



A feed formulation model for Catla fish to optimize nutrients and cost of ingredients using a Linear Programming approach

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Summary

The primary focus of the study was to formulate a least cost feed mix for Catla fish using the Linear Programming (LP) technique from the standard feed mix, while maintaining different nutrient levels within the recommended range. The ten feed ingredients in the feed mix were rice bran, groundnut oil cake, soybean meal, fish meal, mustard oil cake, meat meal, spirulina, moringa (dry leaf), vitamin-mineral premix, and mustard oil. The five nutrients in the different feed mixtures were protein, crude fat, crude fibre, carbohydrates, and ash. Most nutrients in the feed mixture and the digestible energy for fish were within acceptable ranges. Early fingerlings of Catla were procured and fed different formulated feeds to experimental fishes as replicates in four experimental aquariums. The growth parameters, namely weight and length, were recorded at fortnightly intervals to assess the efficacy of the formulated feed. The results revealed significant increases in growth parameters for the LP feed formulations compared to the standard feed formulation. Type-1 showed the best growth parameters among the LP feed formulations, yielding the largest mean weight and length gain. The study provides a practical approach for developing low-cost and nutritionally balanced feed for Catla fish and can help farmers to achieve higher productivity with efficient utilization of locally available feed ingredients. This approach may also reduce feed costs and support sustainable aquaculture practices for commercialization of fish feed.

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Introduction

A branch of mathematics called linear programming (LP) works with modelling decision problems and then using mathematical methods to solve them. It has recently had a significant impact on studies in agriculture, animal husbandry, and livestock, and it is beneficial to fish farmers in identifying the components of fish feed that would increase fish productivity. In the designing of fish feed, several components are blended to give fish the nutrients they require at various stages of development. How we feed the fish during culture determines the weight of marketable fish, and this problem turns out to be an optimization problem that depends on elements like the least amount of time and resources spent. To produce, maintain, reproduce, and grow healthy fish, a fish production system must provide adequate nutrition. The ideal growth, health, and lifespan of fish are determined by their proper, nutrient-rich diet.

Feed formulation is the process of combining various substances to provide animals with the nutrients they require at various stages of production. A diet should provide all the nutrients and energy needed to support an animal's key physiological processes for growth, reproduction, and health. Animal diet formulation can be done using a variety of techniques, including the

square approach, the two-by-two matrix method, the simultaneous equation method, the trial-and-error method, and the Linear Programming (LP) method. The feed formulation model looks for the best possible mix of feed ingredients that will meet the animal's nutritional needs at the lowest cost. The model must adhere to nutrient levels, availability and market prices of feed materials and financial restraints for each type of feed. A linear programming mathematical model of the feed formulation problem is created after defining the choice variables, objective function, and problem constraints.

Waugh (1951) established least-constrained by linear programming and minimising the cost of dairy feeds. His efforts resulted in rations incorporating oil seeds, whole grains, and a 24 percent protein mix using four equations and 14 feeds (variables). Christensen and Mighell (1951) reduced the cost of hog rations by 15 % using soybean oil meal instead of corn to balance protein. The linear programming technique was used to illustrate that soybean oil meal is a lower-cost source of protein than corn. Bath et al. (1968) concluded that feed costs may be reduced by using least-cost concentrated mixes for dairy cows while maintaining optimal milk production. Law et al. (1993) applied linear programming for least-cost feed formulation using locally available feed ingredients. Rahman et al. (2010) investigated feed mix approaches used by nutritionists, researchers and an enhanced algorithm was developed in order to deal with the development of the aquaculture industry. Saxena (2011) compared

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different mathematical programming techniques used for animal diets. A mathematical method based on optimization technique was developed for optimal use of nutrient ingredients to measure animal performance in terms of milk yield and weight gain. Ghosh et al (2011) formulated the nutritionally balanced feeds for fry of commonly cultured fishes in India based on their published nutritional requirements at the least possible cost, considering market prices at three different places in the country. Nath and Talukdar (2014) employed the LP technique in fish feed formulation to improve Assam's fish sector and alleviate poverty, as fish is the primary or secondary source of income for the communities. The goal of the paper is to create a low-cost optimised fish feed composition that meets the nutrient requirements of juvenile and adult *Mystus nemurus* sp. catfish utilising L P. Abbas et al. (2014) evaluated the effects of organic and inorganic fertilizers, applied alone and in combination with supplementary feed, on fish growth in earthen ponds over a full growth period. Results showed that organic manure performed better than inorganic fertilizers, but maximum fish yield was achieved only when supplementary feed was provided. Palani et al. (2019) studied linear encoding problem on price minimization on fish feeds to reduce the cost of production of fish feeds. The LP problem was formulated to evaluate the data, and the optimum solution was obtained at the 2nd iteration with fingerling feeds to be 1.2 of tons and grower's feeds to be 0.8 tons and the least cost of producing the tones of fingerlings and growers was ₹93,358. Zailani et al. (2019) reviewed distinctive methods used in operations research to address different diet issues. In the study, an optimal and practical solution was suggested to solve the diet problem. Chetna et al. (2022) developed the LP model to minimize the cost of fish feed mix without sacrificing the nutrient levels. They showed that a variety of elements can be combined much more effectively than in commercially available feed. The combinations lead to significantly reduced costs while raising nutrient intake, which might be quite advantageous to neighbouring fish farmers. Rahman et al (2022) investigated the comparative effects of commercial fish feed (CFF) and formulated fish feed (FFF) on pond water quality, growth performance, meat quality, survival rate, and antioxidant properties of fish. They concluded that the formulated fish feed (FFF) significantly improved water quality, growth performance, feed efficiency, and meat quality of Catla fish compared to commercial feed. Alwaddood et al. (2022) modified a linear programming model and proposed the most optimum amount of nutrients in *P. hypophthalmus* feed formulation at each life cycle at minimum production cost, based on the solution of the modified model. It was found that the inclusion of cinnamon leaf powder increased feed costs but also offered potential growth benefits, supporting its use as a functional supplement.

The study focuses on optimising the feed mix for Catla fish using the Linear Programming (LP) technique,

based on a standard feed formulation, while ensuring nutrient levels remain within recommended ranges. Ten feed ingredients—rice bran, groundnut oil cake, soybean meal, fish meal, mustard oil cake, meat meal, spirulina, moringa (dry leaf), vitamin–mineral premix, and mustard oil—are included in the formulation. The nutritional composition of the feed mixtures is evaluated in terms of five key nutrients: protein, crude fat, crude fibre, carbohydrates, and ash.

Materials and Methods

LP models were developed to construct nutritionally balanced feeds for fingerling and growers of Catla fish based on their minimal nutritional requirements at the lowest possible price. The developed model met a number of nutritional requirements, availability restrictions, and ingredient requirements.

A linear programming model with “n” decision variables and “m” constraints for the feed mix problem is as follows:

Let

i = Feed nutrient components with

$i = 1, 2, \dots$,

j = Feed ingredients with $j = 1, 2, \dots$,

x_j = Quantity of feed ingredient j in the feed mixture

c_j = Unit cost of feed ingredient j

N = Total quantity (kg) of feed to be produced

Z = Total cost of feed ingredients used to formulate fish feed.

a_{ij} = Amount of nutrient i available in feed ingredient j .

b_j = Dietary requirement of nutrient i for a fish category

The formulation can be done mathematically as a linear programming problem. The objective of the specified model is, $Min\ z = \sum_{j=1}^n c_j x_j$

Subject to:

$\sum_{j=1}^n x_j = N$ (Demand Requirement)

$\sum_{j=1}^n a_{ij} x_j \geq b_j$ (Min Requirement)

$\sum_{j=1}^n a_{ij} x_j \leq b_j$ (Max Requirement)

$\sum_{j=1}^n a_{ij} x_j = b_j$ (Restricted constraints)

With the aim of reducing the cost of feed mix, a linear programming model was developed utilizing the average market prices of ten feed ingredients given above that were restricted in the study. Here, the feed plan shouldn't be regarded as an ideal one, but rather as a means of achieving an economical, nutritionally adequate feed plan for fingerlings and growers of Catla fish with limited dietary needs. The decision variables $x_1, x_2, x_3, x_4, x_5, x_6$ of LP model be quantities of different feed ingredients in the LP model are as follows:

- x_1 = Rice bran
- x_2 = Groundnut oil cake
- x_3 = Soybean meal
- x_4 = Fish meal / Meat meal / Mustard oil cake
- x_5 = Mustard oil
- x_6 = Vitamin-mineral premix / Spirulina / Moringa (dry leaf)

Objective Function (Minimize Cost):

$$Min\ z = 14x_1 + 32.5x_2 + 25x_3 + (40\text{ or }30\text{ or }27)x_4 + 150x_5 + (70\text{ or }300\text{ or }90)x_6$$

Constraints:

1. Protein requirement:

$$30 \leq 0.121x_1 + 0.302x_2 + 0.241x_3 \\ + (0.6485 \text{ or } 0.544 \text{ or } 0.363)x_4 \\ + (0 \text{ or } 0.505 \text{ or } 0.294)x_6 \leq 40$$

2. Crude fat requirement:

$$8 \leq 0.118x_1 + 0.090x_2 + 0.100x_3 \\ + (0.065 \text{ or } 0.048 \text{ or } 0.089)x_4 + 1x_5 \\ + (0 \text{ or } 0.010 \text{ or } 0.052)x_6 \leq 10$$

3. Crude fibre requirement:

$$6 \leq 0.123x_1 + 0.230x_2 + 0.112x_3 \\ + (0.009 \text{ or } 0.074 \text{ or } 0.081)x_4 \\ + (0 \text{ or } 0.021 \text{ or } 0.125)x_6 \leq 10$$

4. Carbohydrate requirement:

$$22 \leq 0.407x_1 + 0.196x_2 + 0.399x_3 \\ + (0.0175 \text{ or } 0.125 \text{ or } 0.290)x_4 \\ + (0 \text{ or } 0.267 \text{ or } 0.3745)x_6 \leq 30$$

5. Ash requirement:

$$8 \leq 0.131x_1 + 0.086x_2 + 0.052x_3 \\ + (0.018 \text{ or } 0.134 \text{ or } 0.082)x_4 \\ + (0.380 \text{ or } 0.110 \text{ or } 0.0805)x_6 \leq 12$$

6. Mass balance constraint:

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 100$$

7. Non-negativity restriction:

$$x_1, x_2, x_3, x_4, x_5, x_6 \geq 0$$

Result and Discussion

Nutritional proximate composition (%) of 10 feed ingredients was collected from different sources (such as www.fao.org) and is given in Table 1. The 10 feed ingredients in feed mix were rice-bran, groundnut oil cake, soyabean meal, fish meal, mustard oil cake, meat meal, spirulina, moringa (dry leaf), vitamin mineral premix, and mustard oil. 5 nutrients in the different feed mix were protein, crude fat, crude fiber, carbohydrates and ash.

Table 1. Nutritional proximate composition (%) of different feed ingredients

S. No.	Ingredients	Protein (%)	Crude Fat (%)	Crude Fiber (%)	Carbohydrates (%)	Ash (%)
1	Rice-bran	12.1	11.8	12.3	40.7	13.1
2	Groundnut oil cake	30.2	9	23	19.6	8.6
3	Soybean meal	24.1	10	11.2	39.9	5.2
4	Fish meal	64.85	6.5	0.9	1.75	18
5	Mustard oil cake	36.3	8.9	8.1	29	8.2
6	Meat meal	54.4	4.8	7.4	12.5	13.4
7	Spirulina	50.5	1	2.1	26.7	11
8	Moringa (Dry leaf)	29.4	5.2	12.5	37.45	8.05
9	Vitamin-mineral premix	-	-	-	-	38
10	Mustard oil	-	100	-	-	-

Data regarding three different compositions (%) of feed ingredients, along with the price used for the laboratory experiment, were obtained from the collaborator, Dept. of Zoology, CCS HAU, Hisar. Using the LINGO software, three feed mixes (type-1 to 3) for Catla fish were formulated at the least cost using Linear Programming (LP) technique from the standard feed mix, maintaining different nutrient levels within the recommended range, shown in Table 2. These feed formulations were considered under both standard and LP-based approaches, along with their average production cost per 100 kg feed. In LP Feed Type-1, higher inclusion of soybean meal (27.41%) and fish meal (25.84%) was observed, indicating the optimization model selected protein-rich ingredients to satisfy protein constraints

efficiently. In LP Feed Type-2, meat meal (48.58%) became the major protein source, replacing expensive fish meal and reducing overall cost. Similarly, LP Feed Type-3 showed a very high inclusion of mustard DOC (75.92%), suggesting its suitability as an economical protein supplement in the optimization process. The average feed cost per 100 kg under LP formulations was lower than or comparable to the standard feed mixes. The standard feed costs ranged from ₹2614.25 to ₹3107.50 per 100 kg, whereas LP feed costs ranged from ₹2566.02 to ₹2639.00 per 100 kg. The lowest cost was observed in LP Feed Type-1 (₹2566.02/100 kg), demonstrating the effectiveness of linear programming in minimizing feed cost through optimal ingredient allocation.

Table 2. Composition (%) of ingredients in different feed mix and average cost per 100kg feed mix

Ingredients	Composition (%) of ingredient in different feed mix						Avg cost/kg
	Standard Feed mix			LP Feed mix			
	Type-1	Type-2	Type-3	Type-1	Type-2	Type-3	
Rice-bran	35	30	26	35.76	33.98	13.37	14
Groundnut DOC	25	28	30	10.00	2.80	8.51	32.5
Soybean meal	25	20	7	27.41	14.00	2.00	25
Fish meal	9	-	-	25.84	-	-	40
Mustard oil	5	-	-	0.00	-	-	150
Vitamin-mineral premix	1	-	-	1.00	-	-	70
Meat meal	-	20	-	-	48.58	-	30

Spirulina	-	2	-	-	0.64	-	300
Mustard DOC	-	-	35	-	-	75.92	27
Moringa	-	-	2	-	-	0.20	90
Avg cost/100kg	3107.50	2614.25	3030	2566.02	2639.00	2581.53	-

Table 3 presents the nutrient composition of standard feed mixes and Linear Programming (LP)-based feed mixes for Catla fish, compared with the recommended nutrient requirements (Ayyappan 2011). In the standard feed mixes, protein contents were comparatively lower, ranging from 23.65% to 28.80%, which indicates that these formulations may not adequately support optimum fish growth. In contrast, all LP-based feed mixes satisfied the recommended protein requirement, with protein levels ranging from 30.71% to 35.08%. Crude fat levels in all LP feed mixes varying from 8.00% to 9.54%. Although Standard Type-1 contained a comparatively high crude fat content (14.47%), this may adversely affect feed utilization and fish health. The LP approach effectively controlled fat levels by balancing lipid-containing ingredients during optimization. However, all standard feed mixes exceeded this limit, with fiber contents between 12.94% and 13.97%, which could reduce digestibility and feed

efficiency. The LP-based formulations successfully restricted crude fiber to exactly 10%, thereby improving the nutritional suitability and digestibility of the feed. Carbohydrate and ash contents in both standard and LP feed mixes were generally maintained within or close to the recommended. The LP formulations showed balanced carbohydrate levels ranging from 26.21% to 30.00%, indicating adequate energy supply through carbohydrate-rich ingredients such as rice bran and also maintained ash content efficiently without excessive mineral accumulation, thereby ensuring the nutritional suitability of the formulated feeds. The LP model's suggested feed mix includes enough energy for fish as well and also demonstrates that digestible energy calculated using the LP model also falls within the desired range. Digestible energy was calculated by using the following formula:

$$\text{Digestible energy (Kcal/kg)} = [(\text{Protein} + \text{Carbohydrate}) * 4 + \text{Crude Fat} * 9] * 10$$

Table 3. Nutritional composition (%) in standard feed mix and LP suggested feed mix

Nutrients (%)	Range of required nutrients	Standard Feed mix			LP Feed mix		
		Type-1	Type-2	Type-3	Type-1	Type-2	Type-3
Protein	30-40	23.65	28.80	27.19	30.71	35.08	32.29
Crude Fat	8-10	14.47	9.04	9.69	9.54	8.00	9.31
Crude Fiber	6-10	12.94	13.89	13.97	10.00	10.00	10.00
Carbohydrates	22-30	29.28	28.71	30.15	27.90	26.21	30.00
Ash	8-12	10.04	10.28	9.38	12.00	12.00	8.83
Digestible Energy (Kcal/kg)	2700-4000	3418.81	3113.92	3165.43	3202.82	3171.60	3329.46

Overall, the results clearly indicate that the LP-based feed formulations were nutritionally superior to the standard feed mixes. The LP technique successfully optimized ingredient proportions to achieve balanced protein, fat, fiber, carbohydrate, mineral content, and digestible energy within the recommended limits,

thereby enhancing the suitability of feed for sustainable and cost-effective aquaculture production. Figures 1, 2 and 3 show the graphical presentation of nutrient composition (%) in the standard feed mix and the LP-suggested feed mix.

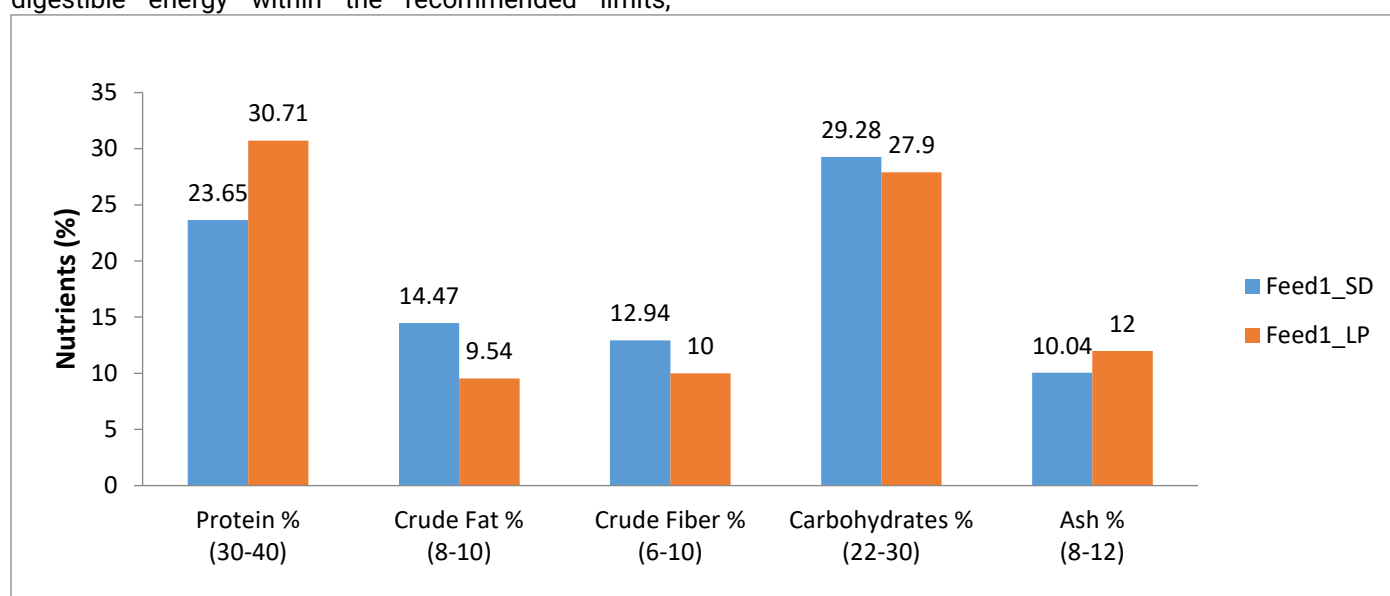


Figure 1. Comparative performance of nutrients composition (%) in feed 1 mix

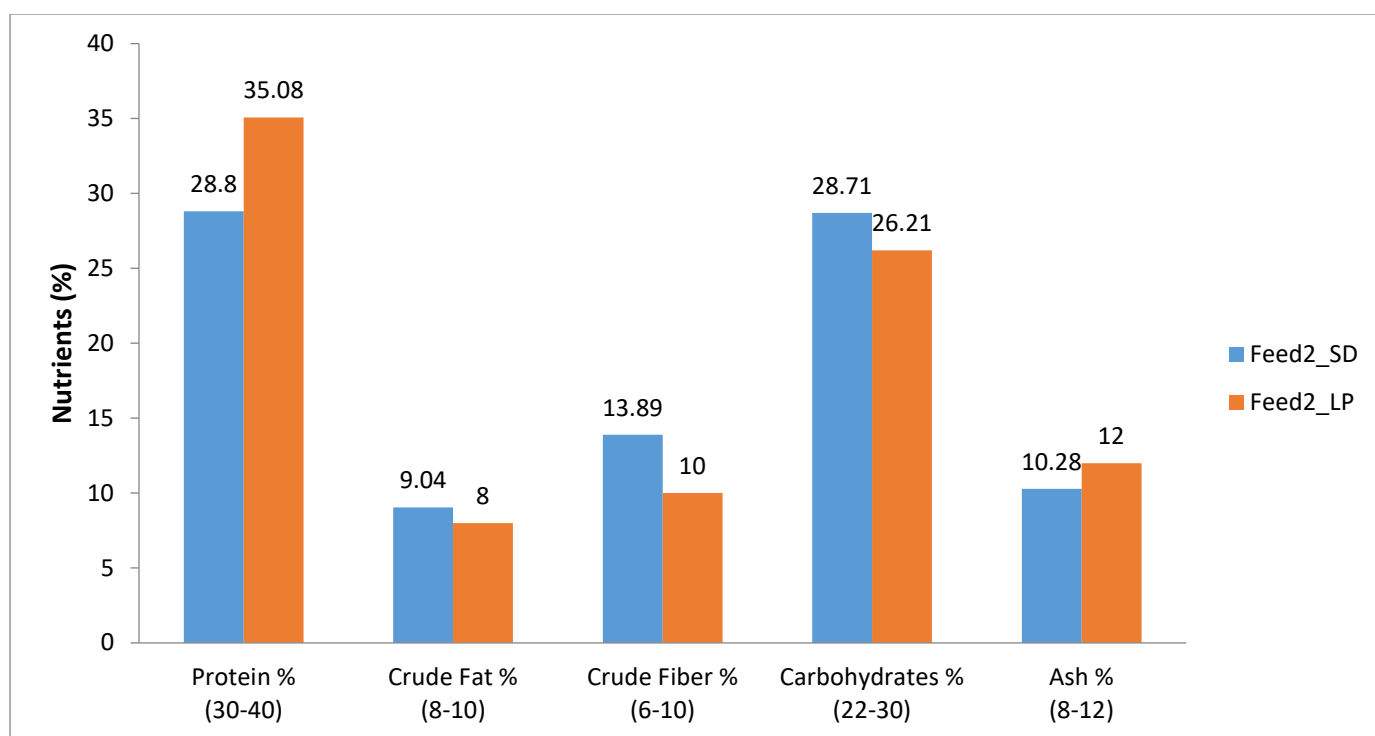


Figure 2. Comparative performance of nutrients composition (%) in feed 2 mix

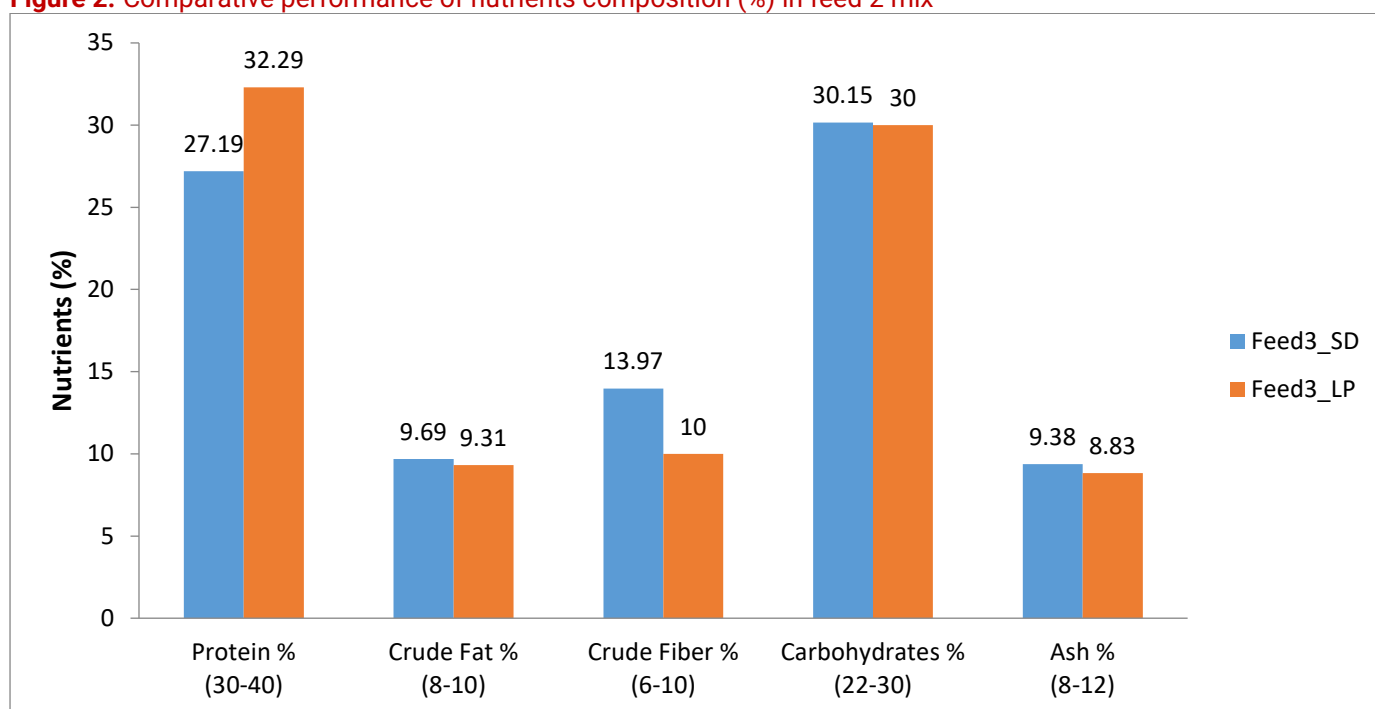


Figure 3. Comparative performance of nutrients composition (%) in feed 3 mix

The experiment was conducted by the collaborator at Screen house, Department of Zoology, CCS HAU, Hisar, for the validation of proposed feed(s). The early fingerlings of Catla were procured from a local fish farmer and acclimatized for the experiment. The four experimental aquariums were set up for each feed mix, and different formulated feeds were fed to the

experimental fish. The growth parameters, namely weight and length, were recorded at fortnightly intervals to assess the efficacy of the formulated feed. The obtained data were analysed through the GRAPES software. Experimental animal and setup are shown in plate 1 and plate 2, respectively.

**Plate 1: Experimental animal****Plate 2: Experimental setup**

The effect of standard and LP feed formulation (type-1 to 3) on growth parameters (weight and length) of Catla fish was shown in Table 4 (a)-(c) and Table 5 (a)-(c), respectively. The maximum mean weight of fish (6.47 and 7.77 gm) was observed by feeding standard and LP feed mix(type-1), respectively on the 60th day of

experiment. Significant weight increase of Catla fish was found for both factors A (feed formulation methods) & B (days intervals) in LP feed formulation in comparison to standard feed formulation of fish, and critical difference (0.11 and 0.18) was obtained for factor A & B, respectively (Table4 (a)).

Table 4 (a). Effect of standard and LP feed formulation(type-1) on weight gain of Catla fish

Days	Mean weight gain(gm)		Mean (Factor B)
	Standard formulation	LP formulation	
0	3.04	3.04	3.04 ^e
15	3.73	3.94	3.84 ^d
30	4.53	4.90	4.72 ^c
45	5.27	5.97	5.62 ^b
60	6.47	7.77	7.12 ^a
Mean (Factor A)	4.61 ^b	5.12 ^a	
CD (Factor A)		0.11	
CD (Factor B)		0.18	
CD (AxB)		0.25	

CD at 5% level of significance

The maximum mean weight of fish (6.43 and 6.77 gm) was observed by feeding standard and LP feed mix (type-2), respectively, on the 60th day of the experiment. Significant weight increase of Catla fish was found for both factors A (feed formulation methods) & B (days

intervals) in LP feed formulation in comparison to the standard feed formulation of fish, and critical difference (0.09 and 0.15) was obtained for factor A & B, respectively (Table 4 (b)).

Table 4 (b). Effect of standard and LP feed formulation (type-2) on weight gain of Catla fish

Days	Mean weight gain (gm)		Mean (Factor B)
	Standard formulation	LP formulation	
0	3.05	3.05	3.05 ^e
15	3.58	3.67	3.62 ^d
30	4.20	4.40	4.30 ^c
45	5.23	5.60	5.42 ^b
60	6.43	6.77	6.60 ^a
Mean (Factor A)	4.50 ^b	4.70 ^a	
CD (Factor A)		0.09	
CD (Factor B)		0.15	
CD (AxB)		NA	

CD at 5% level of significance

The maximum mean weight of fish (6.30 and 7.10 gm) was observed by feeding standard and LP feed mix (type-3), respectively, on the 60th day of the experiment. Significant weight increase of Catla fish was found for both factors A (feed formulation

methods) & B (days intervals) in LP feed formulation in comparison to standard feed formulation of fish, and critical difference (0.06 and 0.10) was obtained for factor A & B, respectively (Table 4 (c)).

Table 4 (c): Effect of standard and LP feed formulation (type-3) on weight gain of Catla fish

Days	Mean weight gain (gm)		Mean (Factor B)
	Standard formulation	LP formulation	

0	3.04	3.05	3.05 ^e
15	3.53	3.73	3.63 ^d
30	4.17	4.57	4.37 ^c
45	5.10	5.37	5.23 ^b
60	6.30	7.10	6.70 ^a
Mean (Factor A)	4.43 ^b	4.76 ^a	
CD (Factor A)	0.06		
CD (Factor B)	0.10		
CD (AxB)	0.14		

CD at 5% level of significance

The maximum mean length of fish (6.63 and 7.53 cm) was observed by feeding standard and LP feed mix (type-1), respectively on the 60th day of the experiment. Significant length increase of Catla fish was found for both factors A (feed formulation methods) & B (days

intervals) in LP feed formulation in comparison to standard feed formulation of fish, and critical difference (0.19 and 0.14) was obtained for factor A & B, respectively (Table 5 (a)).

Table 5 (a). Effect of standard and LP feed formulation (type-1) on length gain of Catla fish

Days	Mean length gain (cm)		Mean (Factor B)
	Standard formulation	LP formulation	
0	3.47	3.50	3.48 ^e
15	4.50	4.67	4.58 ^d
30	5.47	6.00	5.73 ^c
45	6.17	6.50	6.33 ^b
60	6.63	7.53	7.08 ^a
Mean (Factor A)	5.25 ^b	5.64 ^a	
CD (Factor A)	0.09		
CD (Factor B)	0.14		
CD (AxB)	0.19		

CD at 5% level of significance

The maximum mean length of fish (6.50 and 6.53 cm) was observed by feeding standard and LP feed mix (type-2), respectively, on the 60th day of the experiment. Significant length increase of Catla fish was found for factor B (days intervals), no significant

increase was found for factor A (feed formulation methods) in LP feed formulation in comparison to standard feed formulation of fish, and a critical difference (0.12) was obtained for factor B (Table 5 (b)).

Table 5 (b). Effect of standard and LP feed formulation (type-2) on length gain of Catla fish

Days	Mean length gain (cm)		Mean (Factor B)
	Standard formulation	LP formulation	
0	3.53	3.47	3.50 ^e
15	4.33	4.47	4.40 ^d
30	5.47	5.67	5.57 ^c
45	6.13	6.20	6.17 ^b
60	6.50	6.53	6.52 ^a
Mean (Factor A)	5.19	5.27	
CD (Factor A)	NA		
CD (Factor B)	0.12		
CD (AxB)	NA		

CD at 5% level of significance

The maximum mean length of fish (6.47 and 6.73cm) was observed by feeding standard and LP feed mix (type-3), respectively, on the 60th day of the experiment. Significant length increase of Catla fish was found for both factors A (feed formulation

methods) & B (days intervals) in LP feed formulation in comparison to standard feed formulation of fish, and critical difference (0.11 and 0.17) was obtained for factor A & B, respectively (Table 5 (c)).

Table 5 (c). Effect of standard and LP feed formulation (type-3) on length gain of Catla fish

Days	Mean length gain (cm)		Mean (Factor B)
	Standard formulation	LP formulation	
0	3.43	3.50	3.47 ^e
15	4.37	4.43	4.40 ^d

30	5.37	5.63	5.50 ^c
45	5.97	6.23	6.10 ^b
60	6.47	6.73	6.60 ^a
Mean (Factor A)	5.12 ^b	5.31 ^a	
CD (Factor A)		0.11	
CD (Factor B)		0.17	
CD (AxB)		NA	

CD at 5% level of significance

Conclusions

The present study successfully formulated a least-cost feed mix for Catla fish using the Linear Programming (LP) technique in LINGO software, incorporating ten feed ingredients and balancing five key nutrients. The LP-based formulations ensured that all nutrients remained within the recommended ranges, whereas the standard feed mix exhibited deviations beyond acceptable limits. Importantly, the LP model also provided adequate digestible energy for fish growth. Experimental validation demonstrated that the LP feed formulation, particularly Type-1, resulted in the highest growth performance, recording a maximum mean weight of 7.70 g (Table 4a) and a maximum mean length of 7.53 cm. These values were significantly superior to those obtained from the standard feed and other LP formulations. Overall, the findings confirm that LP-based feed formulation Type-1 is the most effective in enhancing growth parameters of Catla fish, thereby highlighting the utility of linear programming as a reliable tool for optimizing aquaculture feed. This approach not only ensures nutritional adequacy but also offers potential economic benefits by reducing feed costs while promoting sustainable fish production.

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