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# APPLICATION OF LINEAR PROGRAMMING ON FISH FARMING (CASE STUDY ALIARA FISH FARM VILLAGE, ILORIN, KWARA STATE)

*Jaiyeola, S. B., Ishaq, A. A., Jimoh, F. M. and Abdullateef Moshood

*Department of Physical Sciences, Faculty of Natural Applied Sciences,*
*Al-Hikmah University, Iorin-Nigeria*

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**ABSTRACT**

*Feed cost remains one of the major challenges limiting profitability in fish farming. This study investigates the use of linear programming as a decision-making tool for developing a cost-effective feed formulation for Common Carp (Cyprinus carpio) at Aliara Fish Farm Village, Ilorin, Kwara State, Nigeria. Information on nutrient composition and ingredient prices was obtained from relevant sources and used to formulate a linear programming model to minimize feed cost while meeting the fish's nutritional requirements. The model was solved using the Linear Interactive and Discrete Optimizer Package (LIPS). The optimal solution consisted of groundnut cake, fish meal, soybean meal, brewer waste, and til cake, whereas wheat bran and rice bran were excluded. The optimized feed satisfied the required nutrient levels at a minimum cost of ₦2,038.29 per 100 kg. The study demonstrates the usefulness of linear programming in improving feed management and reducing production costs in aquaculture.*

## 1. Introduction

Fish farming, or aquaculture, has become a vital solution to global issues of food insecurity, malnutrition and rural unemployment. As the global population grows, the need for sustainable and efficient sources of animal protein intensifies, with fish serving as an essential source of nutrients, including omega-3 fatty acids, vitamins and minerals [1]. According to [2], aquaculture now accounts for over 50% of the fish consumed worldwide, highlighting its growing importance. However, despite its potential, many fish farmers face challenges such as poor planning, inadequate resource management and inefficient use of production inputs, which limit productivity and profitability.

*Corresponding author: Jaiyeola, S. B

*E-mail address:* sbjaiyeola@alhikmah.edu.ng; +2348136786454
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To address these challenges, modern fish farming operations are increasingly turning to operations research tools like linear programming (LP), a mathematical optimization technique that helps allocate limited resources such as feed, capital and labor most efficiently to maximize output and minimize costs.

Linear programming has found widespread application across scientific and practical domains due to its versatility in solving optimization problems. In aquaculture, LP assists farmers in determining optimal feed formulations, fish stocking densities and production schedules, leading to improved yields and reduced waste ([1], [3]). Beyond aquaculture, LP is employed in environmental management to allocate resources sustainably, in healthcare to distribute limited medical resources effectively and in agriculture to optimize crop and livestock planning [4]. Its usefulness extends to biological, chemical and industrial systems where efficiency and cost-effectiveness are critical. Thus, LP serves as a powerful decision-making tool that enhances productivity, promotes sustainability and supports economic growth making it highly applicable in the management and optimization of fish farming systems, such as at the Fish Farm of Aliara Fish Farm Village, Ilorin. [5].

Fish farmers, particularly small-scale operators, often encounter significant challenges arising from high feed costs, limited availability of resources and fluctuating ingredient prices, all of which threaten their production sustainability. Traditional feed formulation methods, such as rule-of-thumb and trial-and-error approaches, frequently result in imbalanced and inefficient feed mixtures that negatively affect fish growth, health and survival rates. To address these issues, this study aimed to investigate the application of linear programming in optimizing feed formulation for fish farming. Specifically, the objectives are to:

i. formulate a linear programming model for fish feed based on collected data;
ii. apply the LIPS program to solve the formulated linear programming problem and
iii. analyze and interpret the results obtained from the LIPS solution to enhance feed efficiency and overall farm productivity.

Fish farming, a vital component of aquaculture, has emerged as a significant contributor to global food security and economic development. As demand for fish continues to rise, optimizing the efficiency and productivity of fish farms becomes increasingly important. Linear programming (LP), a mathematical optimization technique, has been widely applied in agriculture and aquaculture to allocate limited resources effectively. This section reviews existing literature on the application of LP in fish farming, highlighting methodologies, benefits and research gaps.

Several studies have demonstrated the effectiveness of linear programming (LP) in enhancing productivity, profitability and sustainability in aquaculture. [6] showed that LP could optimize fish species and pond sizes to maximize profit, while [7] applied LP to minimize feed costs without compromising fish growth. Similarly, [8] used LP to determine optimal allocations of labor, feed and capital in small-scale Nigerian fish farms, achieving improved efficiency and reduced operational costs. [9] further integrated environmental constraints into LP models, proving that both economic and ecological sustainability could be achieved simultaneously. In related studies, [5] applied LP to feed formulation in Assam, demonstrating that nutritionally balanced feeds could be produced at lower costs compared to traditional methods. Their results revealed LP's potential in tackling high feed costs and unstandardized feed composition, which are major challenges in

fish farming. Similarly, [10] utilized LP to optimize catfish feed in Bangladesh, reducing feed costs while maintaining nutrient balance, thereby proving LP's practical benefits for aquaculture profitability.
The literature also highlights the versatility of LP across agricultural systems and the growing adoption of advanced modeling techniques to address real-world complexities. [4] demonstrated the utility of LP in optimizing mixed farming enterprises in Nigeria, improving gross margins and resource use efficiency. [11] expanded on traditional LP applications by developing a lexicographic linear goal programming (LGP) model that balanced multiple objectives such as profit maximization, cost minimization and efficient pond usage, offering a more realistic decision-making framework for fish farmers. [12] emphasized the value of optimization in managing brackish water fish ponds, integrating economic and environmental factors to enhance sustainability. Further contributions by ([13, [14]) advanced the computational efficiency of LGP algorithms, making them more practical for solving complex multi-objective problems in aquaculture and agriculture. Collectively, these studies affirm that LP and its variants are powerful tools for resource optimization in fish farming, but they also call for future research incorporating nonlinear and stochastic approaches to better capture biological and environmental uncertainties.

Linear programs are problems that can be expressed in standard form as [15]:

| | |
|---|---|
| Find a value of x | |
| That maximizes | $C^T x$ |
| Subject to | $Ax \le b$ |
| And | $x \ge 0$ |

Here the components of $x$ are the variables to be determined, $c$ and $b$ are given vectors and $A$ is a given matrix. The function whose value is to be maximized ($x \to C^T x$ in this case) is called the objective function. The constraints $Ax \le b$ and $x \ge 0$ specify a convex polytope over which the objective function is to be optimized.

## 2. MATERIALS AND METHODS

### 2.1 Data Collection

This section presents and discusses the results obtained from applying linear programming to fish feed optimization at Aliara Fish Farm Village, Ilorin. The analysis was based on data collected from primary and secondary sources, including market prices of feed ingredients, nutrient composition values, and the nutritional requirements of Common Carp (*Cyprinus carpio*).
Seven locally available feed ingredients were considered in the study: groundnut cake, fish meal, soybean meal, brewer waste, wheat bran, til cake, and rice bran. Nutritional parameters examined included protein, lipid, carbohydrate, calcium, and phosphorus contents. These data served as inputs for the formulation of the linear programming model.
The formulated model was solved using the Linear Interactive and Discrete Optimizer Package (LIPS) to determine the least-cost feed mixture that satisfied all specified nutritional requirements. The results, including the optimal ingredient composition and corresponding nutrient balance, are presented in tabular form for ease of interpretation. The findings are discussed in relation to the study objectives and demonstrate the usefulness of linear programming in improving feed management, reducing production costs, and supporting sustainable aquaculture practices.

## 2.2 Quantitative Data Analysis of Linear Programming

This study employed a quantitative research approach using linear programming (LP) to develop a least-cost feed formulation for Common Carp (*Cyprinus carpio*). The optimization model was designed to identify the most economical combination of available feed ingredients while ensuring compliance with the nutritional requirements necessary for fish growth and development.

The research focused on Aliara Fish Farm Village, Ilorin, Kwara State, Nigeria. Data were obtained from both primary and secondary sources to ensure reliability and completeness. The primary data were collected through direct interviews with fish farmers and farm operators, providing information on feeding practices, ingredient availability, and prevailing market prices of feed materials while the secondary data were obtained from published literature and established nutritional references relating to fish feed composition and dietary requirements.

The feed ingredients considered in the study included groundnut cake, soybean meal, rice bran, wheat bran, fish meal, brewer waste, and til cake. Data collected covered nutrient composition, ingredient prices, and the minimum nutritional requirements for Common Carp. These data were subsequently used to formulate the linear programming model, which enabled the selection of an optimal feed mixture that satisfies nutritional standards at minimum production cost.

Table 1: nutrients contents of ingredient-groundnut cake

| | |
|---|---|
| Protein % | 38 |
| Lipid % | 9.01 |
| Carbohydrate % | 27.99 |
| Calcium % | 0.25 |
| Phosphorous % | 0.65 |

Table 2: nutrients contents of ingredient-soybean cake

| | |
|---|---|
| Protein % | 37.03 |
| Lipid % | 7.1 |
| Carbohydrate % | 28.03 |
| Calcium % | ___ |
| Phosphorous % | ___ |

Table 3: nutrients contents of ingredient-rice bran

| | |
|---|---|
| Protein % | 13.24 |
| Lipid % | 4.3 |
| Carbohydrate | 42.65 |
| Calcium % | 0.06 |
| Phosphorous % | 1.50 |

Table 4 nutrients contents of ingredient-wheat bran

| | |
|---|---|
| Protein % | 13.9 |
| Lipid % | 4.2 |
| Carbohydrate % | 55.6 |
| Calcium % | 0.2 |
| Phosphorous % | 1 |

Table 5: nutrients contents of ingredient-fish meal

| | |
|---|---|
| Protein % | 55 |
| Lipid % | 1.8 |
| Carbohydrate % | __ |
| Calcium % | 4.5 |
| Phosphorous % | 2.5 |

Table 6: nutrients contents of ingredient-brewer waste

| | |
|---|---|
| Protein % | 22.8 |
| Lipid % | 17.8 |
| Carbohydrate % | 46.4 |
| Calcium % | __ |
| Phosphorous % | __ |

Table 7: nutrients contents of ingredient til cake

| | |
|---|---|
| Protein % | 45 |
| Lipid % | 12 |
| Carbohydrate % | 24.5 |
| Calcium % | 0.5 |
| Phosphorous % | 1 |

Table 8: minimum nutrient contents requirement of common carp.

| | |
|---|---|
| Protein % | 38 |
| Lipid % | 6 |
| Carbohydrate % | 26 |
| Calcium % | 1 |
| Phosphorous % | 0.6 |

Table 9: market price of ingredients (₦)

| | |
|---|---|
| Groundnut Cake | 24 |
| Fish Meal | 25 |
| Soybean Meal | 18 |
| Brewer Waste | 12 |
| Wheat Bran | 10 |
| Til Cake | 15 |
| Rice Bran | 6 |

## 2.3 Assumptions of the Model

Several assumptions underlie the linear programming formulation:

i. Linearity: The nutrient contribution of each ingredient is linearly additive, i.e., there are no interactions among feed components.
ii. Certainty: All coefficients related to cost and nutrient content are known and constant.
iii. Fixed Prices: Ingredient prices remain constant throughout the analysis period.
iv. Constant Returns to Scale: The nutritional contribution of each ingredient is proportional to its quantity.

These assumptions, although idealized are considered reasonably valid for practical feed formulation under the given conditions. The formulated linear programming model was solved using the LIPS to determine the optimal feed composition and minimum total feed cost.

## 2.4 Model Formulation

The linear programming model was constructed using the following components:

i. Decision Variables $x_n$ : Proportions of each feed ingredient to be included in the final mixture.
ii. Objective Function Z: Minimum total cost of the feed.
iii. Constraints: Minimum nutritional requirements (protein, lipid, carbohydrate, calcium, phosphorus) of the fish and availability constraints of the feed ingredients.
Consider formulation of a feed mixture with ingredients shown in the following table and subject to minimum nutrient is 100 kg. Contents. The quantity of the mixture to be prepared

Let

$x_1$ = quantity of groundnut cake

$x_2$ = quantity of fish Meal

$x_3$ = quantity of soybean Meal

$x_4$ = quantity of brewer waste

$x_5$ = quantity of wheat bran

$x_6$ = quantity of til cake

$x_7$ =quantity of rice bran

all quantities in kg, the programming model required to minimize the total feed cost for the mixture can be written as:

$$Z = 24x_1 + 25x_2 + 18x_3 + 12x_4 + 10x_5 + 15x_6 + 6x_7 \text{ (Cost function)}$$

Subject to nutritional constraint

$38x_1 + 55x_2 + 37.03x_3 + 22.8x_4 + 13.9x_5 + 45x_6 + 13.24x_7 \geq 3800$ *(protein requirement)*
$9.01x_1 + 1.8x_2 + 7.1x_3 + 17.8x_4 + 4.2x_5 + 12x_6 + 4.3x_7 \geq 600$ *(lipid requirement)*
$27.99x_1 + 28.03x_3 + 46.4x_4 + 55.6x_5 + 24.5x_6 + 42.65x_7 \geq 2600$ *(carbohydrate requirement)*
$0.25x_1 + 4.5x_2 + 0.2x_5 + 0.5x_6 + 0.06x_7 \geq 100$ *(calcium requirement)*
$0.65x_1 + 2.5x_2 + 1.0x_5 + 1.0x_6 + 1.5x_7 \geq 60$ *(phosphorus requirement)*
$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 = 100$ *(Total quantity requirement)*
and
$x_i \geq 0$, for $i = 1, 2, \ldots, 7$ *(positivity constraints)*

These assumptions, although idealized are considered reasonably valid for practical feed formulation under the given conditions. We use Linear Interactive and Discrete Optimizer Package (LIPS), a software package developed for solving optimization problems through established linear programming algorithms to obtain the unit cost for each ingredient for fishing feeding.

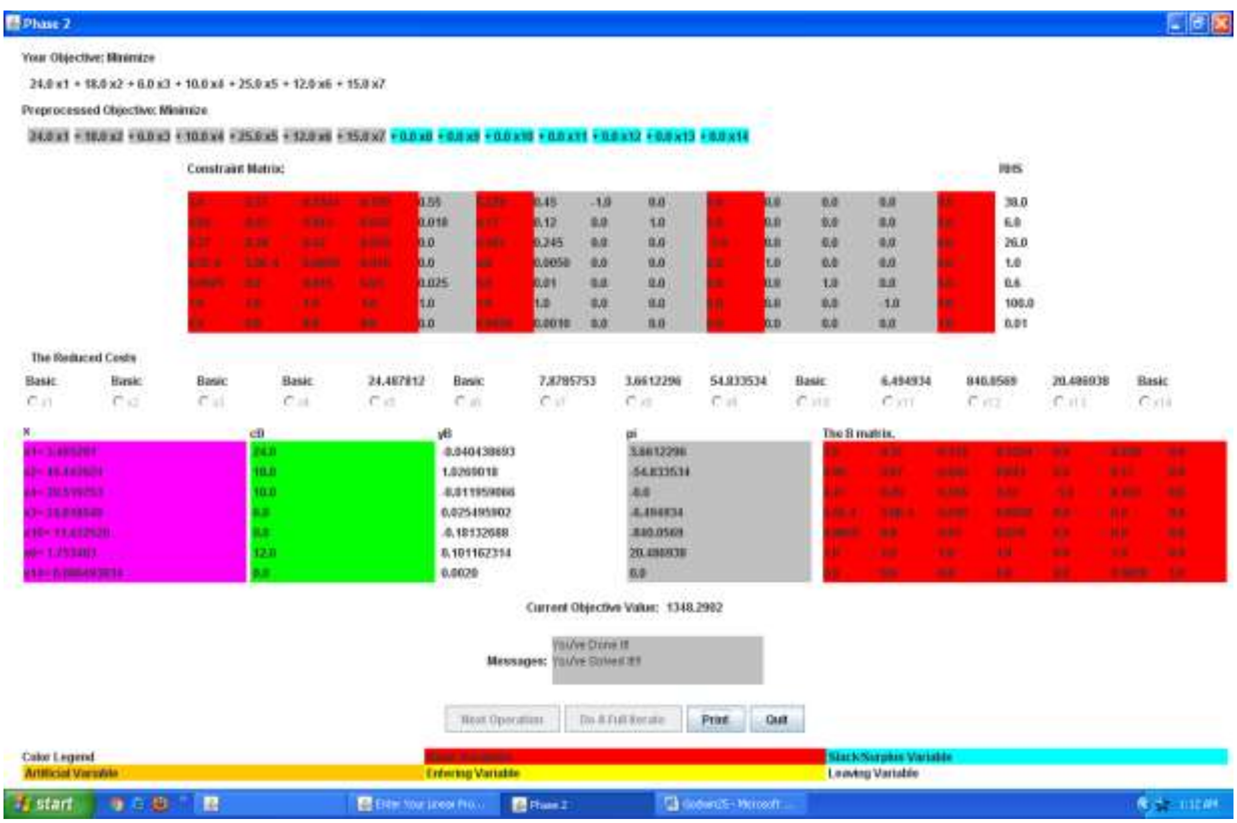


Figure 1: Result from the LIPS

From the LIPS optimization, the optimal quantities of feed ingredients were obtained as follows:

$x_1$ =3.46kg of groundnut cake

$x_2$ =49.44kg of fish meal

$x_3$ =24.82kg of soybean meal

$x_4$ =20.52kg of brewer waste

$x_5$ =0, no quantity of wheat bran

$x_6$ = 1.75kg of til cake

$x_7$ =0, no quantity of rice bran

Now by substituting the values of x into the objective function, we obtained the value:

$$Z = 24x_1 + 25x_2 + 18x_3 + 12x_4 + 10x_5 + 15x_6 + 6x_7$$

$$Z = 24(3.46) + 25(49.44) + 18(24.82) + 12(20.52) + 10(0) + 15(1.75) + 6(0)$$

Table 10: Computation of Ingredient quantities and cost contribution

| **Ingredient** | **Variable** | **Quantity (kg)** | **Unit Cost (₦/kg)** | **Computation** | **Cost Contribution (₦)** | **Percentage contribution (%)** |
|---|---|---|---|---|---|---|
| Groundnut cake | $x_1$ | 3.46 | 24 | 3.46 x 24 | 83.04 | 3.46 |
| Fish meal | $x_2$ | 49.44 | 25 | 49.44 x 25 | 1,236.00 | 49.44 |
| Soybean meal | $x_3$ | 24.82 | 18 | 24.82 x 18 | 446.76 | 24.82 |
| Brewer waste | $x_4$ | 20.52 | 12 | 20.52 x 12 | 246.24 | 20.52 |
| Wheat bran | $x_5$ | 0.00 | 10 | 0.00 x 10 | 0.00 | 0.00 |
| Til cake | $x_6$ | 1.75 | 15 | 1.75 x 15 | 26.25 | 1.75 |
| Rice bran | $x_7$ | 0.00 | 6 | 0.00 x 6 | 0.00 | 0.00 |
| **Total** | | **100** | | | **2,038.29** | **100** |

Therefore, the minimum cost of $Z =$ ₦2,038.29

Using the optimized LIPS formulation previously in Table 10, the nutrient totals were computed from the nutrient coefficients in the LP model and compared against the required minimum nutrient levels as displayed in table 11 below.

Table 11: Computed Nutrient satisfaction

| **Nutrient** | **Original Required value** | **Achieved value** | **Percentage Contribution (%)** | **Excess Requirement (%)** |
|---|---|---|---|---|
| Protein | 3800 | 4053.6 | 51.14 | 6.67 |
| Lipid | 600 | 822.7 | 10.38 | 37.12 |
| Carbohydrate | 2600 | 2689.2 | 33.93 | 3.43 |
| Calcium | 100 | 224.0 | 2.83 | 124.00 |
| Phosphorus | 60 | 136.5 | 1.72 | 127.50 |

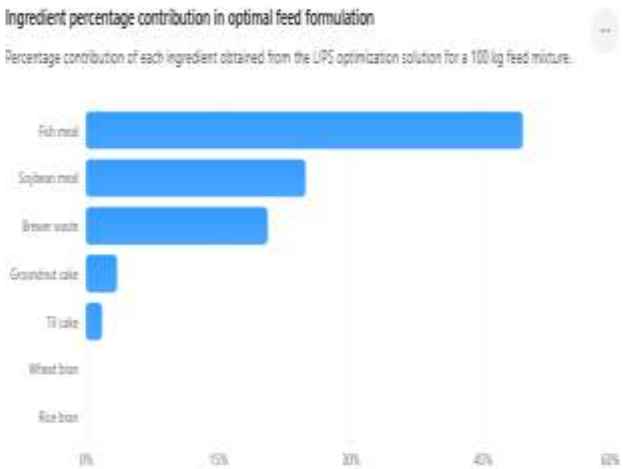


Figure 2: Ingredient Contribution in Optimal Feed (%)

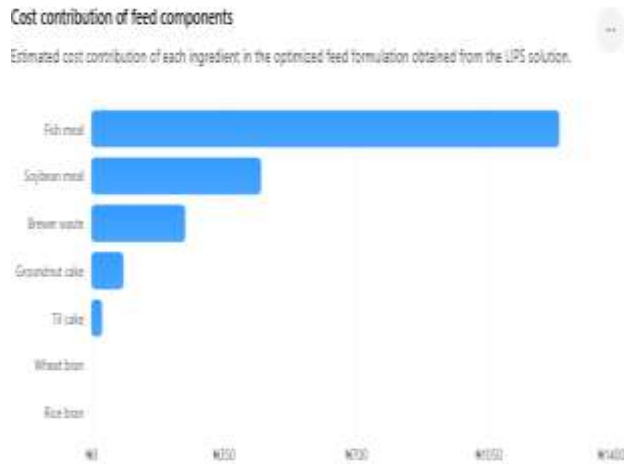


Figure 3: Cost Contribution of Feed Components


Figure 4: Nutrient satisfaction chart

## 3. RESULT

The LP model was solved using the LIPS Optimizer Package, which generated the optimal feed formulation satisfying all nutritional constraints at minimum cost. The model incorporated the objective function of minimizing feed cost while simultaneously satisfying the specified constraints for protein, lipid, carbohydrate, calcium, phosphorus and overall feed quantity. Each constraint was successfully met within the required limits, indicating that the formulated solution is both nutritionally adequate and economically viable. This outcome highlights the practical relevance of linear programming in aquaculture, as it ensures that fish farmers can achieve optimal feed composition without compromising growth performance or exceeding resource limitations.

## 4. DISCUSSION

The results obtained from the linear programming model demonstrate the effectiveness of optimization techniques in formulating a nutritionally balanced fish feed at the minimum possible cost. Using the nutrient composition data and market prices of seven feed ingredients, the LIPS software generated an optimal feed mix that satisfied all nutritional requirements of Common Carp while minimizing total production cost. The objective function produced a minimum feed cost of ₦2,038.29 for the formulated feed mixture. This result confirms that linear programming can serve as a reliable decision-support tool for fish farmers by identifying the most economical combination of available feed ingredients without compromising nutritional quality.
The optimal solution revealed that Fish Meal constituted the largest proportion of the feed formulation (49.44 kg), followed by Soybean Meal (24.82 kg), Brewer Waste (20.52 kg), Groundnut Cake (3.46 kg), and Til Cake (1.75 kg) each at a total cost of ₦1,236.00, ₦446.76, ₦246.24, ₦83.04 and ₦26.25 respectively as seen in Tables 10 and 11. The dominance of Fish Meal in the formulation can be attributed to its high protein content (51.14%) and significant mineral contribution, particularly calcium and phosphorus, which are essential for fish growth and development. Similarly, Soybean Meal and Brewer Waste were included in substantial quantities because they provide adequate levels of protein, lipid, and carbohydrate at relatively moderate costs. Table 11 also shows the computation of the excess nutrient satisfaction levels of protein, lipid, carbohydrate, calcium, and phosphorus as 6.67%, 37.12%, 3.43%, 124.00% and 127.50%, respectively, indicating that the optimized formulation met or exceeded the minimum nutritional requirements for Common Carp. The inclusion of Groundnut Cake and Til Cake in smaller proportions further contributed to meeting the nutritional requirements while maintaining cost efficiency.

An important finding from the optimization process is that Wheat Bran and Rice Bran were assigned zero values in the final solution. This indicates that these ingredients were not economically attractive within the optimal feed formulation despite their availability and relatively low market prices. Although Rice Bran and Wheat Bran provide carbohydrate content, their lower protein and mineral concentrations made them less efficient in satisfying the nutritional constraints compared to other ingredients. Consequently, the model excluded them from the final feed mix, demonstrating the ability of linear programming to eliminate non-essential ingredients and select only those that contribute most effectively toward achieving nutritional goals at the lowest cost.

The charts presented in Figures 2–4 further illustrate the percentage contribution of each ingredient, cost contribution to the optimized feed formulation and nutrient satisfaction. The chart also confirms the varying significance of the ingredients in meeting the nutritional constraints, with Fish Meal, Soybean Meal, and Brewer Waste exhibiting the greatest influence on the solution. To validate the optimization outcome, the obtained LP solution was verified against the nutritional constraints and objective function using direct substitution. All constraints were satisfied and the total cost matched the LIPS output.

Overall, the results validate the applicability of linear programming in aquaculture feed management. By systematically balancing ingredient costs and nutrient requirements, the model provides fish farmers with a practical approach to reducing feed expenses, improving profitability, and promoting sustainable fish production. The findings therefore support the adoption of optimization techniques as an effective strategy for enhancing resource utilization and decision-making in fish farming operations.

## 5 SUMMARY AND CONCLUSION

This study examined the application of linear programming as an optimization tool for fish feed formulation at Aliara Fish Farm Village, Ilorin, Kwara State. The research utilized nutrient composition data and market prices of seven feed ingredients to formulate a least-cost feed mixture for Common Carp (*Cyprinus carpio*). A linear programming model was developed with the objective of minimizing feed cost while satisfying the minimum nutritional requirements for protein, lipid, carbohydrate, calcium, and phosphorus. The model was solved using the Linear Interactive and Discrete Optimizer Package Software (LIPS). The results showed that the optimal feed formulation consisted of fish meal, soybean meal, brewer waste, groundnut cake, and til cake, while wheat bran and rice bran were excluded from the final solution. The optimized formulation met all nutritional constraints at a minimum cost of ₦2,038.29, demonstrating the effectiveness of linear programming in achieving both nutritional adequacy and economic efficiency.

The findings of this study confirm that linear programming is a powerful and reliable mathematical tool for solving feed formulation problems in aquaculture. By systematically evaluating the nutrient contributions and costs of available feed ingredients, the model identified the most economical feed combination capable of satisfying the nutritional requirements of Common Carp. The exclusion of wheat bran and rice bran from the optimal solution further demonstrated the model's ability to eliminate less efficient ingredients and prioritize those with superior nutrient-to-cost ratios. Consequently, the application of linear programming can significantly reduce feed costs, improve resource utilization, and enhance the profitability and sustainability of fish farming enterprises.

Based on the findings of this study, fish farmers should adopt linear programming techniques in feed formulation to minimize production costs and maximize profit without compromising fish nutrition. Aquaculture extension agencies, researchers, and government institutions should provide training and technical support on the use of optimization software such as LIPS and other mathematical programming tools for feed management. Furthermore, future studies should incorporate additional factors such as ingredient availability, seasonal price fluctuations, uncertainty in nutrient composition, and environmental considerations through advanced optimization models such as nonlinear, stochastic, and goal programming approaches to achieve more realistic and comprehensive feed formulation solutions.

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