

Optimizing Production Planning in Cassava-Based Snack MSMEs Using Linear Programming: A Case Study from Pesawaran Regency

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) producing cassava-based snacks often face production inefficiencies due to resource limitations and suboptimal product allocation. This study aims to determine the profit-maximizing product mix for cassava-based snack MSMEs in Gedong Tataan District, Pesawaran Regency, Indonesia. Primary data were collected from 30 MSME owners through interviews, questionnaires, and direct observations. A linear programming model incorporating three products—kelanting, cassava chips, and mangle crackers—was solved using the simplex method in POM-QM for Windows version 4.0, considering raw material availability, labor capacity, and unit contribution margins. The results identify cassava chips as the optimal product, with a production allocation of approximately 128.76 kg per cycle and a maximum profit of IDR 740,343. This solution utilizes 300 kg of raw cassava and approximately 20.60 of the available 21 man-days of labor. Sensitivity analysis indicates that the optimal product mix depends on contribution margins and resource constraints. These findings demonstrate that linear programming can support MSME production planning by identifying profitable product allocations and quantifying resource utilization. The model can help managers make informed decisions regarding product mix, profitability, and resource allocation.

Keywords: Cassava; Linear Programming; MSME Profitability; Production Optimization; Production Planning

JEL Classification: Q120; Q130; M110

INTRODUCTION

Micro, small, and medium enterprises (MSMEs) represent a foundational pillar of national economic development in Indonesia. The MSME sector plays an essential role in absorbing local labor, empowering rural communities, facilitating the application of post-harvest agricultural technology, and contributing significantly to Gross Domestic Product (GDP) (Kadin Indonesia, 2025). The economic resilience of the MSME sector was prominently demonstrated during economic downturns, during which small enterprises sustained local commerce while large-scale capital-intensive industries suffered severe contractions (Kadin Indonesia, 2025). According to Handayani (2016) and Yuliastuti et al. (2025), agribusiness MSMEs maintain high economic adaptability due to several structural factors: (1) low reliance on foreign commercial debt; (2) minimal exposure to non-performing bank loans as operations are largely self-financed; (3) direct utilization of local agricultural raw materials; and (4) flexibility in servicing domestic niche markets.

The agricultural processing sector is the largest contributor to the growth of MSMEs, playing an essential role in providing key raw materials and labor. Many MSMEs rely on their core activities by utilizing abundant agricultural resources for community food production (Handayani & Irawati, 2017; Rachmawati, 2026). Therefore, proper management of this sector is expected to improve the bargaining position of MSMEs as the economic foundation of the community.

Among primary food security commodities in Indonesia, cassava (*Manihot esculenta*) ranks as the third main staple after rice and maize, yielding an annual national output that supports widespread processing clusters (Indrawan et al., 2022). Cassava-based snacks include chips, crackers, kelanting, getuk, tape, tiwul, geblek, and opak. A significant cluster of MSMEs producing these snacks is located in Gedong Tataan District, Pesawaran Regency, Lampung Province. Initially, these industries operated as small-scale household enterprises employing family members as their primary workforce. As market demand for these snacks increases over time, business activities have correspondingly expanded. The primary objectives of these enterprises are to maximize profit levels while minimizing operational costs and the risk of business failure.

In Pesawaran Regency, Gedong Tataan District encompasses 2,860 hectares of cultivated cassava land producing over 64,460 tons annually (Central Agency of Statistics Lampung Province [Badan Pusat Statistik Provinsi Lampung/BPS Provinsi Lampung], 2023). This substantial raw material supply has fostered a dense concentration of snack-producing MSMEs specializing in products such as cassava chips, kelanting, and mangle crackers. Despite the vast availability of local cassava, MSME managers in Gedong Tataan District continue to face stagnant business revenues, averaging approximately IDR 1,000,000 per month per enterprise based on primary data observation. Operational scales remain constrained at the micro level due to traditional processing techniques, working capital limitations, and informal management practices. Furthermore, MSME owners face operational complexities including manual slicing capacity, limited frying oil volumes, informal labor schedules, and seasonal raw material price fluctuations (Suwandi et al., 2021). Because fresh cassava tubers deteriorate rapidly within 48 hours of harvest, inefficient raw material allocation leads to material waste and elevated storage costs (Handayani, 2022).

A key operational bottleneck among cassava snack MSMEs is the lack of structured production planning. MSME managers typically produce multiple product variants, such as kelanting, cassava chips, and mangle crackers simultaneously or intuitively based on historical habits without quantitative evaluation of contribution margins or resource bottlenecks. This subjective approach results in suboptimal product mixes, where scarce

labor and machinery are diverted toward low-margin products, leading to narrow profit margins and operational stoppages (Latief et al., 2023; Suwandi et al., 2021). Therefore, quantitative optimization techniques are required to determine the precise product mix that maximizes enterprise profitability under existing resource constraints.

To address these critical empirical and methodological gaps, the primary objective of this study is to analyze the operational profitability of cassava-based snack MSMEs in Gedong Tataan District, Pesawaran Regency, and to formulate a constrained Linear Programming optimization model to establish the profit-maximizing product combination. In addition to determining the optimal primal solution, this research evaluates dual solutions (shadow prices) and performs sensitivity analysis (right-hand side capacity limits and objective function coefficient ranges) across key operational resource constraints. Evaluating shadow prices provides valuable economic insights into the marginal value of expanding specific bottleneck resources—such as slicing capacity, labor hours, or capital availability—thereby offering actionable, data-driven managerial recommendations for scaling micro-enterprises. Ultimately, this study contributes to the applied agribusiness and operations management literature by providing a replicable quantitative decision-support framework that bridges the gap between empirical production dynamics in rural snack food enterprises and formal operations research in developing economies.

The primary objective of this research is to analyze the operational profitability of cassava-based snack MSMEs in Pesawaran Regency and to formulate an optimization model to establish the profit-maximizing product combination. Furthermore, this study evaluates shadow prices and sensitivity limits of resource constraints to provide actionable managerial recommendations for scaling MSMEs. This research contributes to the applied agribusiness literature by integrating actual product yield factors, manual labor constraints, and empirical contribution margins into an operational optimization framework for rural snack food enterprises.

While prior operations research literature has confirmed the utility of Linear Programming across small manufacturing firms, most existing studies focus on standardized manufacturing sectors with durable raw materials. A pronounced literature gap exists regarding the application of optimization models that explicitly incorporate the perishable physical properties of root crops, yield loss ratios during frying, and variable seasoning requirements in rural micro-enterprises. This study bridges this empirical and methodological gap by establishing a quantitative decision model calibrated specifically for the operational dynamics of cassava snack processing in agricultural developing regions.

LITERATURE REVIEW

Characteristics and Operational Challenges of MSMEs

MSMEs in the agro-food sector have distinct operational characteristics compared to the general manufacturing sector (Tikawati et al., 2026). Agri-food MSMEs depend heavily on raw materials that possess high perishability, seasonal quality variations, and price volatility tied to local agricultural supply chains (Latief et al., 2023). In the processing of cassava snacks, this supply vulnerability significantly increases operational complexity, particularly due to the high weight loss of raw materials (yield loss) during technical reduction stages such as peeling, washing, cutting, and frying (Suwandi et al., 2021). The physical vulnerability of cassava raw materials directly impacts small-scale producers; limitations in working capital affect the flexibility of raw material procurement, the availability of informal labor related to the uncertainty of work hour allocation (man-hours), and the use of small-scale manual equipment limiting processing capacity. The

causal interaction of these limitations leads to daily production decisions that rely solely on managerial intuition, making them vulnerable to cost inefficiencies and suboptimal capacity utilization.

Operational inefficiencies in MSME production decisions can be addressed through an optimization framework that aims to determine the product mix that maximizes total net profit, calculated as the difference between total revenue from each product variant and total variable operating costs. This optimization process is subject to two main resource constraints. The first is the effective raw material constraint, which accounts for technical shrinkage by applying a yield coefficient to the available raw materials, thereby determining the maximum production volume. The second comprises labor and operational capacity constraints, under which the availability of informal labor hours and the processing capacity of batch equipment limit the allocation of production time between product variants.

Through this analytical framework, the combination of products that maximizes profit is achieved rationally when the allocation of raw materials and working hours is prioritized on product variants that provide the largest contribution margin per unit of constrained resources consumed, rather than merely based on the largest production (Zulkarnain et al., 2024).

Production Planning Cassava-Based Snack

Production planning is the main foundation of manufacturing company management and supply chains, designed to systematically allocate limited production resources to meet fluctuating market demand while simultaneously minimizing operational costs or maximizing financial returns (Latief et al., 2023). MSMEs operating in the competitive snack food processing sector require proper production planning. So far, production planning has often been carried out through intuitive heuristics, subjective assessments, or uncalibrated historical routines rather than quantitative optimization tools (Pambreni et al., 2024). Dependence on decision-making based on empirical heuristics makes small-scale managers unable to systematically evaluate the economic trade-offs between competing product lines, assess marginal capacity costs, or optimize multi-product production schedules under rigid operational constraints.

MSMEs agri-food presents unique operational dynamics and structural complexities that significantly exacerbate production planning challenges compared to the traditional discrete manufacturing sector. First, the supply of primary agricultural inputs is subject to significant seasonal yield variations, climate volatility, and market price instability, which disrupts the availability of raw materials and burdens the company's working capital reserves. Second, primary agricultural commodities, such as fresh cassava tubers, exhibit very high spoilage rates and rapid physiological deterioration post-harvest, requiring immediate processing within a tight time window to prevent post-harvest material waste, product quality decline, and direct income loss. Third, micro-scale food processors operate under severe structural resource constraints, characterized by extremely limited working capital cash flow, limited batch processing equipment capacity, manual cutting throughput limits, and informal labor scheduling. Without a structured quantitative decision-making framework, agro-food MSMEs remain highly vulnerable to substantial financial losses due to suboptimal product mix configurations, unmet customer orders, production bottlenecks, and excessive inventory holding costs (Mekonnen et al., 2025; Mokhatla et al., 2026)

To reduce these structural operational inefficiencies, Linear Programming has long been recognized in operations research and management science as the primary mathematical optimization paradigm for resource allocation and production scheduling

(Ali, 2025; Kačmárý & Straka, 2026; Rao, 2023). Linear programming allows decision-makers to formulate constrained optimization models that identify the right product mix needed to maximize the linear objective function—such as net contribution margin or total company profit—subject to a system of linear equality and inequality constraints representing the availability of physical resources, technology transformation factors, and market demand limits.

In addition to determining the optimal primal product combination, linear programming provides critical analytical depth through dual solution analysis and parametric sensitivity testing. Dual values, or shadow prices, quantify the marginal economic value (imputed price) of relaxing certain binding resource constraints, such as acquiring additional working hours, expanding the volume of cooking oil, or increasing machine cutting capacity, thereby offering direct operational guidance for strategic capital allocation. Additionally, sensitivity analysis evaluates the stability and structural resilience of the optimal solution across the range of unit contribution margins and the availability of resources allowed without altering the optimal basis. Contemporary empirical research in agricultural supply chains confirms that integrating deterministic Linear Programming models into the processing workflows of smallholder farmers significantly enhances overall capacity utilization, reduces post-harvest food loss, and establishes data-driven benchmarks to expand rural micro-enterprises.

Linear Programming

Operations research aims to describe, understand, and predict or forecast the behavior of various complex systems in human life and equipment (Pinto et al., 2024). The main goal of operations research is to provide accurate information as a basis for MSME decision-making (Handayani, 2022). Linear Programming is a mathematical optimization technique used to allocate limited resources among competing activities to achieve the best outcome (Nitiasya & Harahap, 2021).

Cassava-based snacks have long been known in the community with various types of food variations. The increase in added value of cassava-based snacks has a positive impact on MSMEs, namely an increase in business income. Food processing businesses are capable of providing income equality for MSMEs (Pambreni et al., 2024).

The application of Linear Programming in agribusiness processing has been validated across diverse empirical settings (Latief et al., 2023; Pratama & Salam, 2025). Research by Latief et al. (2023) demonstrated that applying the Simplex algorithm to small-scale food enterprises increased daily profit accumulation by 18.5% through systematic restructuring of labor hour allocation. Luenberger and Ye (2008) emphasized that Linear Programming sensitivity analysis provides precise tolerance ranges for resource constraints and unit margins without altering the optimal basis. Recent investigations by Zulkarnain et al. (2024) further proved that Linear Programming models effectively identify labor bottlenecks in tuber slicing and frying operations. This study builds upon existing Linear Programming applications by establishing an empirical decision model specifically calibrated for cassava snack processing in Pesawaran Regency.

Although previous literature has confirmed the effectiveness of Linear Programming in various types of SMEs, the majority of studies have focused on commodities with high durability or standardized manufacturing processes (Zubo et al., 2017). There is still a literature gap in the application of Linear Programming that specifically considers the operational dynamics of cassava snack SMEs, the weight loss during frying, and the variation in seasoning usage for each product variant. This research fills that gap by developing an Linear Programming model that integrates real raw material factors, installed frying machine capacity, and upper capital constraints.

RESEARCH METHOD

Study area, Population, and Sampling Procedure

This research was conducted across the cassava snack manufacturing cluster in Karang Anyar Village, Gedong Tataan District, Pesawaran Regency, Lampung Province. The study location was selected purposively because Gedong Tataan District represents the primary center of cassava production and snack processing MSMEs in Pesawaran Regency. The target population comprised all active MSME owners producing cassava-based snacks in the region. The study involved 30 MSME owners producing cassava-based snacks in the study area. The respondents were selected using a simple random sampling procedure (Hair et al., 2023). Data were collected through structured interviews, questionnaires, and direct observations of production inputs and outputs. The collected information was used to estimate average resource requirements, production yields, variable costs, and contribution margins for the three product variants. Data were gathered through structured interviews, questionnaires, and direct observational field measurements of production batch inputs and outputs. The selection of respondents was carried out using a simple random sampling technique. This research uses a survey method, where data are collected from a sample of the population to represent the entire population (Sugiyono, 2018). The data used come from interviews and direct observations of the production activities of cassava-based snacks.

Primary empirical data collected from the 30 sampled MSMEs were systematically aggregated to calculate average input-output coefficients and net profit margins per production cycle. Production inputs were categorized into raw cassava tuber requirements (kg), direct labor hours (person-days, where 1 man-day equals 8 working person-hours), variable costs (including cassava tubers, cooking oil, seasonings, firewood/LPG, and packaging), and product selling prices. The net unit profit (contribution margin, Ci) for each snack product was calculated by subtracting total unit variable costs from the uniform market selling price of IDR 13,000 per kg across all product variants.

The problem was then formulated using the linear programming method and solved with the simplex method using the POM-QM for Windows 4.0 software. Linear Programming is used as a quantitative mathematical analysis to explain and assist in social research and decision-making. Linear Programming is a mathematical analysis technique aimed at optimizing production constrained by certain resource limitations for an optimal solution (Handayani, 2022). The steps of analysis to determine the optimization of snack food production using the Linear Programming equation model can be explained by identifying the problem through the calculation of total production costs, including fixed and variable costs.

Linear Programming Model Specification

The production optimization problem is formulated as a linear programming model and solved using the simplex method in POM-QM for Windows version 4.0. The decision variables represent the production quantities, measured in kilograms per production cycle, of three snack variants: kelanting (X_1), cassava chips (X_2), and mangle crackers (X_3). The objective is to maximize total net contribution (Z), expressed in Indonesian rupiah (IDR) per production cycle, by determining the optimal combination of products subject to the available resource constraints.

The objective function is Maximize $Z = 5,340X_1 + 5,750X_2 + 4,800X_3$, where the coefficients represent the net contribution margin in IDR per kilogram of kelanting, cassava chips, and mangle crackers, respectively. The raw-material constraint is $2.70X_1$

+ $2.33X_2 + 3.33X_3 \leq 300$, where the coefficients represent the kilograms of raw cassava required per kilogram of each product, and 300 kg is the available raw cassava per production cycle. The labor constraint is $0.19X_1 + 0.16X_2 + 0.23X_3 \leq 21$, where the coefficients represent man-days required per kilogram of each product and 21 man-days is the available labor capacity per production cycle. The non-negativity conditions X_1, X_2 , and $X_3 \geq 0$ ensure that production quantities cannot be negative.

The objective function is expressed as Maximize $Z = a_1X_1 + a_2X_2 + a_3X_3$, where a_1 , a_2 , and a_3 represent the net profit per kilogram of kelanting, cassava chips, and mangle crackers, respectively. The model incorporates two resource constraints: raw material availability and labor capacity. The raw material constraint is formulated as $c_{11}X_1 + c_{12}X_2 + c_{13}X_3 \leq b_1$, where c_{11} , c_{12} , and c_{13} represent the raw material requirements per kilogram of each product, and b_1 denotes the total available raw materials per production cycle. The labor constraint is expressed as $c_{21}X_1 + c_{22}X_2 + c_{23}X_3 \leq b_2$, where c_{21} , c_{22} , and c_{23} represent the labor requirements for each product, and b_2 indicates the total available labor capacity per production cycle. These constraints ensure that the production quantities remain within the available resource limits. In addition, the non-negativity conditions, $X_1 \geq 0$, $X_2 \geq 0$, and $X_3 \geq 0$, ensure that the production quantities cannot take negative values.

The formulated model is subsequently processed using POM-QM for Windows version 4.0 to identify the optimal production combination and the maximum achievable net profit under the specified resource constraints.

RESULTS

An empirical survey across the 30 cassava snack MSMEs in Gedong Tataan District reveals that business operations produce three primary processed snack variants: kelanting (X_1), cassava chips (X_2), and mangle crackers (X_3). Under conventional operations, MSMEs process an average batch capacity of 300 kg of raw cassava using 21 man-days of manual labor per cycle. Although most respondents possess the technical capability to manufacture all three snack types, capital limitations and labor bottlenecks cause individual MSMEs to specialize in single-product batches during each operational run.

Table 1 describes the empirical production factors, unit resource input requirements, unit profit margins, and total resource capacities derived from the sampled MSMEs. All technical coefficients and numerical values are standardized using period decimal notation.

Table 1. Production Factors, Technical Coefficient, and Resource Capacities

Product Variant	Raw Material Coefficient	Labor Coefficient	Unit Profit (IDR/kg)
Kelanting (X_1)	2.70	0.19	5,340
Cassava chip (X_2)	2.33	0.16	5,750
Mangle (X_3)	3.33	0.23	4,800
Resources capacity (b_i)	300	21	

As presented in Table 1, the unit contribution margin is set based on a uniform market price of IDR 13,000 per kg for all snack variants. The variable cost per unit is IDR 7,660 per kg for kelanting (providing a net profit C_i = IDR 5,340 per kg), IDR 7,250 per kg for cassava chips (providing C_i = IDR 5,750 per kg), and IDR 8,200 per kg for mangle crackers (providing C_i = IDR 4,800 per kg).

The raw material yield coefficient reflects the empirical processing results due to weight loss and shrinkage during the frying process. The production conversion coefficient values for kelanting, cassava chips, and mangle crackers are 2.70, 2.33, and 3.33, respectively. The availability of the main raw material (cassava) becomes a production constraint limited to 300 kg. If the production strategy is fully allocated (single product specialization), the average output capacity that can be produced is 110 kg for kelanting, 130 kg for cassava chips, and 90 kg for mangle crackers per cycle. The labor constraint is limited to 21 man-days, so the labor conversion coefficients for producing kelanting, chips, and mangle crackers are 0.19, 0.16, and 0.23, respectively. The non-negativity condition ($X_i \geq 0$) ensures mathematical precision and is fully consistent with non-basic variables taking a value of zero in the optimal solution.

Historical production data indicate that cassava snack production is subject to constraints arising from raw material availability and labor capacity. Accordingly, a linear programming model was formulated to maximize total net profit (Z), expressed in Indonesian rupiah (IDR) per production cycle. The objective function is Maximize $Z = 5,340X_1 + 5,750X_2 + 4,800X_3$, where X_1 , X_2 , and X_3 represent the production quantities, in kilograms, of kelanting, cassava chips, and mangle crackers, respectively. The model incorporates a raw material constraint of $2.70X_1 + 2.33X_2 + 3.33X_3 \leq 300.00$, representing the available raw cassava capacity, and a labor constraint of $0.19X_1 + 0.16X_2 + 0.23X_3 \leq 21.00$, representing the available labor capacity in man-days per production cycle. The non-negativity conditions $X_1, X_2, X_3 \geq 0$ ensure that production quantities cannot be negative.

The optimization model is solved using POM-QM for Windows version 4.0. The empirical results of the linear programming analysis are presented in Tables 2, 3, and 4, which provide standardized, editable representations of the software output for systematic interpretation and reporting.

Table 2. Optimal Linear Programming Product Mix Solution and Reduced Costs

Variable	Snack Product Variant	Optimal Output (kg/cycle)	Unit Profit (IDR/kg)	Reduced Cost (IDR/kg)
X1	Kelanting	0.000	5,340	1,323
X2	Cassava Chips	128.76	5,750	0,000
X3	Mangle Crackers	0.000	4,800	3,417

Table 3. Constraint Resource Utilization, Slack/Surplus, and Shadow Prices

Constraint	Resource Type	Capacity (bi)	Actual Usage	Slack / Surplus	Shadow Price (IDR per unit of resource)
C1	Raw Cassava	300.00 kg	300.00 kg	0.00 kg	2,467.81
C2	Labor Capacity	21.00 man-days	20.60 man-days	0.40 man-days	0.00

Table 4. Objective Coefficient Ranges and Right-Hand Side (RHS) Sensitivity Ranges

Parameter	Description	Current Value	Lower Limit	Upper Limit	Allowable Range Status
C(X1)	Profit Kelanting	5,340	No limit	6,663	Increase $\leq 1,323$
C(X2)	Profit Chips	5,750	4,608	Infinity	Decrease $\leq 1,142$

C(X3)	Profit Mangle	4,800	No limit	8,217	Increase $\leq$ 3,417
RHS(C1)	Raw Material	300.00 kg	0.00 kg	305.81	Increase $\leq$ 5.81
RHS(C2)	Labor Capacity	21.00 man-days	20.60 man-days	Infinity	Decrease $\leq$ 0.40

The empirical findings obtained from the POM-QM v4.0 optimization modeling establish that the optimal operational strategy for cassava snack SMEs is a single product specialization strategy that focuses exclusively on cassava chips (X2). Under the profit-maximizing solution, the company produces 128.76 kg of cassava chips per cycle, generating a maximum total net profit of IDR 740,343 per production cycle. The resulting objective function is expressed as Maximize $Z = 5,750 X_2$. The production of secondary products such as kelanting ($X_1 = 0.00$ kg) and mangle crackers ($X_3 = 0.00$ kg) is halted under the current cost structure.

The resource utilization results indicate that raw material availability (C1) is binding at the reported optimal solution. Producing approximately 128.76 kg of cassava chips requires approximately 300.00 kg of raw cassava, leaving no unused raw-material capacity. Based on the stated contribution margin of IDR 5,750 per kilogram of cassava chips and the raw-material requirement of 2.33 kg per kilogram of chips, the implied shadow price is approximately IDR 2,467.81 per additional kilogram of raw cassava, within the range in which the current optimal basis remains valid. This value represents the estimated marginal increase in the objective value for an additional kilogram of raw cassava, assuming the model coefficients and units are correct. In contrast, labor capacity (C2) is non-binding. Producing approximately 128.76 kg of cassava chips requires approximately 20.60 man-days, leaving 0.40 man-days unused from the available 21.00 man-days. The zero labor shadow price indicates that additional labor capacity alone would not increase the maximum objective value under the current model.

The sensitivity analysis of the objective function coefficients confirms high stability for cassava chip production. The unit profit coefficient for cassava chips ($C_2 = 5,750$) has a lower bound of IDR 4,608 per kg and no upper bound (infinity). This indicates that cassava chips remain a prioritized product as long as the contribution margin per unit does not fall below IDR 4,608 per kg. For non-basic variables, the reduced costs are 1,323 for kelanting (X_1) and 3,417 for mangle crackers (X_3). These reduced costs represent the minimum unit profit increase required for kelanting (to reach IDR 6,663 per kg) and mangle crackers (to reach IDR 8,217 per kg) to enter the optimal basis. The reported right-hand-side sensitivity range for raw-material availability extends from 0.00 kg to 305.81 kg, while the current capacity is 300.00 kg. Thus, the reported allowable increase is 5.81 kg before the current optimal basis may change. These values are interpreted within the stated linear programming model and should not be taken as evidence that actual production conditions remain unchanged beyond the reported range.

DISCUSSION

Optimal Product Combination and Managerial Rationale

The empirical optimization results demonstrate that cassava snack MSMEs in Pesawaran Regency achieve maximum business profitability ($Z^* = \text{IDR } 740,343$ per cycle) by specializing exclusively in cassava chip production ($X_2 = 128.76$ kg), while halting secondary production of kelanting ($X_1 = 0.00$) and mangle crackers ($X_3 = 0.00$). This finding demonstrates how linear programming can identify a profit-maximizing

product mix when raw-material availability and labor capacity are limited, with raw-material availability emerging as the binding constraint under the stated model. In small-scale food manufacturing, operational research algorithms systematically allocate bottleneck resources toward the product offering the highest unit contribution margin relative to bottleneck resource consumption (Food and Agriculture Organization of the United Nations & OECD [FAO & OECD], 2023). Cassava chips generate the highest net contribution margin (IDR 5,750 per kg) while requiring the lowest unit labor input (0.160 man-days per kg), making it the mathematically superior product.

This single-product specialization finding aligns with previous Linear Programming agribusiness studies conducted by Latief et al. (2023) and Handayani (2022). Handayani (2022) established that under resource-constrained conditions, optimal returns are achieved when producers concentrate resources on the single commodity offering the highest net return rather than spreading limited capital across multiple low-margin crops. Similarly, Latief et al. (2023) demonstrated that eliminating low-margin cereal lines in food processing SMEs increased total profit accumulation by 18.5% by reallocating labor hours toward high-margin specialization.

Sensitivity Analysis of Contribution Margins and Reduced Cost Interpretation

Sensitivity analysis of objective function coefficients provides essential guidelines for product pricing and cost management. The allowable profit range for cassava chips spans from a lower bound of IDR 4,608 per kg to infinity. This reported interval indicates that cassava-chip specialization remains optimal under changes in its contribution-margin coefficient within the stated sensitivity range, assuming the other model parameters remain unchanged.

For non-basic product lines kelanting (X1) and mangle crackers (X3), reduced costs equal 1,323 and 3,417. In Linear Programming theory, reduced cost represents the penalty in total objective value incurred if one unit of a non-basic variable is forcibly produced, or conversely, the minimum increase in unit contribution margin required for that product to become economically competitive (Luenberger & Ye, 2008). Therefore, kelanting becomes viable only if its unit contribution margin increases by IDR 1,323 (rising from IDR 5,340 to IDR 6,663 per kg), whereas mangle crackers require a margin increase of IDR 3,417 (rising from IDR 4,800 to IDR 8,217 per kg).

It is critical to note that if managerial interventions elevate contribution margins beyond these upper sensitivity thresholds (IDR 6,663 for X1 and IDR 8,217 for X3), the current optimal basis will change, prompting the Simplex algorithm to bring kelanting or mangle crackers into a multi-product optimal mix. As emphasized by Nitisya and Harahap (2021), MSME managers do not need to permanently abandon secondary product lines; instead, they can apply process engineering (such as reducing seasoning waste or improving slicing efficiency) or premium price positioning to elevate unit contribution margins above sensitivity thresholds.

Capacity Sensitivity and Shadow Price Valuation of Binding Constraints

The resource utilization results indicate that raw material availability, rather than labor capacity, is the binding constraint in the reported optimal solution. Producing approximately 128.76 kg of cassava chips uses the available 300.00 kg of raw cassava, while labor utilization is approximately 20.60 man-days out of the available 21.00 man-days. The remaining labor capacity is approximately 0.40 man-days, and its reported shadow price is zero. Based on the stated model, increasing labor capacity alone would not improve the maximum objective value while raw-material availability remains binding. Managerial efforts should therefore prioritize evaluating raw-material availability, procurement costs, and the feasibility of securing additional cassava at a cost that

supports higher profitability. Managers should also maintain sufficient labor and processing capacity to accommodate any feasible increase in production.

For orderly production management, the stock of fresh cassava can be increased in quantity but should still be adjusted to the space limitations that cause storage costs to increase and increase the risk of spoilage (Abdullah et al., 2016). Therefore, MSME managers must shift from speculative raw material purchases to measured inventory management.

CONCLUSION

This study developed a linear programming model to identify the profit-maximizing product mix for cassava-based snack MSMEs in Pesawaran Regency. Under the stated resource constraints and contribution margins, the reported optimal solution allocates production exclusively to cassava chips (X2), with an output of approximately 128.76 kg per production cycle and a reported maximum profit of approximately IDR 740,343. The solution uses the available 300.00 kg of raw cassava and approximately 20.60 man-days of labor from a total capacity of 21.00 man-days. Thus, raw material availability is the binding constraint, while labor capacity has approximately 0.40 man-days of unused capacity. The findings illustrate how linear programming can support production decisions by identifying an optimal product mix and quantifying resource utilization under specified operating conditions. The interpretation of the shadow price and sensitivity ranges should follow the verified optimization output and the units used in the model.

Based on the findings, MSME managers should prioritize evaluating raw material availability, procurement costs, and the feasibility of obtaining additional cassava at a cost that supports higher profitability. Because raw material is the binding constraint in the reported model, increasing labor capacity alone is not expected to raise the maximum profit under the current conditions. Managers should also maintain sufficient labor and processing capacity to accommodate any feasible increase in production. For secondary product lines, particularly kelanting and mangle crackers, process improvements or product differentiation may be considered to increase their contribution margins. Any decision to expand capacity or change the product mix should be assessed against the relevant resource constraints, costs, and verified sensitivity ranges.

Complete specialization in cassava chips represents the reported short-term profit-maximizing solution under the specified contribution margins and resource constraints. However, its practical implementation should also consider customer demand, market acceptance, and the potential effects of discontinuing other product lines. Regional government agencies and financial institutions may support MSMEs through appropriate financing and technical assistance for post-harvest processing improvements, provided that any investment is evaluated against its costs, expected benefits, and the enterprise's actual production constraints.

LIMITATION

Despite providing precise operational insights, this study is subject to several methodological limitations, primarily stemming from the deterministic nature of linear programming, which assumes static parameters and constant returns to scale, thereby overlooking seasonal price volatility, raw material perishability, and market demand fluctuations inherent to cassava processing. Furthermore, although the reported solution identifies cassava-chip specialization as the profit-maximizing product mix under the specified resource constraints and contribution margins, its practical implementation may involve commercial risks because discontinuing kelanting and mangle crackers could affect customer preferences and existing distribution relationships.

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DECLARATION OF CONFLICTING INTERESTS

The authors have declared no potential conflicts of interest concerning the study, authorship, and/or publication of this article.

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