Feed formulation problem in Peruvian aquaculture: A mathematical programming approach

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Abstract

The aquaculture industry in Peru, in recent years, has been growing by 14.4% between 1998 and 2018, and has become popular among small entrepreneurs due to the climate conditions and extensions of water offered by the Peruvian territory. Feeding represents between 40 and 60% of the total costs and this figure is increases by 80% in small-scale or family productions, therefore, there is a need to implement an adequate feeding program for aquaculture. The objective of this research is to develop a linear programming (LP) model that allows the optimization of the fish feed formulation by manufacturing a balanced meal using locally available inputs. Authors like V.O. Oladokun and A. Jhonson (2012) have managed to make a similar model in the poultry sector, achieving a 9% reduction in feed costs. Information was collected from scientific articles and journals on nutritional content, ingredients, and alternatives fish feed consumption; the cost of the ingredients has been obtained using current market information. The mathematical model contains 10 decision variables and 11 restrictions, which was conducted with Solver on Excel. The fish farm used in the case study allowed us to collect the necessary information for the resolution of the model and the analysis of the optimal results. The optimal solution of the PL model reveals a reduction in feed costs with the new formulation compared to the feed used by fish farmers. The analysis of the optimal results allowed us to see how the total feed costs could be affected by the implementation of the sensitivity analysis with the Monte Carlo simulation.

Keywords
Fish farms, Feeding, Formulation, Costs, Linear Programming, Sensitivity Analysis.

1. Introduction
During recent years, aquaculture in the Latin American and Caribbean region has been growing in production quantity by 8.3% per year between 2000-2020, where the cultivation of species such as shrimp, Atlantic salmon, tilapia from the Nile, Chilean mussel, and rainbow trout, in descending order, together contributing 80.4% of the volume of regional production.

At the national level, despite its diversification efforts, aquaculture is oriented to the cultivation of few species, however, the region of San Martín (high jungle) stands out as the national leader in fish farming in the production of tilapia where it is produced almost 50% of the total of this species, registering a growth of 116% in the last 6 years, on the other hand, to achieve a decrease in the cost of production of tilapia, from a cost of S/5.6 to S/4.6 per kilo, it is necessary to implement technological improvements and proper management of balanced feed (Banco Central de Reserva del Perú, 2017). This species is cultivated for local consumption and is still considered an incipient aquaculture due to its production volumes (Kleeberg Hidalgo & Rojas Delgado, 2012), which are not very competitive in Latin America, due to technological gaps, poor research and development strategies, fragmented policies, localized markets, marketing problems and relatively high prices (FAO, 2020).

It should be noted that feed represents between 40% and 60% of the total costs of aquaculture production and these figures increase in small-scale aquaculture where it represents 80%, therefore, the price of commercially available feed determines sustainability. economy of small farmers, and, as the prices of these feeds increase, the more developed aquaculture companies invest in facilities to produce their own feed to develop more efficient businesses (FAO, 2020).

Therefore, to achieve a decrease in the cost of fish production in these artificial environments, adequate feeding management is necessary for success in tilapia farming practices, therefore, the challenge faced by tilapia producers and in emerging countries, is the development of commercial and profitable tilapia feeds using locally available, cheap, and unconventional resources (El-Sayed, 2020).

Bearing in mind that feeding within aquaculture is of the utmost importance, several authors provide multiple data on essential nutritional requirements in the feed of aquatic animals and point out a list of nutritional alternatives in the diet of fish as a basis for economic formulations and productive for commercial aquaculture (El-Sayed, 2020; Lovell, 1989; Ng, W.-K., & Romano, 2013).

For this reason, it has been established to analyze the cost of feeding tilapias in fish farms in the department of San Martín to achieve an improvement in the profitability of commercial beekeepers, this location is conducive to research, since favorable conditions of climate, topography, and abundant water resources for the development of fish farming (Instituto de Investigaciones de la Amazonía Peruana , 2009).

The present investigation would significantly help fish farms, since it allows to efficiently optimize their feeding costs, since these can raise more than 50% of the total production costs or tend to be very high compared to other variable costs (Nasr -Allah et al., 2014; Ng, W.-K., & Romano, 2013; Rahman, 2012; Young et al., 2021).

The linear programming proposal will help solve the problem of the excessive cost generated by fish feed and, although the objective of this research is currently focused on tilapia, the optimization can be adapted to other types of fish or species. of animals, and, also, to the use of diverse types of strains of the same type of fish that did have an impact on the results (Genschick et al., 2021).

1.1 Components for a balanced diet for fish of the tilapia species:

The food diets for tilapia fish are made from proteins that can be of both plant and animal origin, which is composed of amino acids, essential for the structure and function of all living organisms, which is considered the most important in the diet. Their requirements depend on size, life stage, protein source, and protein-to-energy (P: E) ratio. For maximum growth performance, during the starter stage (fingerling), Nilotic-type tilapia requires about 35% to 45% protein, for the growth stage (juvenile) it varies between 30% and 40%, while the adult stage requires 25% to 30%. On the other hand, this fish requires dietary lipids for energy production, protein sparing, and normal growth and development. This requirement varies depending on the protein and energy content of the diet, the lipid source, the form of the granule, the stage of development and water quality. Similarly, to maintain normal growth and a good immune system, vitamins are required in tiny amounts, such as vitamin A, vitamin E and vitamin C. In addition, tilapias digest approximately 35% to 40% carbohydrates digestible. (Table 1). Finally, to maintain their metabolic functions, minerals such as phosphorus and zinc are needed, which are used according to the size of the fish, the source, and the mineral content of both the culture water and the food (El-Sayed, 2020).

Table 1. Nutritional components required in the production of fish-on-fish farms

Constrains	% Constrain	Alevin	Fry	Juvenile	Adult
Raw protein	Min	40	30	25	20
Raw fat	Min	4	4	4	4
Raw fibre	Max	4	4	6	8
Lysine	Min	2.04	1.53	1.28	1.02
Methionine + Cystine	Min	1.28	0.96	0.80	0.64
Calcium	Max	2.50	2.50	2.50	2.50
Salt	Max	2.5	2.5	2.5	2.5
Total phosphorus	Max	1.50	1.50	1.50	1.50
Available phosphorus	Min	0.60	0.60	0.60	0.60
Ash	Max	19	19	19	19
Digestible energy (Kcal kg -1)	Min	2800	2800	2800	2800

1.2 Sensitivity analysis

Due to unstable market conditions such as price changes, post-optimization analysis is necessary to determine the potential economic effects and implications of these formulation changes. This tool assesses how much an outcome (feed cost) changes relative to inputs (input price) and can guide comparative risk assessment of different variables (Ben Fowler, 2012). The parameters such as costs, availability, and requirements for the optimization of the model are not usually known with certainty once it is solved. Therefore, it is debatable to what extent these responses that are mathematically optimal, but imperfectly parameterized in real life, can be trusted. In this way, it is frequent that the constant changes of the currency affect the increase or decrease of food.

2. Methods

To carry out this work, the empirical method was used with a descriptive quantitative approach. The engineering tool to be implemented in the research is linear programming (LP) because it allows optimization results to be obtained to produce fish feed; subsequently, a sensitivity analysis was used based on the analysis of the prices of the inputs according to the Peruvian market to know the variability of the total cost in the preparation of the food. On the other hand, through the bibliographic review through various searches in databases such as Scopus and academic Google, relevant information is detailed on the nutritional components required in the feed and the food alternatives for fish consumption. In addition, data will be extracted within the geographic study area on the prices and availability of inputs.

The proposed feed formulation model seeks the optimal combination of available inputs that will satisfy the nutritional requirements of tilapia at the lowest possible cost. A set of constraints on nutritional levels, availability of inputs, special ingredients to be included, and budget constraints must be met. In addition, it should be considered that the life cycle of this species has four stages, each one considering different nutritional requirements, where the model must be adapted to result in an adequate nutritional diet.

The generic mathematical model in which each type of ration is applicable using the available ingredients has been assembled as follows.

2.1 Generic Model

Mathematical notations:
i: Index that identifies food supplies $i = 1,2,\dots m$
j: Index that identifies the nutritional components of the food $j = 1,2,\dots m$
X_j = Amount of ingredients for feed I in the feed mix (Decision Variable)
T_{ij} = Amount of nutrients i available in the ingredient j
K = Total amount (kg) of feed to be produced
Z = Total costs of feed ingredients used in feed formulation

Ci = Unitary cost of feed ingredient I
Ril = Minimum nutritional requirements (fraction of K) of nutrient i for a fish category
Rih = Maximum nutritional requirements (fraction of K) of nutrient i for a fish category

Objective function:
The objective of the model is to minimize total feed costs

Min Z= $\sum_{j=1}^{n} C_i X_i$

Problem constraints:
The model constraints have to do with limiting the total amount of feed to be produced, the nutritional requirements and the availability of nutrients in the feed ingredients. The following restrictions apply to the food formulation problem.

1. The feed must meet the total demand quantity K for the planning period.
2. The feed must meet the metabolizable energy (ME) and dietary requirement Ri for each nutrient.
3. Restricted ingredients must be present in the food within the acceptable range.

The mathematical equivalent model of the above constraint statements are as follows:

1. Demand requirement
$\sum_{j=1}^{n} X_j \geq$ K
2. Nutrients and energy requirement

$R_{il} \sum_{j=1}^{n} X_j \leq \sum_{j=1}^{n} X_j T_{ij} \leq R_{ih} \sum_{j=1}^{n} X_j$ … ∀i 1,2,...m

Models resumes as follow:

Min Z= $\sum_{j=1}^{n} C_i X_i$

$\sum_{j=1}^{n} X_j \geq$ K

$R_{il} \sum_{j=1}^{n} X_j \leq \sum_{j=1}^{n} X_j T_{ij} \leq R_{ih} \sum_{j=1}^{n} X_j$ … ∀i 1,2,...m

$X_j \geq 0$ j = 1,2,…n

Table 2. Costs and nutritional value of balanced feed inputs

Decision Variable List	Variable	Cost (S// Kg)	Crude protein	Crude fat	Crude fibre	Lysine	Methionine+ cystine	Calcium	NaCl	Total phosphorus	Ash	Digestible energy (kcal)
Fishmeal	X1	4.00	60.50	9.40	-	4.83	2.30	5.000	0.410	2.800	19.10	2800
Fish oil	X2	9.00	28.90	9.71	-	-	-	0.232	3.670	0.252	11.10	2100
Blood meal	X3	6.00	86.76	4.98	0.26	8.85	1.60	0.260	0.330	0.220	4.80	3400
Soybean flour	X4	3.50	51.50	1.22	17.50	3.18	1.45	0.241	0.020	0.674	6.15	3270
Banana flour	X5	5.00	2.65	-	0.90	-	-	0.008	0.001	0.028	-	920
Wheat flour	X6	4.00	12.00	1.70	3.00	-	-	0.022	0.002	0.134	0.56	3620
Rice flour	X7	3.00	6.94	1.30	0.50	0.21	0.25	0.006	0.005	0.094	0.35	3590
Cassava flour	X8	6.00	5.18	2.12	5.70	0.02	0.01	0.057	-	-	-	3510
Corn gluten	X9	10.50	75.20	1.85	0.60	1.70	4.30	0.142	0.029	0.260	1.00	3700

The generic model of the feed formulation can be adapted to the ration that is needed with the nutritional requirements indicated in Table 1. The model has been developed with the nutritional yields of the inputs and their respective costs for each kg of locally available input, which is summarized in Table 2.

Table 2 Summarized Model

Min Z = C1x1 +C2x2 +C3x3 +C4x4 +C5x5 +C6x6 +C7x7 +C8x8 +C9x9 +C10x10;
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≥ $R_{il} \sum_{j=1}^{n} X_j$; - Protein
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≥ $R_{il} \sum_{j=1}^{n} X_j$; - Fat
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8 ≤ $R_{ih} \sum_{j=1}^{n} X_j$;- Fibre
Tijx1+ Tijx2+ Tijx3+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≥ $R_{il} \sum_{j=1}^{n} X_j$; - Lysine
Tijx1+ Tijx2+ Tijx3+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≥ $R_{il} \sum_{j=1}^{n} X_j$; - Methionine + Cystine
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≤ $R_{ih} \sum_{j=1}^{n} X_j$; - Calcium
Tijx1+ Tijx2+ Tijx3+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≤ $R_{ih} \sum_{j=1}^{n} X_j$; - Salt
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≤ $R_{ih} \sum_{j=1}^{n} X_j$; - Total phosphorus
Tijx1+ Tijx2+ Tijx3+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≤ $R_{ih} \sum_{j=1}^{n} X_j$; - Ash
Tijx1+ Tijx2+ Tijx3+ Tijx4+ Tijx5+ Tijx6+ Tijx7+ Tijx8+ Tijx9 ≥ $R_{il} \sum_{j=1}^{n} X_j$; -Digestible energy (kcal)

Then, a comparison of the optimal solution was made with the costs of the balanced food bags used in the study place during the entire life cycle of the fish befor

3. Results

The result of preparing the fish feed for the case under study has been conducted using the hypothesis analysis Solver tool that seeks the optimal value of an objective cell in Excel, this value is compared with the feeding cost measured in bags of balanced feed used in the study farm for each phase of the fish life cycle. (Table 3)

Table 3. Optimal solution linear programming model

Variable	Ingredients	Quantity (kg)	Unit cost	Total cost
X1	Fishmeal	10.88	S/ 4.00	S/ 43.53
X2	Fish oil	0.00	S/ 9.00	S/ -
X3	Blood meal	0.00	S/ 6.00	S/ -
X4	Soybean flour	5.47	S/ 3.50	S/ 19.13
X5	Banana flour	0.00	S/ 5.00	S/ -
X6	Wheat flour	0.00	S/ 4.00	S/ -
X7	Rice flour	8.65	S/ 3.00	S/ 25.95
X8	Cassava flour	0.00	S/ 6.00	S/ -
X9	Corn gluten	0.00	S/ 10.50	S/ -
	Total	25.00		
	Total cost	88.62		S/ 88.62

The fish farm under study does not have an existing food processing practice, therefore, a comparative Table 3. will be prepared detailing the quantities of bags used during the stages of the life cycle and their costs vs. the cost of balanced feed elaborated. (Table 4)

Table 4. Cost and quantity of bags of balanced feed purchased vs. Cost and quantity of bags of balanced feed produced

	Balanced feed cost				Proposed feed formulation cost			
Process stage	**Monthly feed cost (Kg)**	**Amount of 25 kg bags used**	**Cost of a 25 kg bag**	**Total cost**	**Monthly feed cost (Kg)**	**Amount of 25 kg bags used**	**Cost of a 25 kg bag**	**Total cost**
Alevin	80.33	3.21	S/ 220.00	S/ 706.86	80.33	3.21	S/ 88.61	S/ 284.70
Fry	249.75	9.99	S/ 155.00	S/ 1,548.45	249.75	9.99	S/ 84.80	S/ 847.15
Juvenile	289.80	11.59	S/ 115.00	S/ 1,333.08	289.80	11.59	S/ 83.39	S/ 966.66
Adult	504.00	20.16	S/ 110.00	S/ 2,217.60	504.00	20.16	S/ 83.33	S/ 1,679.93
Total	1123.88			S/ 5,805.99	1123.88			S/ 3,778.45
Feed cost per kg				S/ 5.17				S/ 3.36

The processing of fish feed is more effective based on the linear programming method, this is a substantial savings of about 35%. The sensitivity analysis results of the feed formulation model are summarized in Table 5., while the status of the resources is summarized in Table 6.

Table 5. Sensitivity analysis variable

Variable	Objective coefficient	Reduce Permissible	Increase Permissible	Reduced cost
X1: Fishmeal	4	0.3990	1.0362	0
X2: Fish oil	9	5.5843	1E + 30	5.5843
X3: Blood meal	6	1.5193	1E + 30	1.5193
X4: Soybean flour	3.5	16.2089	0.3319	0
X5: Banana flour	5	2.1098	1E + 30	2.1098
X6: Wheat flour	4	0.9540	1E + 30	0.9540
X7: Rice flour	3	1.9755	0.9857	0
X8: Cassava flour	6	3.1316	1E + 30	3.1316
X9: Corn gluten	10.5	7.4720	1E + 30	7.4720 ≤

Table 6. Sensitivity analysis constrains

Constrains	Right side constrains	Reduce permissible	Increase permissible	Dual prices
1 (>=)	0	0.8210	0.5098	1.8492
2 (>=)	0	1E + 30	0.2021	0
3 (<=)	0	0.2636	0.5162	-1.9060
4 (>=)	0	1E + 30	0.2076	0
5 (>=)	0	1E + 30	0.0312	0
6 (<=)	0	0.0671	1E + 30	0
7 (<=)	0	0.5788	1E + 30	0
8 (<=)	0	0.0253	1E + 30	0
9 (<=)	0	2.3048	1E + 30	0
10 (>=)	0	1E + 30	9403.08	0
11 (>=)	25	25	1E + 30	3.5446

The results shown in the dual prices of the surplus resources (fat, lysine, methionine+ cystine, calcium, salt, phosphorus, ash, and energy) are zero. This means that there will be no economic benefit in allocating more or less of that resource; nonetheless by increasing a unit in any other resource will cause a change in the objective value. For example, if a unit increases in the total quantity of protein value, the objective value will increase by 1.8492 withing the range of 0.5098 ≤ RHS 0.8210.

4. Discussion

From the results obtained, it is evident that there are many products that can be obtained locally at an affordable price for the preparation of feed for tilapia in the separate phases of the life cycle compared to the purchase of a balanced commercial product and that help to obtain a significant reduction in total cost production of this species. On the other hand, it is important to consider that the prices of inputs vary each season, added to global problems such as the crisis in Ukraine, where the supply of some products can influence their costs, therefore the importance of an analysis of sensitivity and local food alternatives present in this research.

5. Conclusions

Aquaculture is a growing industry in Peru that will be particularly important as a source of healthy food and to avoid the destruction of natural ecosystems. This study was able to improve the feed cost of tilapia fish farms with local inputs and the assistance of a liner modelling software. Tables show the nutritional values of all the inputs used and considered in the fish feed formulation; most of them are quickly found in Peruvian territory. It is showed that there is a considerable decrease in feed costs while using the feed formulation model and your own food than buying it from a seller or company.

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