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Optimization of Catfish (*Clarias* sp.) Feed Formulation Using Linear Programming to Minimize Production Costs

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Abstract

Feed costs constitute the largest component in aquaculture operations, accounting for over 60% of total production costs. This presents a major operational constraint for micro to medium-scale catfish (*Clarias sp.*) farmers amidst high fluctuations in market raw material prices. This study aims to determine the most optimal catfish feed formulation by minimizing costs to the lowest point, while strictly meeting the national standard nutritional thresholds based on SNI 01-4087-2006. The quantitative method utilized is the Operations Research discipline through a Linear Programming approach assisted by Microsoft Excel Solver computational software. Experimental simulations were conducted using estimated market price databases for the 2025/2026 period across four primary local raw material candidates: fish meal, soybean meal, rice bran, and corn meal. The mathematical model was executed using the Simplex algorithm to find the feasible solution point. Computational optimization results demonstrate that the best formulation composition to produce 100 kg of feed consists of 37.65 kg of fish meal, 60.00 kg of rice bran, and 2.35 kg of corn meal, without utilizing soybean meal. This formulation is validated to produce feed with precise proportions of 30.00% protein, 11.66% fat, and 8.00% crude fiber, with a total independent production cost of IDR 10,453 per kilogram. Compared to the average commercial manufactured feed price reaching IDR 15,000 per kilogram, this optimization model significantly offers a potential production cost reduction efficiency of 30.31%. This research empirically proves that the application of Linear Programming mathematical modeling can be implemented as a precise decision support system for farmers to achieve high-quality feed independence.

Keywords: Linear Programming, Optimization, Fish Feed, Cost Efficiency, Operations Research.

INTRODUCTION

Catfish (Clarias sp.) cultivation is one of the leading sectors in Indonesia's freshwater aquaculture, offering significant economic prospects. The increasing market demand for catfish compels cultivators to continuously enhance their production capacity. However, a persistent major constraint faced by cultivators is the high operational cost. According to previous studies, the majority of required costs in aquaculture are allocated to feed expenses, where more than 60% to 70% (Safitri et al., 2020), and potentially up to 75% due to reliance on imported raw materials (Muntafiah, 2020), of the total production costs are concentrated solely on fulfilling animal feed requirements. Particularly in regions with continuously growing populations of residents and cultivators, such as the Madura region (Pamekasan, 2020), the dynamics and fluctuations of feed raw material prices in the 2025/2026 period demand that cultivators possess an independent strategy for producing their own formulated feed to maintain profit margin stability. Quality feed must not only be affordable but is also required to contain balanced macronutrients, especially protein as the primary agent for fish growth. In the downstream sector, this catfish commodity has also proven to be highly potential for development into diversified processed products with high nutritional and economic value for the community (Putra et al., 2024).

Conventionally, manual feed formulation (trial-and-error) often encounters difficulties in determining the exact mathematical proportions to ensure raw material prices remain affordable while the nutritional content does not violate the Indonesian National Standard (SNI) thresholds. Conventional methods are prone to producing formulations that are either excessively dense with expensive nutrients (causing costs to inflate) or, conversely, deficient in essential nutrients (resulting in stunted fish growth). Regarding the resolution of this feed cost optimization problem, mathematical approaches from the Operations Research discipline, specifically Linear Programming (LP), have proven effective across various industrial and aquaculture sectors.

Therefore, this study aims to apply a Linear Programming model using the Simplex algorithm to formulate the most cost-efficient composition of catfish feed based on fish meal, soybeans, rice bran, and corn while strictly adhering to the national nutritional standards (SNI). The results of this study are expected not only to serve as a theoretical reference in the field of applied computer science but also to be practically implemented as a computational decision support system for cultivators to achieve budget efficiency and independence in high-quality feed production.

LITERATURE REVIEW

A literature review indicates that the Linear Programming method is highly reliable in addressing problems of cost minimization and the allocation of limited resources. Previous studies have demonstrated that the Linear Programming method can be utilized precisely for the nutritional optimization of poultry rations to obtain an ideal composition at the lowest feed cost without compromising the quality of essential nutrients (Azhari et al., 2025). In line with this, the fundamental theory of Operations Research asserts that the simplex method in Linear Programming is highly capable of solving resource allocation problems involving more than two decision variables (Febriansah & Prasojo, 2018). More specifically, at the scale of local cultivators, this method has proven effective in optimizing the production combination of catfish and Pangasius aquaculture to achieve maximum profit margins amidst land and resource constraints (Mujiarto et al., 2015).

The reliability of this optimization algorithm has also been broadly proven within the scope of freshwater aquaculture commodities through various computational model variations. The integration of computational models in the design of artificial feed was developed utilizing the Fuzzy Linear Programming method to optimize 8 types of artificial feed raw materials with nutritional constraints including protein, carbohydrates, fat, and fiber, where the study results successfully reduced production costs by 2.50% compared to a crisp linear approach (Devani, 2019). On the other hand, optimization using a heuristic artificial intelligence approach was conducted by implementing the Multi-Objective Genetic Algorithm (MOGA) to determine the feed composition for African catfish (lele dumbo) and Siamese catfish (patin siam). The results demonstrated a 100% success rate in fulfilling nutritional requirements and achieved a cost efficiency of 46.5% (Wardhani et al., 2011). In the field of automation, recent research integrates linear regression algorithms with the Internet of Things (IoT) to automate the scheduling and mechanical accuracy of catfish feeding (Juwita, Intan ; Efan, Efan ; Febriansyah, 2023). Not limited to the mixing of raw materials in the upstream sector, linear programming-based optimization interventions have even been effectively applied to boost production profits in the downstream capacity of home-based food industries producing catfish-based traditional crackers (kerupuk and kemplang) (Romadhon et al., 2021), along with improving the efficiency of their distribution costs (Yusuf & Hikmayani, 2017) Specifically in the context of direct catfish farming, linear programming was implemented to optimize the mixing of feed based on tofu dregs and rice bran, which proved successful in providing a computationally efficient cost formulation (Lahur & Lamabelawa, 2018), and is capable of serving as an adaptive decision support system for MSMEs (Rachmatika et al., 2022)

Although a variety of computational methods have been widely used in previous research, prior studies still possess specific limitations. For instance, research on catfish feed formulation using alternative ingredients (Lahur & Lamabelawa, 2018) still focuses on very simple mixtures of raw materials. Previous computational modeling emphasized constraints on fuzzy sets (Devani, 2019), whereas genetic experiments (Wardhani et al., 2011)relied on random searches where the feasibility value of the solution fluctuates depending on generation parameters. Consequently, these models have not been strictly and deterministically aligned with the exact parameters of national quality standards. To date, there remains a significant research gap concerning the mathematical modeling of catfish feed formulation that is strictly bound by the national nutritional quality standard parameters, namely SNI 01-4087-2006 (Badan Standardisasi Nasional, 2006), while simultaneously integrating economic price fluctuation simulations of the four main local raw material components at the latest distributor level. The absence of such a standardized, crisp linear computational model makes it difficult for independent cultivators to formulate feed proportions that are both nutritionally valid and economically optimal.

METHOD

A. Research Design

This research is an applied quantitative study utilizing modeling and simulation methods from the Operations Research discipline. The primary approach employed is Linear Programming with the Simplex algorithm to solve a cost minimization problem bound by various nutritional constraints.

he population in this study encompasses all alternative commercial and local fish feed raw materials. The sample used is focused on four main raw materials (fish meal, soybean meal, rice bran, and corn meal) based on estimated market price data. The instrument utilized in this research is computational software (Solver system) to obtain precise optimization results.

B. Research Procedures

The systematic stages in this research can be seen visually in Figure 1.

Fig. 1 Stages of Operations Research

Based on the aforementioned cycle, the research framework begins with identifying the problem of high commercial feed prices, followed by data collection on local raw materials alongside the SNI nutritional quality standard parameters. Once the database is compiled, the process proceeds to the construction of a Linear Programming model, which is executed through a Simplex algorithm simulation to yield an analytical output that is highly optimal both nutritionally and financially.

Data collection in this model utilizes secondary data, specifically the simulated market prices of raw materials at the distributor level for the 2025/2026 period. The nutritional requirements and constraints refer strictly to the national quality standard for catfish feed, SNI 01-4087-2006 (Badan Standardisasi Nasional, 2006). The nutritional content percentages of each raw material, along with their estimated prices, are presented in Table 1.

Table 1 Nutritional Content and Estimated Prices of Raw Materials

No	Type Of Raw Material	Protein (%)	Fat (%)	Fiber (%)	Price (Rp/Kg)
1	Fish Meal (x_1)	60	10	2	18.500
2	Soybean Flour (x_2)	40	5	6	14.500
3	Rice bran (x_3)	12	13	12	5.500
4	Corn Flour (x_4)	9	4	2	8.000

The mathematical model architecture is designed to produce 100 kg of catfish feed. The concept of the flow of raw material allocation into the feed formulation process is ilustrated in the conceptual model in Figure 2.

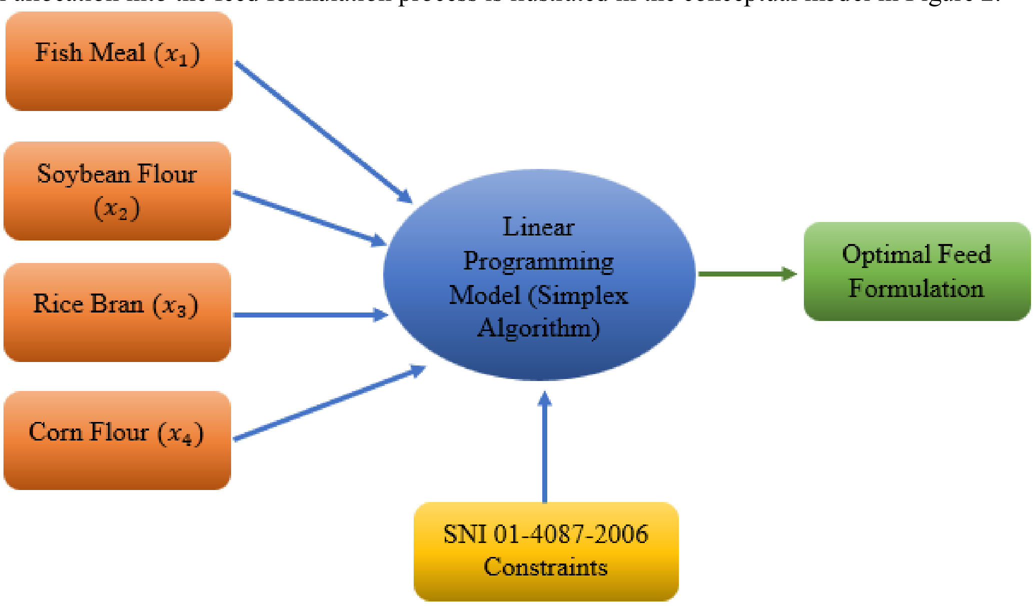

Fig. 2 Conceptual Model of Feed Raw Material Transportation

The model maps four candidate raw material sources (fish meal, soybean meal, rice bran, and corn meal) along with their respective specific macronutrient contents and estimated prices per kilogram. All of these raw material components will enter a formulation process engine that will computationally select and distribute the optimal proportions to yield a single output of a 100 kg batch of catfish feed mixture. This feed output is strictly bound by three absolute prerequisite parameters of the SNI 01-4087-2006, namely the threshold limits for protein, fat, and fiber.

The decision variables defined in this model are: x_1 = amount of Fish Meal (kg), x_2 = amount of Soybean Meal (kg), x_3 = amount of Rice Bran (kg), x_4 = amount of Corn Meal (kg).

Objective Function (Minimize Production Cost):

$$Z = 18.500x_1 + 14.500x_2 + 5.500x_3 + 8.000x_4 \qquad (1)$$

Constraint Functions are formulated based on the total capacity and the SNI 01-4087-2006 parameters as follows:

Total Capacity:

$$x_1 + x_2 + x_3 + x_4 = 100 \quad (2)$$

Protein Constraint (Minimum 30% of 100kg):

$$0{,}60x_1 + 0{,}40x_2 + 0{,}12x_3 + 0{,}09x_4 \geq 30 \quad (3)$$

Fat Constraint (Minimum 5% to 15% of 100kg):

$$0{,}10x_1 + 0{,}05x_2 + 0{,}13x_3 + 0{,}04x_4 \geq 5 \quad (4)$$

$$0{,}10\,x_1 + 0{,}05\,x_2 + 0{,}13\,x_3 + 0{,}04\,x_4 \leq 15 \quad (5)$$

Fiber Constraint (Maximum 8% of 100kg):

$$0{,}02x_1 + 0{,}06x_2 + 0{,}12x_3 + 0{,}02x_4 \leq 8 \quad (6)$$

Non-negativity Constraint (Variables cannot be negative):

$$x_1, x_2, x_3, x_4 \geq 0 \quad (7)$$

To find the optimal solution of the mathematical model formulated in Equations (1) to (7), this study implements a simulation scenario using the Solver Add-in in Microsoft Excel spreadsheet software. The computational scenario is designed through the following procedural stages to ensure replicability:

1) Data Matrix Construction: The first step is to design a matrix interface on the computational worksheet that separates parameter data (nutritional content and prices), decision variable cells (weight allocation of each raw material), and the target cell (total cost).
2) Computational Equation Formulation: Unlike manual calculations, the objective function and constraint functions in the system are converted using the computational syntax formula $= SUMPRODUCT(array1, array2)$. This function works by multiplying the decision variable cell range (ingredient weights) by the parameter cell range (prices or nutritional percentages), then automatically summing them to obtain the total cost, total protein, total fat, and total fiber values in real-time as each iteration runs. To ensure the accuracy of the total load summation (Total Weight), the computational function $= SUM()$ is used.
3) Solver Engine Parameter Configuration: Once the cell relations are defined by formulas, the algorithm parameters are inputted into the Solver interface window with the following specifications:
   - *Set Objective*: Directed to the 'Total Cost' formula cell representing the Z function.
   - *To*: The Min (Minimization) option is selected, as the primary objective is to determine the feed formulation with the lowest price (Cost minimization).
   - *By Changing Variable Cells*: Directed to the decision variable cell range (x_1, x_2, x_3, x_4), which is initially set to zero.
   - *Subject to the Constraints*: The bounding mathematical rules (Equations 2 to 6) are inputted sequentially (e.g., Total Protein ≥ 30; Total Fat ≥ 5 and ≤ 15, etc.).
   - *Make Unconstrained Variables Non-Negative*: This parameter is activated to fulfill the absolute prerequisite of Equation (7), ensuring the computational engine does not produce negative raw material outputs.
   - *Solving Method*: The Simplex LP (Linear Programming) method is selected, which is specifically designed to solve linear models with a smooth and continuous structure.

The benchmark for the success of this model is finding the minimum value of the objective function (Z) represented in Rupiah (IDR) per kilogram, in which all nutritional constraint requirements are deemed feasible or fulfilled. If the computational results display the status "Solver found a solution," then the formulation scenario is declared mathematically successful.

RESULT

Based on the variable data, objective function, and mathematical constraint functions formulated in the methodology stage, the simulation was conducted using the Simplex algorithm utilizing decision support software (Solver Add-in in Microsoft Excel). The first step in executing the simulation is inputting the cost parameters and nutritional constraints into the software interface, as shown in Figure 3.

	A	B	C	D	E	F	G	H
1	RAW MATERIAL DATA							
2		Fish Meal	Soybean Meal	Rice Bran	Corn Meal	Sign	SNI Standard	Total
3	Price(IDR/Kg)	18500	14500	5500	8000			0
4	Protein	0,60	0,40	0,12	0,09	≥	30	0
5	Min Fat	0,10	0,05	0,13	0,04	≥	5	0
6	Max Fat	0,10	0,05	0,13	0,04	≤	15	0
7	Fiber	0,02	0,06	0,12	0,02	≤	8	0
8	Total Weight	1	1	1	1	=	100	0
9								
10	Formulation Result(Kg)	0	0	0	0			
11								

Fig. 3 Input of Cost Parameters and Nutritional Constraints into the Computational System

Once the cell structures are connected via formulas, the execution step of the Simplex algorithm is configured through the Solver Parameters settings window. At this stage, the Objective Function cell (Total Cost) is set to the minimum value (Min). The determination of iteration limits is conducted by inputting all SNI constraints (Protein ≥ 30, $Fat \geq 5$ and ≤ 15, Fiber ≤ 8, and Total Weight $= 100$) into the Subject to the Constraints column. The specific details of the parameter input into the Solver engine are shown in Figure 4.

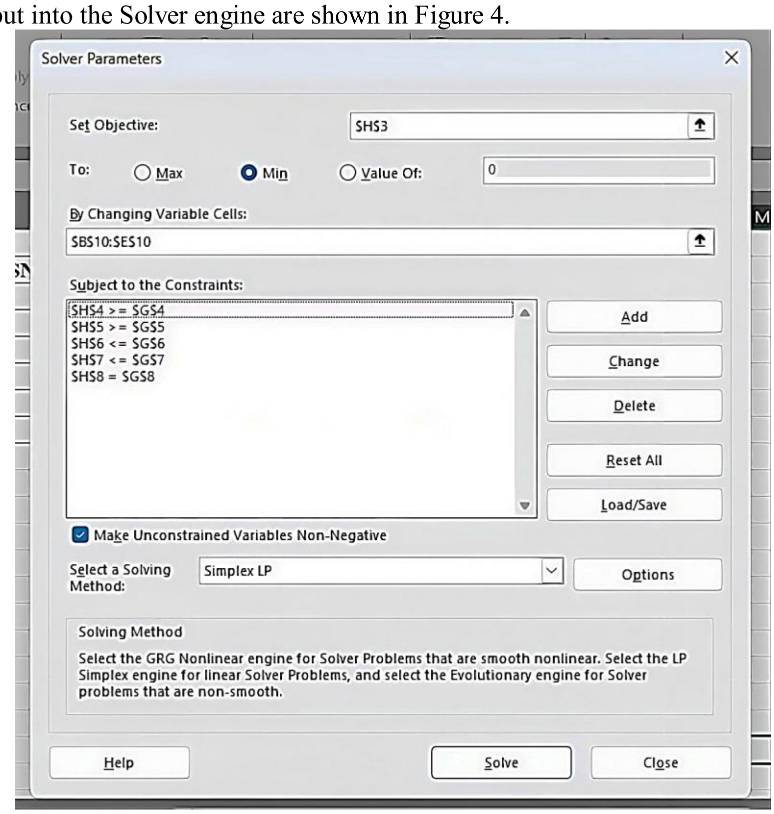

Fig. 4 Configuration Details of the Solver Parameters Dialog Box and Constraint Inputs

Once all mathematical parameters have been validated within the system, the execution process (Solve) is initiated. The system automatically performs Simplex computational iterations to determine the most precise allocation combination. The resulting matrix output upon successful optimization (indicated by the "Solver found a solution" notification) is comprehensively represented in Figure 5.

	A	B	C	D	E	F	G	H
1	RAW MATERIAL DATA							
2		Fish Meal	Soybean Meal	Rice Bran	Corn Meal	Sign	SNI Standard	Total
3	Price(IDR/Kg)	18500	14500	5500	8000			1045294,118
4	Protein	0,60	0,40	0,12	0,09	≥	30	30
5	Min Fat	0,10	0,05	0,13	0,04	≥	5	11,65882353
6	Max Fat	0,10	0,05	0,13	0,04	≤	15	11,65882353
7	Fiber	0,02	0,06	0,12	0,02	≤	8	8
8	Total Weight	1	1	1	1	=	100	100
9								
10	Formulation Result(Kg)	37,64705882	0	60	2,352941176			
11								

Fig. 5 Simulation Results of the Simplex Algorithm Computation

Based on the optimization simulation results using the Simplex algorithm shown in Figure 5, the most optimal raw material combination to produce 100 kg of catfish feed was obtained. The composition consists of 37.65 kg of Fish Meal, 60.00 kg of Rice Bran, and 2.35 kg of Corn Meal, without allocating any Soybean Meal usage (0 kg). Through this computational formulation, the minimum total production cost required is IDR 1,045,294 per 100 kg, or equivalent to IDR 10,453 per kilogram of feed. This formulation is proven to be mathematically feasible and has fulfilled all the nutritional constraints of SNI 01-4087-2006, specifically achieving exactly 30.00% total protein, 11.66% fat, and a maximum crude fiber level of 8.00%.

To validate the feasibility of the solution generated by the Solver, a manual verification of the nutritional calculations was conducted by substituting the optimal decision variable values ($x_1 = 37.65$; $x_2 = 0$; $x_3 = 60$; $x_4 = 2.35$) into the constraint functions. Table 2 presents a summary of the verification results from these calculations.

Table 2 Verification of Nutritional Calculations from Optimization Results

Type Of Raw Material	Composition (kg)	Protein (60,40,12,9 %)	Fat (10,5,13,4 %)	Fiber (2,6,12,2 %)
Fish Meal (x_1)	37,65	22,59	3,76	0,75
Soybean Flour (x_2)	0,00	0,00	0,00	0,00
Rice bran (x_3)	60,00	7,20	7,80	7,20
Corn Flour (x_4)	2,35	0,21	0,09	0,05
Total	**100,00**	**30,00**	**11,65**	**8,00**

As an example of verification for the protein constraint according to Equation (3):

$$0{,}60(37{,}65) + 0{,}40(0) + 0{,}12(60) + 0{,}09(2{,}35) \geq 30$$

$$22{,}59 + 0 + 7{,}2 + 0{,}2115 = 30{,}0015 \geq 30$$

The result of this substitution calculation shows a value of 30.0015, which means the solution is proven feasible as it satisfies the minimum threshold of 30% according to the SNI 01-4087-2006 standard.

DISCUSSION

This optimal minimum cost condition is achieved because the Linear Programming mathematical model operates logically and strictly in distributing the nutritional load. The algorithm restricts the use of raw materials with high purchase prices, such as fish meal (IDR 18,500/kg), and allocates them as minimally as possible, only until the lower bound nutritional targets are met. Calculations prove that the formulated protein level touches the lower limit exactly at 30.00%. This indicates that the algorithm successfully restrains the wasteful use of expensive feed components without violating the minimum quality standard of 30%.

An interesting phenomenon from these computational results is the total elimination of soybean meal (0 kg). Economically and mathematically, this occurs because its unit price (IDR 14,500/kg) is deemed less competitive by the system when compared to the substitution combination of fish meal and rice bran. To fulfill the remaining feed capacity volume to reach the 100 kg target, the algorithm automatically prioritizes the use of the cheapest filler material, namely rice bran (IDR 5,500/kg). Furthermore, the exceptionally high proportion of rice bran (60 kg) provides a dual advantage; the abundant natural fat content in rice bran automatically boosts the total feed fat achievement to touch 11.66%. This figure falls within the safe SNI range without inflating production costs, ensuring farmers do not need to incur extra expenses for commercial fish oil components. All model constraints are evaluated as feasible.

The average price of factory-made commercial catfish feed with a 30% protein quality specification in the current market is estimated to reach approximately IDR 15,000 per kilogram. This feed formulation, resulting from Linear Programming calculations, yields a significantly lower production cost of IDR 10,453 per kilogram. This directly offers a highly significant production cost reduction efficiency of 30.31% (a savings margin of IDR 4,547 per kilogram).

When critically compared to traditional feed formulations that frequently rely on trial-and-error methods, the simulation results of the Simplex algorithm are far more precise and superior. Conventional methods are prone to producing formulations that are either excessively dense with expensive nutrients (causing costs to inflate) or, conversely, deficient in essential nutrients (resulting in stunted fish growth). This study confirms and aligns with the findings of (Azhari et al., 2025) and (Lahur & Lamabelawa, 2018), that the use of optimization-based mathematical modeling provides a systematic guarantee to cultivators. The application of Operations Research technology practically enables middle-to-lower scale aquaculture industries to cut costs that were previously often wasted due to the inefficiency of manual raw material proportion calculations (Rachmatika et al., 2022).

In real-world field implementation, the prices of fish feed raw materials frequently experience significant fluctuations due to climate change, major harvest seasons, and regional macroeconomic dynamics. The primary advantage of the Linear Programming computational model developed in this study is its capacity for dynamic adaptation (sensitivity analysis). Should an extreme price surge occur in the primary raw materials for instance, if the price of fish meal skyrockets well beyond IDR 18,500/kg cultivators simply need to update the price parameters (objective function) in the Solver matrix system. The Simplex algorithm system will precisely recalculate the iteration matrix and automatically seek a new intersection route (pivoting) to substitute a portion of the fish meal composition with alternative protein sources that competitively have lower real-time prices (such as soybean meal), provided that the minimum nutritional constraints of 30% protein remain unviolated. This flexibility proves that this optimization model design is not merely static for the 2025/2026 pricing period but is highly robust to be utilized as a continuous, long-term Decision Support System for MSME-scale farmers.

CONCLUSION

This study concludes that the application of the Linear Programming method, computationally assisted by the Simplex algorithm, is proven to significantly optimize cost efficiency in the formulation of catfish (Clarias sp.) feed. The developed mathematical model successfully generated a least-cost formulation of IDR 10,453 per kilogram. This optimization result provides a tangible economic impact in the form of a production cost savings efficiency of 30.31% when compared to the average price of commercial manufactured feed in the market. Specifically, the resulting optimal formulation consists of 37.65% Fish Meal, 60.00% Rice Bran, and 2.35% Corn Meal, without allocating any Soybean Meal at all (0%). This mixture combination is strictly proven to have fulfilled all the crucial nutritional quality constraints established in SNI 01-4087-2006, which include achieving exactly 30.00% protein content, 11.66% fat content, and a maximum crude fiber level of 8.00%. For future research development, it is recommended that this linear computation-based fish feed formulation be tested in vivo directly in catfish fingerling grow-out ponds to measure and validate the Feed Conversion Ratio (FCR) in the field.

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