, indicating a robust relationship. However, given the theoretical significance of both variables and concerns about multicollinearity, it was decided to remove the "age" variable from further regression analysis. A comprehensive consideration of theoretical significance, statistical significance, and the possible effect on the overall performance of the model guided this choice.

Multiple linear regression analysis

The findings of the multiple linear regression analysis conducted to identify the factors influencing banana yield are presented and interpreted below. The overall significance of the regression model was evaluated using analysis of variance (ANOVA), with the results summarized in (Table 7).

Table 7: ANOVA results for factors affecting banana yield

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	788.402	4	197.101	48.140	<.001**
Residual	388.958	95	4.094		
Total	1177.361	99			

Dependent Variable: Banana yield, R2 =0.670, **P < 0.05, (Source: Field Survey Data, 2023)

It was shown that the farmer's experience and educational level significantly affected the yield of bananas. The estimated regression function equation is provided as follows:

$$Y = -0.565 + 0.284X_1 + 0.193X_2 + 0.133X_3 - 0.055X_4 + 1.194$$

The data presented in the table revealed that the variables of farmer's experience and educational level had a positive and highly significant relationship with the banana yield (Table 8). Also, the family size of the farmer and farm size for banana cultivation have a non-significant relationship with banana yield. Meanwhile, a study by Kashyap & Guleria (2015) revealed that farm size, education, and marital status of the farmer were significantly related to the fruit yield at the 0.05 significance level.

Table 8: Regression analysis for the factors affecting banana yield

Model	Unstandardized Coefficient		Standardized Coefficient	T	Sig.	Multicollinearity Statistics	
	B	SE	Beta			Tolerance	VIF
(Constant)	-.565	1.194		-.474	.637		
Experience	.284	.021	.801	13.484	<.001*	.986	1.014
Education level	.193	.066	.172	2.905	.005*	.990	1.010
Family size	.133	.174	.045	.767	.445	.988	1.012
Farm size (ac)	-.055	.263	-.012	-.209	.835	.990	1.010

Dependent Variable: Banana yield, **P <0.05, *P <0.01, SE: Standard Error, VIF: Variance Inflation Factor, (Source: Field Survey Data, 2023)

Variance Inflation Factor (VIF) and tolerance values were calculated to assess multicollinearity among the predictor variables. The VIF values ranged from 1.010 to 1.014, and tolerance values ranged from 0.986 to 0.990. Since all VIF values are well below the commonly accepted threshold of 5 and tolerance values are close to 1, these results indicate that multicollinearity is not a concern in the final regression model.

According to the model summary, the regression analysis yielded an R^2 value of 0.670 and an Adjusted R^2 of 0.656, indicating that approximately 67% of the variation in banana yield is explained by the four predictor variables, namely farm size, family size, education, and experience. The close alignment between R^2 and Adjusted R^2 highlights the model's robustness and suggests that the predictors included provide a reliable explanation of the yield variability. The remaining 33% of unexplained variance may be attributed to other factors not captured in the current model.

To ensure the validity of the regression model, diagnostic tests were performed to examine whether the assumptions of linear regression were satisfied.

The residual statistics indicate that the mean of the residuals is effectively zero, with a standard deviation close to 1 (Table 9).

Table 9: Residual statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	2.5316	14.1119	7.8844	2.82200	100
Residual	-5.22533	8.26326	.00000	1.98214	100
Std. Predicted Value	-1.897	2.207	.000	1.000	100
Std. Residual	-2.582	4.084	.000	.980	100

Dependent Variable: Banana Yield
(Source: Field Survey Data, 2023)

This suggests that the residuals are symmetrically distributed around the regression line, supporting the assumption of unbiased errors. The standardized residuals mostly lie within acceptable limits, indicating the absence of significant outliers that could affect the model's validity.

The histogram of standardized residuals approximates a normal distribution, exhibiting a bell-shaped curve (Figure 3). This supports the assumption that the residuals are normally distributed, which is critical for the validity of the regression model.

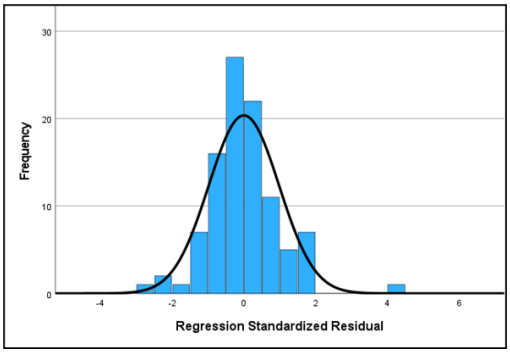


Figure 3. Histogram of standardized residuals
Mean: 8.79E-16, Std. Dev: 0.980, N:100 (Source: Computed by the author using SPSS software)

The Normal P–P plot shows that the standardized residuals closely follow the diagonal line, further confirming that the residuals meet the assumption of normality (Figure 4).

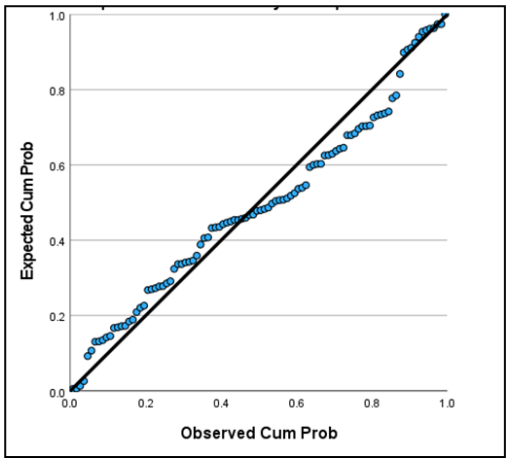


Figure 4. Normal P-P plot of regression standardized residual
(Source: Computed by the author using SPSS software)

Together, these residual diagnostics confirm that the assumptions of normality, linearity, and homoscedasticity are reasonably met, indicating that the regression model is statistically valid and reliable.

CONCLUSION & RECOMMENDATION

The purpose of this research was to conduct an economic analysis of banana production, examine the socio-economic status of banana farmers, identify challenges in banana cultivation, assess the profitability of banana production, understand the factors influencing banana yield, and evaluate the availability of extension services in the *Valikamam East* DS division of the Jaffna district. The study clearly understood the cost of production, profit, and profitability of banana production. It was found that banana production was profitable with a B: C ratio of 2.38. The socio-economic status of banana farmers, including experience, age, education, family size, marital status, and ethnicity, was examined in this study. It was found that the availability of extension services was not sufficient in the particular area. According to the survey, climate hazards, high labour costs, pests and diseases, a lack of timely technical advice, a lack of labour, high transportation costs, and insufficient irrigation were identified as the challenges and constraints banana farmers faced in the study area. Based on severity, these were ranged among them. A significant association was observed between the farmer's experience and educational level with banana yield. In contrast, a non-significant association was found between the family size of the farmer and the farm size dedicated to banana cultivation and banana yield.

Farmers and relevant officials must prioritize the systematic documentation of production costs, returns, and cultivation practices to enable data-driven decision-making that enhances the economic viability of banana farming. Building on these findings, this study underscores the significance of its insights and provides actionable guidance for farmers, policymakers, extension agents, and farmer organizations to enhance banana production in the *Valikamam East* region. The observed benefit-cost ratio of 2.38 indicates that banana cultivation is profitable, suggesting that with targeted support, greater farmer participation and expansion are achievable. Addressing key challenges such as labor shortages, pest infestations, and limited irrigation access is essential for promoting cost-efficient farming practices. Extension agents play a vital role by providing training on climate-resilient agriculture, integrated pest management, and environmentally sustainable control methods, while efforts to strengthen record-keeping and farm management, particularly for less-experienced farmers can significantly improve

productivity. Policymakers are urged to invest in climate-resilient infrastructure, such as water-saving irrigation systems, promote mechanization appropriate for smallholder farmers to mitigate labor constraints, expand access to credit and subsidized inputs, and enhance extension services, especially in underserved areas. Farmer organizations further contribute by facilitating cooperative marketing, organizing collective training, and advocating for policies responsive to grassroots needs. Moreover, this research establishes a foundation for future studies focused on the comparative profitability of different banana varieties, evaluation of market channels to optimize farmgate prices, and assessment of export potential alongside farmers' adaptability to export-driven cultivation. Through the implementation of these targeted interventions, stakeholders can collectively advance the sustainability, profitability, and resilience of banana farming in the region.

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AUTHOR CONTRIBUTION

VT was responsible for the study design, data collection, analysis, and initial manuscript preparation. GT supervised the research process, provided methodological guidance, and contributed to the review and refinement of the manuscript.

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