Journal of Agricultural Science; Vol. 15, No. 8; 2023
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

How Do Small-Scale Cassava Producers Overcome Global Issues? Cassava Profit and Technical Efficiency in Cambodia

Tamon Baba[1], Hisako Nomura[2], Tha Than[3], Pao Srean[3] & Kasumi Ito[4]

[1] College of Letters, Ritsumeikan University, Kyoto, Japan

[2] Faculty of Agriculture, Kyushu University, Fukuoka, Japan

[3] Faculty of Agriculture and Food Processing, National University of Battambang, Battambang, Cambodia

[4] International Center for Research and Education in Agriculture, Nagoya University, Nagoya, Japan

Correspondence: Hisako Nomura, Faculty of Agriculture, Kyushu University, Motooka 744, Fukuoka 819-0395, Japan. Tel: 81-92-802-4762. E-mail: hnomura@agr.kyushu-u.ac.jp

Received: April 5, 2023 Accepted: June 11, 2023 Online Published: July 15, 2023

doi:10.5539/jas.v15n8p1 URL: https://doi.org/10.5539/jas.v15n8p1

The research is financed by JSPS JP 21KK0013 and the Science and Technology Research Partnership for Sustainable Development (SATREPS) in collaboration with the Japan Science and Technology Agency (JST, JPMJSA1508) and Japan International Cooperation Agency (JICA).

Abstract

Cassava producers face numerous economic and natural challenges that impact their profitability. Economically, they encounter price fluctuations for cassava chips and fresh tubers in the global market. Additionally, unexpected weather conditions and diseases affect production. Given the volatility of global prices and unpredictable natural events, producers employ various strategies to maximize their diminishing profits. However, it remains uncertain which practices are more effective in achieving profitability. The factors that influence profitability in farming, such as density, replanting, and the choice of selling the product, either fresh or dry, have been identified in this study. Therefore, the objective of this study is to investigate the determinant factors, including inputs to profit efficiency and farming strategies specific to cassava plantations, that lead to enhanced profit capture. We employ a Cobb-Douglas stochastic frontier model to analyze the technical efficiency of profit capture. Our study suggests that producers should avoid buying additional bunches for replanting and focus on planting at an optimized density to maximize profits. Other strategies showed uncertain outcomes. Knowledge of correct farming practices can improve efficiency and profit optimization.

Keywords: stochastic profit frontier analysis, technical efficiency, , cassava, vegetation density, Cambodia

1. Introduction

1.1 Background Information

Cassava (*Manihot esculenta* Crantz) is one of Cambodia's most important cash crops, primarily cultivated by small-scale producers. Its production has seen rapid growth since 2005, reaching 13,512,755 tons in 2019, with an average yield of 27.20 tons per hectare (ha), and a total cassava harvesting area of 652,531.00 ha (Food and Agriculture Organization of the United Nations [FAO], 2021; Ministry of Agriculture, Forestry and Fisheries in Cambodia [MAFF], 2020). Recognizing its significance, the Cambodian government has initiated the promotion of cassava processing industries under the "National Policy on Cassava 2020-2025" (Royal Government of Cambodia [RGC], 2020). This new policy aims to enhance the profitability of cassava for small producers by creating more value-added products and increasing its market value. In addition, the policy includes the "Productivity of Cassava Production in Cambodia has been Enhanced through Yield-up and Production Cost Reduction without harm to Agricultural Ecology System" project, which strives to develop the cassava sector within the macroeconomic framework.

However, the cassava production situation in Cambodia is not without its challenges. While cassava is predominantly grown as a cash crop rather than a food crop, the harvested tubers are exported as unprocessed fresh or dried chips at low prices to neighboring countries where they are processed and re-exported, because the

cassava processing industry in Cambodia is underdeveloped (voorheen Stichting Nederlandse Vrijwilligers [SNV], 2015). As a consequence, the Cambodian cassava industry is highly susceptible to international price fluctuations, placing its producers in a precarious economic position, especially when facing decreasing demand from global markets. For example, China increased its cassava imports as a material for bioethanol production between 2008 and 2017. However, in 2017, China reduced its import of dried cassava tubers (FAO, 2021) due to the availability of cheaper alternatives like crude oil. Consequently, cassava prices in Cambodia experienced a steep decline in 2017. The prices of fresh tubers plummeted to 108,000-144,000 riels (26-35 USD) per ton. The prices of dried tubers have changed, falling from as high as 720,000 riels (176 USD) in 2014 to between 360,000-420,000 riels (88-102 USD) per ton (The Phnom Penh Post, 2017). Although the prices partly recovered in 2018, mainly due to increased demand from Thailand, fresh tubers are still priced at 270,000 riels (69 USD) per ton, whereas dried tubers are at 735,000 riels (190 USD), lower than previous levels (Khmer Times, 2018). Consequently, Cambodian cassava producers are greatly impacted by international demand and face the risk of economic losses caused by price reductions.

1.2 Study Rationale

To maximize profits for cassava producers, it is crucial to consider both input and output variables. However, in the current scenario of international cassava trade, where global demand and prices fluctuate, profit differences are primarily caused by quasi-fixed inputs. In other words, inputs, production techniques, and selling strategies, such as planting density (Baba et al., 2021), replanting, and the choice between selling as fresh tubers or dried chips, are not optimally selected to adapt to short-term market changes, as observed in the field.

Thus, studies focusing on cassava production should explore agricultural farming practices that enhance cassava profitability and impact technical efficiency. In the face of global price fluctuations, producers employ various strategies to capture diminishing profits. However, determining which practices truly lead to profit capture remains uncertain. It is possible that some strategies, while assumed to generate profit, may actually result in reduced profitability. Thus, this study aims to investigate the factors that contribute to capturing profit and improving technical efficiency in cassava plantations, including inputs to profit efficiency and farming strategies. We employ a Cobb-Douglas stochastic frontier model to achieve this purpose.

1.3 Field Observation and Literature Review

During our field observations, we examined various farming strategies employed in cassava production. Firstly, we analyzed the impact of planting density on technical profit efficiency. Currently, the majority of small-scale Cambodian producers prefer manual planting of cassava seedlings because machinery for cassava planting remains uncommon. The usual practice is to plant cassava stem cuttings vertically in the ground. However, we found variations in density among different farms. On average, the spacing between plants within a row is 0.39 meters, ranging from of 0.20 to 0.80 meters, while the distance between plants in two rows averages 1.14 meters, ranging from 0.50 to 1.50 meters. Consequently, the planting density ranges from 8,333 to 66,667 plants per ha, with an average of 25,300 plants per ha. This indicates that Cambodian producers are planting *a priori*. Although the ideal planting density depends on the specific cassava variety and soil conditions, making it difficult to determine, it is suggested that cassava should be grown at a density of 10,000 plants per ha, with a range of 6,889 to 15,625, depending on soil fertility (Bureau of Agricultural Economic Research, 2009). A study investigated the optimal density for the current most popular varieties, namely Kasetsart 50 (KU 50) and Rayong 7 (R 7) (Baba et al., 2021), and found that the optimal density for KU 50 was 20,833 plants/ha, whereas it was 30,769 plants/ha for R 7.

Secondly, besides the physical inputs used in production, additional costs are incurred from replanting cassava, which we refer to as the "replanting cost." These costs arise when producers need to purchase extra replanted seedlings due to factors such as severe drought or heavy rainfall, as well as damage caused by pests or diseases. These circumstances often lead to growth damage during the sowing and early rooting stages. While it is a common practice among producers, it is unclear whether replanting is beneficial for maximizing profits.

Thirdly, we explore the different forms in which cassava tubers are sold and the target market for these sales. Cassava tubers can be sold either in fresh form, dried form, or both. Additionally, the transportation of cassava from the fields can be done in two ways: either by producers themselves, which may involve hiring labors, or by engaging middlemen, who sometimes assist with harvesting tubers (Ito et al., no date). Although dried tubers fetch a higher price than fresh tubers, they require additional processes such as chipping and drying, which can take several days and incur additional costs.

Moreover, there are several constraints that can impact cassava production profitability, including the rise in labor costs and the prices of agricultural inputs and services due to high inflation (Hing & Thun, 2009). Baba et

al. (2022) conducted a study using the Cobb-Douglas stochastic frontier production model in the Battambang and Pailin provinces, and revealed a significant positive effect of tractor or truck hire costs on cassava "yield"; the cost of cassava uprooting machines had a negative and significant impact. These aspects of input costs may also have implications for cassava profitability. Peuo et al. (2021) provided insights into the break-even points for cassava sale prices and yields, as well as the proportion of each cost item in relation to the total revenue in the Battambang and Pailin provinces. Additionally, Sopheak (2017) calculated the production costs and conducted a Cobb-Douglas regression analysis to analyze cassava profitability; however, his study did not include factors that influence technical efficiency. Hence, in our study, we consider these factors that influence technical efficiency.

1.4 Hypotheses and Their Correspondence to Research Design

This study analyzes the factors that influence both cassava profitability and technical efficiency in the Battambang and Pailin provinces of Cambodia. While previous studies have examined technical efficiency in cassava production among small-scale producers worldwide and identified various factors, their focus has primarily been on cassava yield rather than the profits derived (Soukkhamthat & Wong, 2016; Muhaimin, 2017; Muayila & Mujinga, 2018; Ironkwe, 2014; Olurotimi, 2018; Ogunniyi et al., 2018; Okoye et al., 2016; Abass et al., 2017; Srisompun & Boontang, 2020). Thus, this article, by employing a Cobb-Douglas stochastic frontier production model, sheds light on the specific strategies employed by cassava producers that lead to profit generation.

This study identifies the production strategies that lead to profit maximization. Firstly, we examine the effect of planting density on profitability. It is expected that profitability will decrease beyond the optimal density. Therefore, identify the optimal threshold of density for achieving technical efficiency. Our hypothesis is that there is no difference in profit efficiency across different density thresholds. We choose a conservative value of 20,833 plants/ha as the threshold to explore the diminishing effect and the difference in technical efficiency.

Secondly, we determine whether replanting is beneficial for maximizing profit. To examine this, we include replanting costs in the model, taking into account producers' production performance under climate change, pests, and diseases. Our hypothesis is that there is no difference in the technical efficiency of replanting.

Thirdly, we consider the different product types available, such as fresh tubers, dried chips, or both. Producers can devise strategies to maximize profits by combining the above forms, while considering financial and geographical limitations. Although these factors can potentially enhance cassava profitability, there is limited research exploring their detailed impacts. Therefore, we hypothesize that the product type does not significantly affect profit efficiency at the time of sale.

2. Method

2.1 Study Area and Data Collection

The study was conducted in the northwestern provinces of Battambang and Pailin in Cambodia, which share a border with Thailand (Figure 1). These provinces are known for their significant cassava and rice production. Battambang, being the largest province, has a total cassava cultivation area of 108,551 ha, resulting in a cassava production of 2,620,638 tons. Pailin province, meanwhile, has a cassava cultivation area of 42,110 ha and is the seventh-largest producer, yielding 842,200 tons of cassava (MAFF, 2020).

Figure 1. Survey areas in Cambodia (Created by the authors using Google Maps)

2.2 Sampling Procedures and Sample Size

A series of questionnaire-based structured interviews on cassava production was conducted in two districts of Pailin province and six districts of Battambang province from April to November 2017 for one cycle: 2015/2016 (planting) and 2017 (harvesting). We applied random sampling using a stratified selection method based on the cassava plantation area to categorize the respondents into three groups: less than 1 ha, between 1 ha and less than 5 ha, and 5 ha or more, based on the list provided by the district. In recent years, there has been an increase in foreign investors who purchase state land for cassava plantations to produce biofuel. However, this study focuses on investigating the production efficiency of individual farm households in cassava production. While we interviewed household members engaged in cassava farming, the number of interviewed producers was 205. Three of them were omitted from the analysis. The two largest loss-making producers were excluded from the analysis as their data did not conform to the expected pattern even after normalization. The third producer was also dropped from the analysis as he was the only one who sold their cassava both to a silo and a middleman, which did not fit the established categories. Therefore, the total number of respondents in the study is 202, comprising 141 participants from Battambang province and 61 from Pailin province.

2.3 Analytical Framework

We analyzed the effects of specific agricultural farming practices on the profitability and output-oriented technical efficiency of cassava producers. We employed parametric econometric techniques using the stochastic production frontier approach introduced by Aigner et al. (1977) and Meeusen and van Den Broeck (1977) for this purpose.

$$\pi_i = f(X_i, \alpha) \exp(v_i - u_i) \quad i = 1, \ldots N \tag{1}$$

We assume that a cassava producer, i, generates a vector of the annual profits π_i, which is estimated by adding the profit from both selling fresh tubers, dry tubers, or both, as well as selling stems as seedlings for subsequent propagation in a year. X_i is a vector of quasi-fixed inputs and α is a parameter to be estimated. The term v_i is assumed to be an independently and identically distributed two-sided normally distributed random error (v - N[0, σ_v^2]), independent of u_i. It represents stochastic effects outside the producer's control, such as weather, natural disasters, luck, measurement errors, and other statistical noise. The term u_i is a non-negative random error term, which is independently and identically distributed as truncations at zero in the normal distribution with a mean $-z_i\delta$, and variance σ_u^2 (|N($-z_i\delta$, σ^2_u|). It represents the technical inefficiency of the farm.

Regarding the production function, two alternative approaches are commonly applied: the Cobb-Douglas production function and the Transcendental Logarithm Function (Translog function). The Cobb-Douglas function imposes a prior restriction on farm technologies by assuming constant production elasticities and elasticities of substitution equal to unity. Meanwhile, the Translog function overcomes the limitations of the Cobb-Douglas function shortage by adding the cross-multiplication terms and square terms of all input variables into the model. However, upon conducting a log-likelihood test, the hypothesis that the Cobb-Douglas function is more effective could not be rejected. Therefore, we adopt the Cobb-Douglas function. The general form of the Cobb-Douglas profit frontier for the ith farm is defined as:

$$\ln\pi_i = \alpha_0 + \sum_{j=1}^{j} \alpha_i \ln x_{ij} + v_i - u_i \quad (2)$$

The likelihood function is expressed in terms of the variance parameters $\sigma_v^2 + \sigma^2$ and $\gamma \equiv \sigma^2/\sigma_v^2$, where, $0 \le \gamma \le 1$.

The output-oriented technical efficiency of production for the ith cassava producer is defined by the following function:

$$PE = \exp(-u_i) = \exp(-z_i\delta - \omega_i) \quad (3)$$

The technical inefficiency model is thus related to a vector of farm-specific managerial and household characteristics subject to statistical error (Battese & Coelli, 1995) and can be expressed as:

$$u_i = z_i\delta + \omega_i \ge 0 \quad (4)$$

where, z_i is the farm-specific managerial and household characteristics, and the error and ω_i are random variables with a normal distribution as $\omega_i \sim N(0, \sigma_\omega^2)$.

As $u_i \ge 0$, $W_i \ge -z_i\delta$, the distribution of ω_i is truncated from below at the variable truncation point $-\omega_i\delta$.

2.4 Empirical Model

We analyzed the profit function and technical efficiency of cassava production by using cassava profit as the output variable and production inputs such as labor cost, machine cost, and other production inputs, as well as socio-economic information such as age, gender, and years of cassava production as independent variables. In order to estimate a model that focuses on costs as possible factors influencing cassava profit, we included inputs for cassava production, such as the cost of hiring labor, renting field, purchasing seedlings, and fertilizers, among others, and then converted them into a value per ha (riels/ha, where 4,000 riels are approximately equivalent to 1 USD). It is important to note that since we asked about the costs in the investigated cycle only, producers might have used inputs from the last production cycle or obtained them from others for free. The stochastic profit frontier model is defined in Equation (5).

$$\ln\pi'_i = \alpha'_0 + \sum_{j=1}^{12} \alpha'_i \ln x_{ij} + v'_i - u'_i \quad (5)$$

where, π_i is the normalized net profit. The "profit per ha" is obtained by subtracting total input cost from total revenue. Total revenue is obtained by selling fresh or dried tubers and stems.

Total input cost consists of the jth variable inputs represented as X_i on the ith farm. X_{i1} represents the "labor hire cost per ha." Even small-scale producers hire neighbors or others as labors for various tasks in cassava production, such as plowing fields, raising beds, planting cassava cuttings, applying fertilizers, pesticides, and herbicides, weeding, harvesting tubers and stems, chipping and drying tubers, and transporting them. It is also possible for neighbors or family members to support cassava production for free. X_{i2} is "field rent cost per ha." Several producers rented fields for cassava production. They paid money for field owners every year. X_{i3} is "seedlings for the first planting cost per ha." Some producers purchased stem bunches as seedlings for the first planting cycle. Cassava propagates by cutting the remaining cassava stems after harvesting the tubers (Tokunaga et al., 2018). Therefore, producers keep harvested stems for the next cycle and do not need to purchase branches every year. However, they may buy stems when they do not have enough stems or want to try new varieties. Typically, cassava stems are bunched by strings, with one bunch containing 20 stems in general. X_{i4} is "seedlings for replanting cost per ha." Some producers purchased bunches of stems for replanting. Cassava fields are easily affected by floods, droughts, pests, and diseases, leading to the death of stems. In such cases, producers remove the dead stems, purchase additional stems, and plant them. X_{i5} is "fuel for machine cost per ha." Some producers purchase fuel for machines such as tractors, trucks, sprayers, motorbikes, and cars used in cassava production. We asked about the fuel cost for these machines. If producers used these machines for other crops as well, the cost was calculated by multiplying the ratio of the cassava field size to the total field size. Although several producers had motorbikes and cars for transporting stems and tubers, these were used more frequently in their daily lives. Therefore, we did not include the cost of these machines in our analysis; however, the fuel cost related to cassava production were added in X_{i5}. X_{i6} is "fertilizer cost per ha." This includes the cost of fertilizer, including manure, urea, phosphorus pentoxide, nitrogen, phosphorus, potassium, foliar, accelerator, natural fertilizer, and chemical fertilizer. X_{i7} is "not fertilizer cost per ha." It represents the cost of herbicide, pesticide, and fungicide. X_{i8} is the "material cost for after harvest per ha." This includes the cost for items used for packing or drying tubers after harvest, such as packages, nets, strings, and covers.

X_{i9} represents the "tractor or truck purchase cost per ha." Tractors are used for tasks such as plowing and raising beds using accessories, and transporting tubers, stems, and inputs such as fertilizers. They are commonly purchased by small-scale producers and also used for transportation. To estimate the machinery purchase costs, we considered depreciation. It is worth nothing that Cambodia does not have a specific method for calculating

depreciation, such as statutory useful life. Therefore, we followed the rules set out by the National Tax Agency in Japan. The depreciation calculation was based on the straight-line method, rather than the declining-balance method, with tractors and other agricultural equipment having a useful life of seven years. If the producers could not recall the purchase price or the year of purchasing the machinery, we assumed that the machinery was purchased more than seven years ago and excluded it from the depreciation calculation. In the case of second-hand machinery, depreciation was calculated using the straight-line method due to the difficulty of determining its precise value.

The remaining input variables are as follows. X_{i10} is "Sprayer purchase cost per ha." Sprayers are used for applying liquid chemicals, such as herbicides and pesticides. Similar to X_{i11}, we calculated its cost following the depreciation method, multiplying it by the ratio of the cassava field size to the total field size. X_{i11} represents the "tractor or truck hire cost per ha." As machinery costs can be high for small-scale producers, many of them choose to hire tractors or trucks for their cassava activities. Although this cost can include hired labor costs for driving and fuel costs, we did not separate them. X_{i12} refers to "uprooting machine hire cost per ha." Uprooting machines can be hired for harvesting tubers. Therefore, this cost may include leased labor costs for driving and fuel costs, similar to other hired machinery.

The logarithm of the output of technical efficiency in Equation (6) is obtained by setting u_i in Equation (4).

Then,

$$u_i^{'} = \delta_0^{'} + \sum_{k=1}^{z} \delta_k^{'} Z_{ik} + \omega_i^{'} \tag{6}$$

where, Z_{ik} represents the farm-specific characteristics of the ith farm. Specifically, Z_{i1} represents "gender" and is a dummy variable for male respondents. Z_{i2} represents "age." Z_{i3} represents the "educational level" of the respondent, classified as follows: 1 = no formal education, 2 = graduated from primary school, 3 = graduated from secondary school, 4 = graduated from high school, and 5 = graduated from university. Z_{i4} represents "full time" and is a dummy variable for a full-time producer. Z_{i5} represents the "number of cassava farming family members." It represents the count of family members participating in cassava production. Z_{i6} represents "cassava farming experience," indicating the number of times the producer has planted/harvested cassava. Z_{i7} represents the log form of "cassava planting density," which denotes the number of plants per hectare. In model two, we derive it by creating four dummy variables (dplanteddensity1: density < 1.666, dplanteddensity2: ≥ 1.666 and < 2.084, dplanteddensity3: ≥ 2.084 and < 3.000, and dplanteddensity4: density ≥ 3.000) to verify hypothesis two. Z_{i8} represents "replanting" and is a dummy variable indicating whether stems are replanted if they die due to natural disasters or pests and diseases. Z_{i9} represents "the existence of whitefly in cassava fields during the cycle" and is a dummy variable. In model three, we examine the third hypothesis. Z_{i10} represents "sell tubers as fresh" as a dummy variable. Lastly, Z_{i11} represents "sell tubers after dried," also a dummy variable. We separately examined hypotheses two and three, and the results are shown as Models two and three.

3. Results

3.1 Descriptive Summary of Variables

Table 1 summarizes the definitions, measurement units, and summary statistics of all the dependent and independent variables. The profit was calculated by subtracting the total input cost from the total revenue. On average, the profit was 922,825.13 riels (231.71 USD) per ha. Total revenue was 3,315,899.00 riels (828.97 USD) per ha, ranging from 136,500.00 (34.13 USD) to 14,053,000.00 (3,513.25 USD). The revenue consisted of both tuber sales and stem sales. The revenue from tuber sales was 3,307,766.00 riels (826.94 USD) per ha, ranging from 136,500.00 (34.13 USD) to 14,053,000.00 (3,513.25 USD). The revenue from selling stems was 164,294.60 riels (41.07 USD) per ha, ranging from 3,333.33 (0.83 USD) to 640,000.00 riels (160.00 USD). It is worth noting that only 10 producers (4.95%) sold stems.

The total input cost per ha averaged 2,393,073.00 riels (598.27 USD), ranging from 0.00 to 7,115,515.00 riels (1,778.88 USD). The total input cost encompassed various expenses, including labor hire cost, field rent cost, seedlings for the first planting cost, seedlings for the replanting cost, fuel cost for machine, fertilizer cost, not fertilizer cost, material cost, tractor or truck purchase cost, sprayer purchase cost, tractor or truck hire cost, and uprooting machine hire cost.

Table 1. Descriptive summary of variables used in the study (n = 202)

Variables	Definition	Mean	Standard Deviation	Minimum	Maximum
Profit Function	1,000 Riel per ha				
profits	Net income	922.826	1,916.024	-4,128.508	12,500.000
laborhire	Labor hire	872.213	791.404	0.00	6,010.000
rentland	Field rent	100.346	276.494	0.00	1,380.000
seedling	First seedling	153.072	384.092	0.00	2,880.000
seedreplant	Seed replanting	40.242	112.347	0.00	871.212
fuel	Fuel for machine	92.696	97.931	0.00	499.400
fertilizer	Fertilizer	103.103	148.105	0.00	920.000
notfertilizer	Not fertilizer	185.427	146.267	0.00	825.000
material	materials	87.904	145.024	0.00	1,030.000
tractorown	Tractor or truck purchase	169.340	436.395	0.00	3,290.000
sprayer	Sprayer purchase	9.540	24.048	0.00	289.916
tractorhire	Tractor or truck hire	500.616	311.543	0.00	1,470.000
uprooting	Uprooting machine hire	77.729	104.754	0.00	410.714
Technical Inefficiency Function					
gender	1 = Male, 0 = Female	0.927	0.261	0	1
age	Years	48.995	13.290	21.00	78.00
education	1 = No formal education, 2 = Primary school, 3 = Secondary school, 4 = High school, 5 = University	1.410	0.740	1.000	5.000
fulltime	1 = Full-time, 0 = Part-time	0.859	0.349	0	1
farmmem	Number of cassava farming family members (persons)	2.546	1.059	0	6
cassavatimes	Times	4.078	3.035	0.000	16.000
planteddesnity	= 1/distance between plants in the row × distance between plants in two rows (plants/ha/10,000)	2.516	0.881	0.833	6.667
dplanteddensity1	a dummy of density < 1.666	0.134	0.341	0	1
dplanteddensity2	dummy of density ≥ 1.666 and < 2.084	0.248	0.433	0	1
dplanteddensity3	a dummy of density ≥ 2.084 and < 3.000	0.342	0.475	0	1
dplanteddensity4	a dummy of density ≥ 3.000	0.277	0.449	0	1
replant	1 = Yes, 0 = No	0.307	0.463	0	1
seewhitefly	1 = Yes, 0 = No	0.483	0.501	0	1

Altogether, 32 (15.84%) producers rented fields for cassava production with a cost of 633,437.20 riels (158.36 USD) per ha per year, with a range from 0.17 to 11.67 ha. Additionally, 173 (86.64%) producers hired labors for various activities with an average cost of 1,018,422.00 riels (254.61 USD) per ha.

For the first planting in the cycle, 54 (26.73%) producers purchased new stems because they did not have enough at a cost of 572,603.90 riels (143.15 USD) per ha. Moreover, 44 (27.78%) respondents bought stems for replanting at a cost of 184,746.20 riels (46.19 USD) per ha.

In terms of inputs, 133 (65.84%) respondents purchased fertilizers for cassava production, including manure, urea, phosphorus pentoxide, nitrogen, phosphorus, potassium, foliar sprays, accelerators, organic fertilizer, and other chemical fertilizers, with an average cost of 156,592.00 riels (39.15 USD) per ha. Additionally, 191 (94.55%) producers bought herbicides, pesticides, and fungicides for 196,106.10 riels (49.03 USD) per ha. Moreover, 169 (83.66%) respondents bought packages, nets, strings, and covers for packing or drying tubers for 105,609 riels (26.40 USD) per ha.

Machinery costs were calculated using the aforementioned depreciation method. Among the respondents, 48 (23.76%) purchased tractors or trucks for 712,642.40 riels (178.16 USD) per ha, and 136 (67.33%) bought sprayers for 14,169.08 riels (3.54 USD) per ha. Moreover, 185 (91.58%) producers rented the machines, including hiring labor costs for 546,619.10 riels (136.65 USD) per ha, while 75 (37.13%) hired uprooting machines for 209,349.70 riels (52.34 USD) per ha.

The results show that 141 (69.80%) respondents resided in Battambang province and 61 (30.20%) in Pailin province. Furthermore, 187 (92.57%) of the householders were males and 15 (7.43%) were females. The average age of the respondents was 49.03 years old. In terms of education level, 145 (71.78%) individuals did not

graduate from primary school, 38 (18.81%) graduated from primary school, 15 (7.43%) from secondary school, 3 (1.49%) from high school, and 1 (0.50%) from university.

The farmers had an average farm size of 3.68 ha dedicated to cassava production, which accounted for 72.46% of their total farm size. Among the producers, 160 (79.21%) individuals indicated that cassava production was their main source of income, and 174 (86.14%) responded that they were full-time producers. On average, 2.55 family members were involved in cassava production, highlighting the significant role of cassava profit in their lives. Additionally, the respondents reported an average of 4.078 cassava production cycles, with the maximum number of cassava production being 16. The mean of harvested tubers was 17.61 tons per ha. On average, the planting density was calculated as 2.516 plants per m^2, that is, 25,162 plants per ha. Three peaks of most commonly used density were identified. The first peak was between 1.666 and 2.083 plants per m^2, with 13.37% of the producers using this density. The density of 2.083 was determined as the optimal yield obtained based on our project experiment for KU 50 (Baba et al., 2021). Most of varieties of the respondents seemed to be using KU 50 from our field observation. The second one was between 2.083 and 3.000, peaked at 2.777 plants per m^2, with 34.16% of the producers using this density. The most commonly used density was between 2.083 and 3.000. The proportion of producers using a density of 3.000 or above was 27.72%.

As cassava production can be easily affected by pests, diseases, and climate, 44 (27.78%) respondents bought stems for replanting, and 62 (30.69%) producers replanted. By contrast, 18 producers did not buy stems but used their own stems or got them for free for replanting. In addition, 125 (61.88%) producers reported that they saw mealybugs in their fields, and 97 (48.02%) producers reported seeing whiteflies in their fields, both of which can damage cassava stems. Furthermore, 22 (10.89%) producers' fields were affected by floods, 104 (51.49%) by drought, and 17 (8.42) by both flood and drought.

After harvesting tubers, producers need to sell them to obtain cash. Among the respondents, 77 (38.12%) producers sold tubers as fresh, 108 (53.47%) as dried, and 17 (8.42%) as both. Additionally, 150 (74.26%) producers sold tubers to silos by themselves and 52 (25.74%) to middlemen.

*3.2 Stochastic Frontier Profit Function Model Estimation*Table 2 presents the estimated parameters for the stochastic frontier profit efficiency model. Analyses were made by removing producers whose profit was less than zero. To estimate the influence of the variables "log of density," "the degree of density" in the form of dummy variables, as well as "fresh" and "both fresh and dry" as base categories, we prepared three models. Additionally, we included the variable of producers selling cassava and its interaction terms with the final product. Among all the input variables, the labor hire cost and the fertilizer cost were negative and significant at the 10% level or smaller for all three models. In model one, the fuel cost was positive and significant at the 10% level.In model one, although not statistically significant, field rent, the first purchase of seedlings, additional purchase of seedlings, purchase of not fertilizer (herbicide, pesticide and fungicide), tractor or truck hire, and uprooting machine hire costs were positively associated, while material, tractor or truck purchase, and sprayer purchase costs were negatively associated. However, in model two, compared to model one, the uprooting machine hire cost became negative, and tractor or truck hire, and uprooting machine hire costs became negative in model three, although they were not statistically significant.

The second half of Table 2 presents the estimated parameters for the technical inefficiency of cassava profit. As the results show technical inefficiency, we interpret the negative signs as indicators of efficiency. In model one, the results indicate that gender iis negative and significant effects at the 1% level, while being full-time has a negative and significant effect at the 5% level. Additionally, planted density is negatively and significantly associated at the 10% level. Meanwhile, factors such as the frequency of cassava production, whether replanting occurred, and the recognition of whitefly existence in cassava fields during the cycle have positive and significant effects, indicating technical inefficiency.

In model two, the results focused on the degree of density. According to the result, there is no statistical difference when density is between 1.666 and 2.084, compared to densities less than 1.666. However, compared to a density of between 2.084 and 3.000, there is a significant difference when the density is less than 1.666. Furthermore, when the density exceeds 3.000, it significantly differs from when the density is less than 1.666, although the coefficient is highest when the density ranges between 2.084 and 3.000.

In model three, the impact of selling cassava tubers in "fresh," "dry," or both forms was revealed. However the results did not indicate any significant influences from the interaction terms of "fresh" and "fresh and dry" with silo, compared to selling both forms, while they are positive. As beforementioned, cassava tubers can be sold in fresh or dried form, or both.

Table 2. Estimated parameters for the cassava profit per ha stochastic frontier model (n = 141)

Variables	Model 1			Model 2			Model 3		
	Coef.		Std. Err.	Coef.		Std. Err.	Coef.		Std. Err.
Frontier									
ln*laborhire*	-0.01	*	(0.009)	-0.02	**	(0.009)	-0.01	**	(0.009)
ln*rentland*	0.01		(0.011)	0.01		(0.012)	-0.01		(0.012)
ln*seedling*	0.00		(0.010)	0.00		(0.010)	0.00		(0.009)
ln*seedreplant*	0.00		(0.011)	0.00		(0.012)	0.00		(0.010)
ln*fuel*	0.02	*	(0.015)	0.02		(0.011)	0.02		(0.011)
ln*fertilizer*	-0.01	*	(0.008)	-0.02	*	(0.008)	-0.01	**	(0.008)
ln*notfertilizer*	0.01		(0.016)	0.00		(0.018)	0.01	*	(0.018)
ln*material*	-0.01		(0.012)	-0.00		(0.013)	-0.01		(0.013)
ln*mtrown*	-0.00		(0.009)	-0.00		(0.009)	-0.01		(0.011)
ln*sprayer*	-0.01		(0.009)	-0.01		(0.009)	-0.01	*	(0.009)
ln*mtrhire*	0.00		(0.013)	0.00		(0.014)	-0.00		(0.013)
ln*uprooting*	0.00		(0.007)	-0.00		(0.008)	-0.00		(0.008)
Cons.	14.80	***	(0.281)	14.72	***	(0.304)	14.75	***	(0.237)
Technical Inefficiency									
gender	-15.69	***	(5.683)	-19.77	***	(5.333)	-5.51	***	(2.244)
age	-0.04	*	(0.025)	-0.09	**	(0.039)	-0.06	***	(0.041)
education	0.52		(0.679)	0.18		(0.671)	0.46		(1.154)
fulltime	-2.17	**	(1.051)	-2.62		(4.507)			
farmmem	-0.77	**	(0.337)	-1.07	***	(0.272)	0.16	***	(0.245)
cassavatimes	1.00	***	(0.214)	1.22	***	(0.194)	0.64	***	(0.099)
seewhitefly	5.00	***	(1.228)	6.82	***	(1.199)	2.43	***	(0.623)
ln*planteddensity*	-3.16	*	(1.617)						
dplanteddensity2				-2.54		(4.731)			
dplanteddensity3				-3.74	***	(1.348)			
dplanteddensity4				-2.82	**	(1.266)			
replantornot	9.55	*	(5.129)	11.24	**	(4.867)			
fresh							1.42		(1.717)
fresh&dry							-0.18		(1.768)
freshxsilo							-3.90		(2.557)
Fre&drxsilo							0.76		(2.218)
silo							-1.63		(1.369)
Cons.	2.01		(2.523)	4.50		(5.516)	-2.30		(2.729)
Vsigma Cons.	-1.45	***	(0.251)	-1.32	***	(0.270)	-1.84	***	(0.320)
Log-likelihood	-169.5313			-164.322			-175.007		

Note. *ln* is the natural logarithm; standard errors are in parentheses; significant at *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$, respectively.

3.3 Technical Efficiency Score

The frequency distribution of technical efficiency indice, is illustrated in Figure 2. The figure indicates a limited distribution of the technical efficiency across different efficiency scores. The mean, minimum, and maximum levels of technical efficiency levels are presented in Table 3. The table reveals that the mean technical efficiency scores of 0.562, ranging from 0.004 to 0.994. This suggests that if a producer's technical efficiency improved to a fully efficient level, the inputs used could be reduced by approximately 43.8% without decreasing the current output level, thus increasing the gross margin of producers.

Furthermore, this score also implies that profitability could be enhanced by 77.94% [(0.562 − 1)/0.562 × 100] through full efficiency improvement, based on the mean efficiency value of 0.562. Moreover, the average technically efficient producers could potentially reduce their costs by 43.46% [(1 − 0.562/0.994) × 100]

assuming that the optimal cost could be improved up to the maximum efficiency level. Lastly, the most technically inefficient producers could achieve cost saving of 99.60% [(1 − 0.004/0.994) × 100] if they were able to reach the maximum technical efficiency level of their counterparts, considering an improvement from 0.004 to 0.994. It is worth mentioning here that estimates were made by removing producers whose profit was less than zero. Thus, the true profit technical efficiency score is considered to be lower.

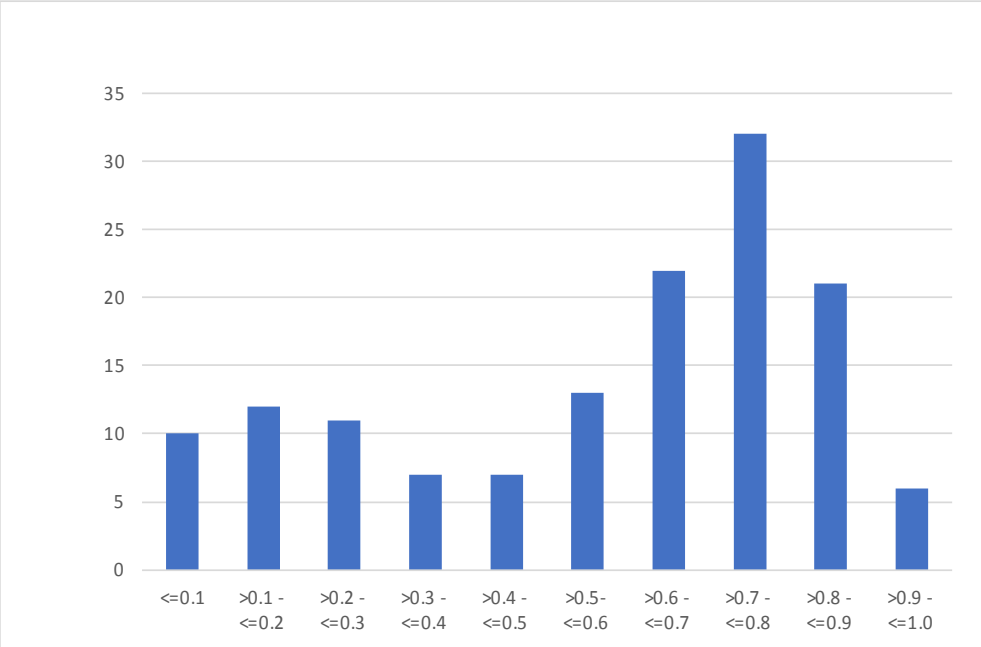

Figure 2. Frequency distribution of technical efficiency

Table 3. Technical efficiency scores summary (n = 141)

	Obs	Mean	Std.	Min.	Max.
TE(1)	141	0.562	0.266	0.004	0.994

Note. (1) Technical Efficiency.

Next, Table 4 presents technical efficiency categorized by density. We conducted a sensitivity analysis for other peak points of density, specifically at 1.666, 2.564, 2.777, and 3.333. The farms with planting densities equal to or greater than 2.777 and 3.000 had the highest mean efficiency scores, when compared against the overall mean technical efficiency. Thus, although the optimal yield obtained from Baba et al. (2021) was 2.083, in the study area, the mean efficiency score for densities equal to or greater than 2.777 and 3.000 was the highest, and beyond 4.166, which represents a higher density following greater than 3.333 and 4.166, the mean efficiency starts to decrease.

Table 4. Technical efficiency scores by density (n = 141)

Density	Obs	Mean	Std. Err.	Min.	Max.
< 1.666	35	0.472	0.270	0.004	0.980
≥ 1.666 & < 2.084	11	0.616	0.289	0.072	0.911
≥ 2.084 & < 2.564	19	0.507	0.273	0.006	0.822
≥ 2.564 & < 2.777	11	0.585	0.261	0.114	0.920
≥ 2.777 & < 3.000	27	0.647	0.251	0.087	0.959
≥ 3.000 & < 3.333	0	0	0	0	0
≥ 3.333 & < 4.166	33	0.604	0.234	0.061	0.993
≥ 4.166	5	0.589	0.177	0.386	0.790

Table 5 presents the technical efficiency scores categorized by whether the crop was replanted or not. Our hypothesis was that there was no difference in technical efficiency between replanted and non-replanted crops. However, the technical efficiency score for replanted crops was found to be 0.499, while the technical efficiency score for non-replanted crops was 0.587. The result indicated that the average efficiency score for non-replanted crops was statistically higher than the mean of the technical efficiency of replanted crops at the 5% significance level.

Table 5 Technical efficiency scores by replanted or not (n = 141)

Density	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]		p-value[1]
Not replanted	100	0.587	0.026	0.259	0.536	0.639	0.018 **
Replanted	41	0.499	0.043	0.275	0.412	0.586	

Note. p-value is based on the one-tailed test.

3.4 Revenue and Cost Analysis per Hectare

Table 6 presents the average revenue and cost analysis per ha in our study. We included those producers whose profits are less than zero. Total profit was calculated by subtracting the total input cost from the total revenue. The total revenue was obtained from two sources, selling fresh and dried tubers and stems. However, the revenue from selling stems was very small (0.25%). The total input cost comprised twelve items: labor hire cost, field rent, first seedling, seed replanting, fuel for machine, fertilizer, not fertilizer such as herbicide and fungicide, materials, tractor or truck purchase, sprayer purchase, tractor or truck hire, uprooting machine hire. Labor hire cost represents the highest percentage of the total costs. Another factor to consider is the Benefit-Cost Ratio (BCR). In our study, the BCR was determined to be 1.39, indicating that for every 1 riel invested in cassava farming, a return of 1.39 riel is expected.

Table 7. Revenue and cost analysis per hectare (n = 202)

Variables	Amount (riels)	Amount (USD)	Percentage
Total profit	922,826.13	230.71	
Total revenue	3,315,899.00	828.97	100.00
Selling tubers	3,307,766.00	826.94	99.75
Selling stems	8,133.39	2.03	0.25
Total input cost	2,393,073.00	598.27	100.00
Labor hire cost	872,212.90	218.05	36.45
Field rent cost	100,346.50	25.09	4.19
Seedlings for the first planting cost	153,072.30	38.27	6.40
Seedlings for the replanting cost	40,241.75	10.06	1.68
Fuel for machine cost	92,696.45	23.17	3.87
Fertilizer cost	103,102.60	25.78	4.31
Not fertilizer cost	185,427.00	46.36	7.75
Material cost	87,904.32	21.98	3.67
Tractor or truck purchase cost	169,340.80	42.34	7.08
Sprayer purchase cost	9,539.58	2.38	0.40
Tractor or truck hire cost	500,616.5	125.15	20.92
Uprooting machine hire cost	77,728.86	19.43	3.25
Benefit-Cost Ratio (BCR): 1.39			

4. Discussion and Policy Implication

Based on the results of the cassava profit frontier function, the labor hire cost and the fertilizer cost were negative and significant at the 10% level or smaller for all three models. These findings indicate that each 1% increase in fertilizer cost, as well as labor hire cost, has a negative effect on profit efficiency. This suggests that cassava producers are overspending on fertilizer and labor hire costs. Furthermore, other costs such as material,

and tractor or truck purchase costs showed a tendency to negatively affect profit efficiency, but they were not statistically significant. These results suggest that cassava producers are incurring significant expenses in various processes. Therefore, it can be presumed that social structural challenges may be contributing to these results. For example, out of the respondents, 149 (73.76%) producers indicated that increasing agricultural inputs and hiring labors put pressure on their business. Additionally, 65 (32.18%) producers identified labor scarcity as a problem.

Similarly, Hing and Thun (2009) also pointed out these challenges. Unfortunately, the situation has not improved, and many individuals have migrated from Battambang and Pailin provinces to work in Thailand or other places. Furthermore, 25 (12.38%) respondents reported taking a cassava production loan. In order to maximize profits, producers need to accurately calculate their necessary expenses, and the government should establish a system for local agricultural organizations to provide agricultural machinery loans to producers.

We prepared three models to examine the potential impact of planted density, replanting, and selling product forms on technical inefficiency. In terms of inefficiency scores, a negative coefficient indicates that the technical efficiency positively affects the profit efficiency. Model one revealed that male producers who work full-time producers and have family members involved in cassava production had a positive and statistically significant effect on technical inefficiency. By contrast, producers who experience more years of cassava production, replant seedlings, and encounter whiteflies in their cassava fields during the cycle exhibited negative technical efficiency. These findings suggest that as producers gain experience, their profit efficiency tends to decrease. We also discovered that replanting cassava leads to technical inefficiency due to the drying of stems after planting. Replanting is a common practice in Cambodia, but it becomes costly as producers use extra inputs such as seedlings and fertilizer. Thus, the extension may recommend that producers refrain from planting as it directly impacts profit efficiency. Additionally, producers experience profit losses when whiteflies, which act as vectors for cassava mosaic disease, are present in their fields.

In terms of optimal density, model two revealed that the density between 2.084 and 3.000 had the highest coefficient and was positively technically significant. Furthermore, the efficiency score sensitivity analysis of Table 4 demonstrated that the score for densities equal to and greater than 2.777 and less than 3.000 was larger than the mean of the total technical efficiency. These results indicate that the highest technical efficiency is observed for densities between 2.777 and 3.000, and efficiency decreases when the density reaches 3.333 or higher.

Model three indicated that the form in which cassava tubers are sold (fresh, dry, or both) was found to be statistically insignificant. However, notable differences in trends were observed across provinces. For example, all 61 respondents in Pailin province brought tubers to silos themselves, while 52 out of 141 respondents in Battambang province relied on middlemen for this task. Regarding the form of tubers sold, 54 out of 61 Pailin producers sold tubers in fresh form, 5 in dry form, and 2 sold both forms. Moreover, 23 out of 141 Battambang producers sold tubers in fresh form, 103 in dry form, and 15 sold both forms. This suggests that Pailin producers tended to sell fresh tubers to silos by themselves, while Battambang producers tended to sell dried tubers to silos or middlemen. The location of silos or factories to which middlemen transport the cassava product can impact the gate price for both dried and fresh cassava (Ito et al., 2021). Pailin, being closer to Thailand, has large silos and factories such as Charoen Pokphand Group Co., Ltd. The cassava producers produce along with the National Roads no. 57 and no. 59 in a narrow area. Thus, the middlemen had easy access to producers and silos or factories. Although Battambang also shares a border with Thailand, cassava producers are scattered throughout the province, and access to the National Road is sometimes limited. Reflecting these differing access conditions, both the prices of fresh and dried tubers in Pailin are higher compared to those in Battambang: Fresh is 144.73 riel per kilo, and dry is 466.14 riel per kilo in Pailin.

By contrast, the price of fresh tubers is 135.37 riel per kilo, while the price of dried tubers is 415.32 riel per kilo in Battambang. Based on the above information, we can assume that the location allows Pailin producers to transport fresh tubers to silos at a lower cost and obtain sufficient cash. However, Battambang producers tend to dry the tubers and sell them to silos or middlemen, expecting higher profits or avoiding transportation difficulties. Nonetheless, there was no difference in technical efficiency between the two provinces. Thus, when cassava producers aim to maximize profits, it is necessary to consider the advantages certain producers could capture from producers' geographical factors as well as that of factories rather than a one-size-fits-all approach for all producers in Cambodia.

Furthermore, selling fresh tubers eliminates the need to purchase items for packing or drying tubers and hiring labors for these tasks. However, transportation costs can be more expensive for fresh tubers due to their heavier

weight. In our estimation, the ratio of fresh and dry weights is 1 to 0.57, which aligns with the range of 0.53 to 0.57 calculated by Peuo et al. (2021). Additionally, the price of fresh tubers is lower compared to that of dried tubers. In our survey, the price was 140.95 riels per 1 kilo for fresh tubers and 418.17 riels per 1 kilo for dried tubers. Selling dried tubers requires additional expenses for drying, transportation, and hiring labors, but transportation costs can be reduced, and producers can sell tubers at higher prices.

If the fields are located nearby a silo or well-paved road, producers have the option to transport tubers directly to the silo. However, this process requires machine costs and fuel costs, either for using their own machines or hiring machine along with a driver and fuel. On the other hand, producers also have the option to sell tubers to middlemen. In this scenario, middlemen can provide labors and machines to come to the fields and harvest the tubers. If the fields are distant from a silo or lack labors and machines for transportation, producers sell the tubers to middlemen who then bring them to a silo. The cash that producers receive from middlemen would be the amount after deducting necessary expenses incurred by the middlemen.

The result indicates that the profitability of selling tubers in dry, fresh, or both forms may be influenced by financial or geographical constraints. However, our study has its limitations We were unable to identify the specific silos or factories where middlemen took the fresh or dried tubers, as producers did not have knowledge of their final destinations. Additionally, road conditions could potentially limit access for large trucks to the production site and the silo, and vice versa. In order to investigate which form of the product yields higher profits, further research could focus on analyzing the distance from the farm to the silo or factories and examining the road access.

Finally, according to Table 7, our results are comparable to the findings of previous studies. Although there have been no profit frontier analyses on cassava production in Cambodia, some studies have conducted production cost surveys in Battambang province. It should be noted that different studies have different variable definitions and data collection methods, making direct comparison of actual costs difficult. However, the following points can be highlighted. Firstly, labor hire costs accounted for the highest percentage of total costs. Our study found that labor hire costs constituted 36.45% of total costs, while previous studies reported 34.52% (Hing & Thun 2009), 61.66% (Ou et al., 2016), 47.20% (Sopheak et al., 2017), and 36.66% (Peuo et al., 2021) in their respective studies. These findings support the notion that labor hiring costs play a crucial role in cassava production. Secondly, BCR is another factor to consider. The BCR score in our study was 1.39, meaning that for every 1 riel invested in cassava farming, a return of 1.39 riel is realized. This figure is consistent with other studies conducted in Cambodia, which reported BCRs of 1.85 (Ou et al., 2016), 1.31 (Sopheak et al., 2017), and 1.40 (Peuo et al., 2021). It is important to note that our study was conducted in 2017 in Battambang and Pailin provinces, collecting information on cassava production during the 2016-2017 cycle, a period marked by a sharp drop in the price of cassava tubers, as beforementioned. Thus, we need to consider price fluctuations. According to our survey, the cost of fresh tubers was 140.95 riel per kilo, and that of the dried tubers was 418.17 riel per kilo. Ou et al. (2016) conducted a survey in Kampong Cham and Pailin provinces in January-February 2014, and the price of fresh tubers was 303.40 riel per kilo in Kampong Cham and 248.08 riel per kilo in Pailin province. Sopheak et al. (2017) surveyed between January to May 2017 at 16 out of 24 provinces: Banteay Meanchey, Battambang, Kampong Cham, Kampong Thom, Kompot, Kratie, Mondulkiri, Preah Vihear, Pursat, Rattanakiri, Siem Reap, Stueng Treng, Svay Reing, Takeo, Otdor Meanchey, and Pailin, but did not report the price of tubers. Peuo et al. (2021) conducted a survey in February and March 2019 in Battambang and June and July 2019 in Pailin, and the price of fresh tuber was 246.12 riel per kilo. Based on yield and unit price, total revenue is higher, and in relation to the total costs, the higher the BCR. Even if the labor hire costs have a prominent share, when the cassava price and yield decrease, costs that play crucial roles, such as labor hire costs, become more significant in terms of their proportion to the total cost, leading to diminished profits. Therefore, if labor costs increases with inflation while the commodity unit price and yield decrease, it can squeeze profits.

5. Conclusion

This study utilized a stochastic frontier profit efficiency model to examine the factors influencing the profitability of cassava producers and the strategies employed by producers to enhance their profits in Cambodia. Effective management of input costs is crucial for improving cassava profitability in the country. The study collected data from a sample of 202 small-scale cassava producers with an average experience of 4.11 cycles in cassava production in the Battambang and Pailin provinces in northwestern Cambodia. The findings revealed that fertilizer cost and the labor hire cost had a significant negative impact on cassava profit across all three models. It was observed that while the commodity price decreases due to changes in the global trade demand, the local labor market's labor does not immediately adjust. As a result, labor hire costs impact profitability, leading to reduced profits. Furthermore, the costs associated with material for post-harvest processes, as well as tractor

or truck purchase costs, displayed a negative trend, although these relationships were not statistically significant. Moreover, the technical efficiency score for cassava profit was 0.562, indicating that on average, technically efficient producers could potentially reduce their costs by 43.46%.

To counteract diminishing profits, related to producers' strategies, our study suggests that producers should refrain from purchasing additional bunches for replanting and instead plant at the optimized density to maximize profits. We recommended maintaining a planting density between 2.777 and 3.333. These findings align with another study conducted on the KU 50 variety. It is important for producers to be aware of proper farming practices as it can enhance technical efficiency and optimize profitability. However, the impact of other strategies yielded ambiguous outcomes, indicating that the profitability derived from selling the final product in either dry, fresh, or both forms may be influenced by financial or geographical constraints. By implementing the farming practices identified in our study to improve technical efficiency and reduce costs, Cambodian producers can optimize their profitability.

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