Original Research Article

Modeling of Polyculture Fish Feed Using Mathematical Programming

ABSTRACT

In fish farming, feed accounts for the majority of production costs, driving up overall production costs. The adoption of a linear programming approach to minimize the cost of fish feed without sacrificing the nutrients levelis significantly better than inefficient techniques like the trial and error method in terms of cost production and hence in profit. The difficulty in selecting the nutrients has a significant impact on how little money is needed to meet daily nutritional requirements. In the current work, a mathematical model for optimizing fish feed for polyculture was developed, examined and a suitable least cost feed mixture using locally available ingredients for polyculture fish was suggested. The suggested model was solved with Microsoft Excel to make it more user-friendly.

Keywords: Fish farming, Optimum model, Linear programming, Simplex method, Sensitivity analysis

1. INTRODUCTION

Fisheries is one of the prime sectors which have major contribution in economic and social development of India. Fresh water fish farming plays an important role in outdoor swap in numerous countries including India. It's known for its versatility of providing food, nutritional, ecological safety & securities and employment. Increasing production and relatively lower initial investment motivates entrepreneurs and small scale farmers to adopt fisheries as a profession. The production of two or more fish species in a specific aquaculture habitat is known as Polyculture. In India, Haryana comes 2nd in the average annual fish production. The average annual fish production in the state is 7000 kg per hectare beside a national average of 2900 kg per hectare. The state has also gained self-reliance in seed production of Indian Major Crop and Common Crop (https:\\harfish.gov.in). The major assertion of the Fisheries department of Haryana is to bring all available water bodies under fish culture by creating a class of fish farmers through hands on training and providing essential financial and technical assistance (https:\\harfish.gov.in).

It is well known that the financial resources available with any farmer are scarce and the same is the case of fish farmers. Porchelvi *et al.* (2018) has reported that in the fish farming, farmer has the maximum expenditure on cost of production.

Feed formulation is the process of combining various substances to give animals 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 a 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.

Waughand Frederick [1] (1951) established least-costrationd 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 [2] (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.

Fisher *et al*. [3] (1953) applied linear programming techniques to adjust layer and hog rations as the price of cottonseed meal fluctuated. Analyzing four different price situations, they indicated that alfalfa meal (15 percent crude protein) would replace cottonseed meal (41 percent crude protein) as the price of cotton seed meal reaches its point of critical difference.

Bath *et al.* [4] (1968) concluded that feed cost may be reduced by least-cost concentrated mixes for dairy cows while maintaining optimum milk production.

Law *et al.* [5] (1993) applied linear programming for least–cost feed formulation using locally available feed ingredients

Rahman *et al*. [6] (2010) investigated feed mix approaches used by nutritionists, researchers and an enhanced algorithm was developed in order to deal with the development of aquaculture industry.

Saxena [7] (2011) compared different mathematical programming techniques used for animal diets. A mathematical method based on optimization technique was developed for optimal use of nutrient ingredient to measure animal performance in terms of milk yield and weight gain.

According to Jayasankar [8] (2014) small and marginal farmers with customary mind-set and confined resources are reluctant to adopt supplemental feeding techniques. However, supplemental feeding of cultured fish is adopted by West Bengal. Feed cost can be significantly confined by restoring to feeds made from locally available ingredients. Production-demand ratio of feed concentrate is 44:143, prompt deficiency of 69%.

Nath and Talukdar [9] (2014) used the LP technique in fish feed formulation as an effort to improve Assam's fish industry and lessen poverty, since fish is the primary or secondary income for the communities.

Palani *et al.* [10] (2019) studied linear encoding problem on price minimization on fish feeds to reduce the cost of production of fish feeds. LP problem was formulated to evaluate the data and the optimum solution was obtained at 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.* [11] (2019) reviewed distinctive methods used in operation research to know different diet issues. In the study an optimal and practical solution was suggested to solve diet problem.

In this paper the linear programming is used to formulate fish feed models based on farmers information. Also the LP model has been developed using information of dietary requirement based on literature and locally available ingredients. The two approaches were compared as the study was planned to make a bridge between scientific investigation and fish farmers for understanding and optimizing sources so that the feed cost can be reduced. Alternate plans of fish feed for fry, fingerling and grower fulfilling minimal nutrition requirement and made with locally available ingredients will generate more options of feed mixtures for polyculture fish farming.

2. Material and Methods

The data about the nutrient requirements of fry, fingerling and grower stage of fish (rohu, catla, migil) and nutrient composition of feed ingredients were obtained from the literature and schedule-structured interviews of farmers from seven different location of Hisar district, viz Dabra, PaniharChak, Rajli, Shamsukh, Sundawas, Shahpur villages and Blue Bird Lake, Hisar. The prices of ingredients were obtained from local market.

Mathematical formulation of the model:

The linear programming model used for feed formulation is of the following form:

Objective function: Minimize Z = $\sum_{j=1}^{n} c_j x_j$

Subject to the Constraints:

$\sum_{j=1}^{n} x_j$ = N (Total quantity of feed composition)
$\sum_{j=1}^{n} a_{ij} x_j \geq b_i$ (Minimum requirement)
$\sum_{j=1}^{n} a_{ij} x_j \leq b_i$ (Maximum requirement)
$\sum_{j=1}^{n} a_{ij} x_j = b_i$ (Restricted constraints)

where, Z = Total cost of feed ingredients used to formulate fish feed

b_i = Feed nutrients componenets with i = 1,2,….,m
x_j = Feed ingredient with j = 1,2,…,n
c_j = Unit cost of feed ingredient j

x_j = Quantity of feed ingredients j in the feed mixture
a_{ij}= Amount of nutrients i avaliable in feed ingredient j.
b_j= Requirement of nutrient i for a fish stage

There is no single feed ingredient that can provide all the nutrients required for optimal growth of polyculture fish. Feed formulation for polyculture fish's life stages fry, fingerling and grower were attempted in this study. Fourteen ingredients were considered for feed formulation through linear programming. Let x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13} and x_{14} be the respective quantities in kg of mustard oilseed cake, rice bran, fish meal, wheat, soybean, pearl millet, maize, Meringa, jiggery, fish oil, vitamin, mineral premix, salt and di-calcium phosphate was considered for the mixture used in model formulation. Nutritional requirement of these stages of fish in terms of five nutrients mainly crude protein, crude fat, ash, carbohydrates and crude fiber were collected from [13] (www.fao.org) and used for the analysis. The information regarding the nutrient requirements of life stages (fry, fingerling and grower), the prices of ingredients, and nutrient composition of fish feed ingredients to be used in the mathematical model construction is listed in the tables below.

Table 1. Farmer's Fish feed ingredients and nutrition level (%)

Nutrients	Mustard oilseed Cake	Rice bran	Jaggery	Fish feed
Crude protein	30.12	12.20	0.40	32
Crude fat	8.90	11.80	0.10	4
Ash	6.70	13.10	5	0
Carbohydrates	29	40.60	28.80	0
Crude fiber	5.90	12.30	10	4

Table 2. Nutritional Composition of different feed ingredients (column 1 to 14 values in %)

Sr. No.	Ingredients	Crude Protein	Crude Fat	Ash	Carbohydrates	Crude Fiber
1.	**Mustard oilseed cake(x_1)**	30.12	8.90	6.700	29	5.90
2.	**Rice bran(x_2)**	12.20	11.80	13.100	40.60	12.30
3.	**Fish meal(x_3)**	52	7.60	25.20	0	3.10
4.	**Wheat (x_4)**	11	1	2	9	12.15

5.	**Soybean (x_5)**	48	3.10	6.30	40	3
6.	**Pearl millet(x_6)**	11.20	4.30	10.40	80	2.80
7.	**Maize (x_7)**	10.40	15	10.00	21	24
8.	**Maringa(x_8)**	30.20	2.220	8.05	63.20	7.20
9.	**Jaggery(x_9)**	0.40	0.10	0.50	28.80	10
10.	**Fish oil(x_{10})**	0	100	0	40	0
11.	**Vitamin(x_{11})**	13.50	3.90	5.30	60	3
12.	**Mineral premix(x_{12})**	5	0.50	38	30	4
13.	**Salt(NaCl) (x_{13})**	0	50	90	0	0
14.	**Di-calcium phosphate(x_{14})**	0	0	95	5	0

Table 3. Market prices of Ingredients [₹/kg]

Sr. No.	Ingredients	Cost/kg
1.	**Mustard oilseed cake(x_1)**	23
2.	**Rice bran(x_2)**	12
3.	**Fish meal(x_3)**	27
4.	**Wheat(x_4)**	19
5.	**Soybean (x_5)**	40
6.	**Pearl millet(x_6)**	16
7.	**Maize(x_7)**	13
8.	**Maringa(x_8)**	35
9.	**Jaggery(x_9)**	35
10.	**Fish oil(x_{10})**	120
11.	**Vitamin(x_{11})**	350
12.	**Mineral premix(x_{12})**	300
13.	**Salt(NaCl) (x_{13})**	24
14.	**Di-calcium phosphate(x_{14})**	32

2.1 Sensitivity Analysis

In LP models objective coefficients and the constraints are the input or parameters of the model. The optimal solution is obtained by the values of the coefficients and coefficients are selected from the sample data. The sensitivity analysis help us to know about how "sensitive" optimal solution is change in data values. It also measures how optimal solution affected by the changes in the input coefficients. There are two types of sensitivity analysis: first due to changes in the objective function coefficients and secondly changes in the available resources or R.H.S. value of constraints.

2.1.1 The linear programming model construction for farmer's plan can be written as:

Model A

Objective Function:

Minimize $Z = 23x_1 + 12x_2 + 35x_3 + 82x_4$

Subject to constraints:

(Minimum Nutrition Requirements)

$0.3012x_1+0.122x_2+0.004x_3+0.32x_4 \geq 25$; (Crude Protein)

$0.089x_1+0.118x_2+0.001x_3+0.04x_4 \geq 3.5$; (Crude fat)

$0.29x_1 + 0.406x_2 + 0.288x_3 \geq 24$;(Carbohydrates)

(Maximum Nutrition Requirements)

$0.067x_1 + 0.131x_2 + 0.05x_3 \leq 7$; (Ash)

$0.059x_1 + 0.123x_2 + 0.1x_3+0.04x_4 \leq 12$; (Crude fiber)

(Ingredients Quantity Constraints)

$20 \leq x_1 \leq 25$, $x_2 \geq 25$, $x_3 \leq 6$, $x_4 \geq 30$

$x_1 + x_2 + x_3 + x_4 \geq 100$

$x_1, x_2, x_3, x_4 \geq 0$ (Non-Negativity Constraints)

2.1.2 The linear programming model construction for fry stage can be written as:

Model B

Objective Function:

Minimize $Z = 23x_1 + 12x_2 + 27x_3 + 19x_4 + 40x_5 + 16x_6 + 13x_7 + 35x_8 + 35x_9 + 120x_{10} + 350x_{11} + 300x_{12} + 24x_{13} + 32x_{14}$

Subject to constraints:

(Minimum Nutrition Requirements)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.005x_{12}+0.5x_{13}\geq 4$;(Crude fat)

$0.29x_1 + 0.406x_2 +0.09x_4+ 0.4x_5+0.8x_6+0.21x_7+0.632x_8+0.288x_9+0.4x_{10}+0.6x_{11}+0.3x_{12}+0.05x_{14}\geq 27$;(Carbohydrates)

(Maximum Nutrition Requirements)

$0.3012x_1+0.122x_2+0.52x_3+0.11x_4+0.48x_5+0.112x_6+0.104x_7+0.302x_8+0.004x_9+0.135x_{11}+0.05x_{12}\leq 40$;(Crude Protein)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.005x_{12}+0.5x_{13}\leq 8$;(Crude fat)

$0.067x_1+0.131x_2+0.252x_3+0.02x_4+0.063x_5+0.104x_6+0.1x_7+0.805x_8+0.05x_9+0.053x_{11}+0.38x_{12}$ $0.9x_{13}+0.95x_{14}\leq 7$;(Ash)

$0.059x_1+0.123x_2+0.031x_3+0.1215x_4+0.03x_5+0.028x_6+0.24x_7+0.72x_8+0.1x_9+0.03x_{11}+0.04x_{12}\leq 12$;(Crude fiber)

(Ingredients Quantity Constraints)

$x_1\leq 20$, $x_2\geq 5$, $x_4\leq 5$, $x_8=0.02$, $x_9=3$;

$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9+x_{10}+x_{11}+x_{12}+x_{13}+x_{14}=100$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}\geq 0$(Non-Negative Constraints)

2.1.3 The linear programming model construction for fingerling stage can be written as:

Model C

Objective Function:

Minimize $Z = 23x_1 + 12x_2 + 27x_3 + 19x_4 + 40x_5 + 16x_6 + 13x_7 + 35x_8 + 35x_9 + 120x_{10} + 350x_{11} + 300x_{12} + 24x_{13} + 32x_{14}$

Subject to Constraints:

(Minimum Nutrition Requirements)

$0.3012x_1+0.122x_2+0.52x_3+0.11x_4+0.48x_5+0.112x_6+0.104x_7+0.302x_8+0.004x_9+0.135x_{11}+0.05x_{12}\geq 33$;(Crude Protein)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.005x_{12}+0.5x_{13}\geq 5$;(Crude fat)

$0.29x_1 + 0.406x_2 +0.09x_4+ 0.4x_5+0.8x_6+0.21x_7+0.632x_8+0.288x_9+0.4x_{10}+0.6x_{11}+0.3x_{12}+0.05x_{14}\geq 32$;(Carbohydrates)

(Maximum Nutrition Requirements)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.005x_{12}+0.5x_{13}\leq 15$;(Crude fat)

$0.067x_1+0.131x_2+0.252x_3+0.02x_4+0.063x_5+0.104x_6+0.1x_7+0.805x_8+0.05x_9+0.053x_{11}+0.38x_{12}$ $0.9x_{13}+0.95x_{14}\leq 12$;(Ash)

$0.059x_1+0.123x_2+0.031x_3+0.1215x_4+0.03x_5+0.028x_6+0.24x_7+0.72x_8+0.1x_9+0.03x_{11}+0.04x_{12}\leq 12$;

(Crude fiber)

(Ingredients Quantity Constraints)

$x_1\leq 20$, $x_7\geq 5$, $x_8=0.02$, $x_9=3$;

$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9+x_{10}+x_{11}+x_{12}+x_{13}+x_{14}\leq 100$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}\geq 0$; (Non-Negative Constraints)

2.1.4 The linear programming model construction for grower stage can be written as:

Model D

Objective Function:

Minimize $Z = 23x_1 + 12x_2 + 27x_3 + 19x_4 + 40x_5 + 16x_6 + 13x_7 + 35x_8 + 35x_9 + 125x_{10} + 350x_{11} + 300x_{12} + 24x_{13} + 32x_{14}$

Subject to Constraints:

(Minimum Nutrition Requirements)

$0.3012x_1+0.122x_2+0.52x_3+0.11x_4+0.48x_5+0.112x_6+0.104x_7+0.302x_8+0.004x_9+0.135x_{11}+0.05x_{12}\geq 25$;(Crude Protein)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.005x_{12}+0.5x_{13}\geq 3.5$;(Crude fat)

$0.067x_1+0.131x_2+0.252x_3+0.02x_4+0.063x_5+0.104x_6+0.1x_7+0.805x_8+0.05x_9+0.053x_{11}+0.38x_{12}+0.9x_{13}+0.95x_{14}\geq 8$;(Ash)

$0.29x_1+0.406x_2+0.09x_4+0.4x_5+0.8x_6+0.21x_7+0.632x_8+0.288x_9+0.4x_{10}+0.6x_{11}+0.3x_{12}+0.05x_{14}\geq 27$;

(Carbohydrates)

$0.059x_1+0.123x_2+0.031x_3+0.1215x_4+0.03x_5+0.028x_6+0.24x_7+0.72x_8+0.1x_9+0.03x_{11}+0.4x_{12}\geq 6$;

(Crude fiber)

(Maximum Nutrition Requirements)

$0.089x_1+0.118x_2+0.076x_3+0.01x_4+0.031x_5+0.043x_6+0.15x_7+0.222x_8+0.001x_9+x_{10}+0.039x_{11}+0.05x_{12}+0.5x_{13}\leq 16$;(Crude fat)

$0.067x_1+0.131x_2+0.252x_3+0.02x_4+0.063x_5+0.104x_6+0.1x_7+0.805x_8+0.05x_9+0.053x_{11}+0.38x_{12}+0.9x_{13}+0.95x_{14}\leq 19$;(Ash)

$0.059x_1+0.123x_2+0.031x_3+0.1215x_4+0.03x_5+0.028x_6+0.24x_7+0.72x_8+0.1x_9+0.03x_{11}+0.4x_{12}\leq 13$; (Crude fiber)

(Ingredients Quantity Constraints)

$x_1\geq 30$, $x_2\geq 10$, $x_3\leq 5$, $x_4\geq 5$, $x_5\geq 10$, $x_6\geq 5$, $x_7\geq 5$, $x_8=0.02$, $x_9=3$;

$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8+x_9+x_{10}+x_{11}+x_{12}+x_{13}+x_{14}\leq 100$

x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13},$x_{14}\geq 0$; (Non-Negative Constraints)

As can be seen, the mathematical models are given in a similar manner, except for the different parameters used for each stage. The decision variable x_j represents the different types of ingredients, where the coefficient c_j is the unit price of the ingredients.

3. RESULTS AND DISCUSSION

This section presents the results of the fish feed formulation using the LP model. Optimal results were obtained using Microsoft excel solver for farmer's pattern, fry, fingerling and grower stages. The tables below present details on the nutrient composition of the ingredients for farmer's plan, fry, fingerling and grower.

Table 4. LP model suggested quantity of ingredients in feed mix for farmer's plan

Ingredients	Cost(₹)	Quantity of ingredients (kg)	Percentage of ingredients in feed composition
Mustard oilseed cake(x_1)	23	25	23.55
Rice bran(x_2)	12	39.94	37.63
Jaggery(x_3)	35	1.85	1.74
Fish feed(x_4)	82	39.34	37.06
	Minimum Cost (106.13kg)	4345.19	

Table 5. LP model suggested quantity of ingredients in feed mix for fry

Ingredients	Cost(₹)	Quantity of ingredients(kg)
Mustard oilseed cake(x_1)	23	17
Rice bran(x_2)	12	5
Fish Meal(x_3)	27	3
Wheat (x_4)	19	5
Soybean (x_5)	40	67.16
Pearl Millet(x_6)	16	0
Maize (x_7)	13	0
Maringa(x_8)	35	0.02
Jaggery(x_9)	35	3
Fish oil(x_{10})	120	0
Vitamin(x_{11})	350	0
Mineral premix(x_{12})	300	0
Salt(NaCl) (x_{13})	24	0
Di-calcium phosphate(x_{14})	32	0

Table 6. Sensitivity analysis on objective function coefficients in LP model for fry

Name	Final Value	Obj. function	Max. Range	Min. Range
Mustard oilseed cake(x_1)	17	23	27.55	-
Rice bran(x_2)	5	12	-	0.65
Fish Meal(x_3)	2.81	27	43.80	-6.85
Wheat (x_4)	5	19	-	9.85
Soybean (x_5)	67.16	40	-	31.83
Pearl Millet(x_6)	0	16	-	2.11
Maize (x_7)	0	13	-	1.72
Maringa(x_8)	0.02	35	-	-
Jaggery(x_9)	3	35	-	-
Fish oil(x_{10})	0	120	-	0.88
Vitamin(x_{11})	0	350	-	8.76
Mineral premix(x_{12})	0	300	-	-28.08
Salt(NaCl) (x_{13})	0	24	-	-78.75
Di-calcium phosphate(x_{14})	0	32	-	-83.17

Table 7. Sensitivity Analysis of available resources in LP model for fry

Name	Final Value	Constraint R.H.S.	Max. R.H.S.	Min. R.H.S.	Shadow Price
Mustard oilseed cake	17	20	-	17	0
Jaggery	3	3	5.57	1.86	38.16
Maringa	0.02	0.02	0.74	0	77.22
Wheat	5	5	8.64	3.51	9.14
Rice bran	5	5	13.20	3.55	11.34
Crude fiber	4.64	12	-	4.64	0
Crude protein	40	40	41.43	39.46	93.09
Total quantity	100	100	101.15	97.21	0.88
Crude fat	4.45	4	4.45	-	0
Carbohydrates	35.15	27	35.15	-	0
Crude fat	4.45	8	-	4.45	0
Ash	7	7	9.54	6.46	-88.48

Table 8. LP model suggested quantity of ingredients in feed mix for fingerling

Ingredients	Cost(₹)	Quantity of ingredients(kg)
Mustard oilseed cake(x_1)	23	20
Rice bran(x_2)	12	14.91
Fish Meal(x_3)	27	21.37
Wheat (x_4)	19	0

Soyabean (x_5)	40	25.82
Pearl Millet(x_6)	16	9.85
Maize (x_7)	13	5
Moringa(x_8)	35	0.02
Jaggery(x_9)	35	3
Fish oil(x_{10})	120	0
Vitamin(x_{11})	350	0
Mineral premix(x_{12})	300	0
Salt(NaCl) (x_{13})	24	0
Di-calcium phosphate(x_{14})	32	0

Table 9. Sensitivity Analysis on objective function coefficients in LP model for fingerling

Name	Final Value	Obj. function	Max. Range	Min. Range
Mustard oilseed cake(x_1)	20	23	27.22	-
Rice bran(x_2)	14.91	12	12.81	7.80
Fish Meal(x_3)	21.37	27	38.27	23.84
Wheat (x_4)	0	19	-	16.42
Soyabean (x_5)	25.82	40	43.11	34.29
Pearl Millet(x_6)	9.85	16	24.14	14.42
Maize (x_7)	5	13	-	11.50
Moringa(x_8)	0.02	35	-	-
Jaggery(x_9)	3	35	-	-
Fish oil(x_{10})	0	120	-	12.79
Vitamin(x_{11})	0	350	-	19.50
Mineral premix(x_{12})	0	300	-	-10.26
Salt (NaCl) (x_{13})	0	24	-	-50.76

Table 10. Sensitivity Analysis of available resources in LP model for fingerling

Name	Final Value	Constraint R.H.S.	Max. R.H.S.	Min. R.H.S.	Shadow Price
Jaggery	3	3	9.57	0	26.11
Moringa	0.02	0.02	2.00	0	55.02
Maize	5	5	13.13	0	1.49
Mustard oilseed cake	20	20	34.80	0.99	-4.22
Total quantity	100	100	104.58	95.65	9.91
Crude protein	33	33	36.82	24.79	65.52
Crude fat	7.14	5	7.14	-	0
Crude fiber	6.24	12	-	6.24	0
Carbohydrates	32	32	36.941	28.69	7.19
Crude fat	7.14	15	-	7.14	0
Ash	12	12	14.68	10.34	-67.42

Table 11. LP model suggested the quantity of feed ingredients for grower

Ingredients	Cost(₹)	Quantity of ingredients(kg)
Mustard oilseed cake(x_1)	23	43.41
Rice bran(x_2)	12	23.56
Fish Meal(x_3)	27	5
Wheat (x_4)	19	5
Soyabean (x_5)	40	10
Pearl Millet(x_6)	16	5
Maize (x_7)	13	5
Moringa(x_8)	35	0.02
Jaggery(x_9)	35	3
Fish oil(x_{10})	120	0
Vitamin(x_{11})	350	0
Mineral premix(x_{12})	300	0
Salt(NaCl) (x_{13})	24	0
Di-calcium phosphate(x_{14})	32	0

Table 12. Sensitivity Analysis on objective function coefficients in LP model for grower

Name	Final Value	Obj. function	Max. Range	Min. Range
Mustard oilseed cake(x_1)	43.41	23	26.01	18.75
Rice bran(x_2)	23.56	12	13.91	5.96
Fish Meal(x_3)	5	27	36.43	-
Wheat (x_4)	5	19	-	11.26
Soyabean (x_5)	10	40	-	33.97
Pearl Millet(x_6)	5	16	-	11.38
Maize (x_7)	5	13	-	10.89
Moringa(x_8)	0.02	35	-	-
Jaggery(x_9)	3	35	-	-
Fish oil(x_{10})	0	120	-	4.51
Vitamin(x_{11})	0	350	-	12.79
Mineral premix(x_{12})	0	300	-	7.58
Salt(NaCl) (x_{13})	0	24	-	4.51
Di-calcium phosphate(x_{14})	0	32	-	4.51

Table 13. Sensitivity Analysis of available resources in LP model for grower

Name	Final Value	Constraint R.H.S.	Max. R.H.S.	Min. R.H.S.	Shadow Price
Crude fibre	8.17	13	-	8.17	0
Maize	5	5	17.32	0	2.10

Jaggery	3	3	11.17	0	30.24
Moringa	0.02	0.02	7.31	0	11.95
Mustard oilseed cake	43.41	30	43.41	-	0
Wheat	5	5	15.16	0	7.73
Rice bran	23.56	10	23.56	-	0
Fish meal	5	5	11.04	0.54	-9.43
Soybean	10	10	16.71	0	6.02
Pearl millet	5	5	17.84	0	4.61
Total quantity	100	100	119.70	93.28	4.51
Crude protein	25	25	27.43	22.59	61.38
Crude fat	8.35	3.5	8.35	-	0
Crude fat	8.356	16	-	8.357	0
Ash	9.171	19	-	9.172	0
Ash	9.171	8	9.171	-	0
Carbohydrates	32.534	27	32.534	-	0
Crude fiber	8.176	6	8.176	-	0

The result achieved through the developed models shows that the cost of the farmers feed plan was ₹4350.86 for 106.13 kg mixture with 39.94kg rice bran, 39.34kg commercially available feed/fish feed, 25kg mustard oilseed cake and 1.85kg jaggery The cost of 100 kg pack was calculated and it would be ₹ 4099.26. Also it was found that 67.16 kg soyabean, 17kg mustard oilseed cake, 5kg wheat, 5kg rice bran, 3kg fish meal, 3kg jaggery and 0.02kg moringa are required to formulate 100 kg of fish feed that satisfies the minimum nutrient contents requirements of fry at a total cost for raw material of ₹3411.74. For fingerling, 25.82kg soybean, 20kg mustard oilseed cake, 21.37kg fish meal,14.91kg rice bran, 9.85kg pearl millet, 3kg jaggery and 0.02kg moringa are required to formulate 100 kg of fish feed that satisfies the minimum nutrient contents requirements of fingerling of ₹2577.73.For grower, 43.41kg mustard oilseed cake ,23.56kg rice bran, 10.82kg soyabean, 5kg fish meal, 5kg wheat, 5kg pearl millet, 5kg maize, 3kg jaggery and 0.02kg moringa are required to formulate 100kg of fish feed that satisfies the minimum nutrient contents requirements of grower at a total cost for raw material of ₹2162.05. Sensitivity analysis of fry model shows that nutrients such as crude protein, ash, rice bran, wheat, moringa & jaggery were the binding constraints and mustard oilseed cake was non –binding. For fingerling model nutrients such as crude protein, ash, carbohydrates were binding and non–binding nutrients were crude fat, crude fiber. Moreover,

in the optimal solution, ingredients such as wheat, pearl millet, maize, moringa & jaggery were binding constraints and mustard oilseed cake, rice bran was non–binding. For grower the binding nutrient crude protein and non-binding nutrients were crude fat, ash, carbohydrates, crude fiber. Moreover, in the optimal solution, ingredients such as mustard oilseed cake, maize, moringa & jaggery were binding constraints.

4. CONCLUSION

Farmers always looks for alternatives of nutriotional adequate fish feed mixture. The model developed in this study showed a reduction in the cost of fish feed mixture as compared to commercial fish feed mixture. This contribute to reduction of the production cost of fish feed not only for farmers but also will increase the profit of fish feed manufacturers.

This research shows that if farmer used the result of fry model the minimum feed cost of mixture can be reduced up to 16.77% and if farmers will use the proposed plan for the fingerling stage, the reduction in expenditure would be 24.44%. Also if farmers will use the proposed plan for the grower stage the reduction in expenditure would be 16.12%. If the farmers use the recommendation of feed composition for fry which is maximum of all the three they can save at least ₹687.52/100kg feed composition. Three alternate feed plans were suggested for the polyculture fish (fry, fingerling & grower stage). The cost for farmer's plan was found the highest in comparison to the other three stage wise feed mix plan Sensitivity analysis of the developed models showed minimum and maximum range of ingredients for feed mix, where the optimal LP solution will remain unchanged within these range of values of the ingredients.

REFERENCE

1. Waugh, Frederick, V. (1951). The minimum-cost dairy feed. Journal of Farm Economics, Vol. 33: 299-310.
2. Christensen, R.P. and Mighell, R.L. (1951). Food production strategy and the protein-feed balance. Journal of Agriculture Economics, Vol. 33: 183-191.
3. Fisher, Walter D., and Schruben, L.W. (1953). Linear programming applied to feed-mixing under different price conditions. Journal of Farm Economics, Vol. 35: 471-483.
4. Bath, D. L., Bishop, S. E., Hutton, G. A., Jr., and Oliver, J. C. (1968). Computer-formulated least-cost concentrate mixes for dairy cows. Journal of Dairy Science, Vol. 51: 1616-1619.
5. Law, A.T., Poh, Y.T. and Ang, K.J. (1993). Least-Cost Feed Formulation for Juvenile Macro brachium rosen bergii (DeMan) by Using the Linear Programming Technique. Pertanika Journal Tropical Agriculture Science, Vol. 16(2):119-127.
6. Rahman, R.A., Ang, C.L., and Ramli, R. (2010). Investigation Feed Mix Problem Approaches: An Overview and Potential Solution. *World Academy of Sciences, Engineering and Technology*, Vol. 70: 467-475.
7. Saxena, P. (2011). Comparison of linear and non-linear programming techniques for animal diet. Applied Sciences, Vol. 1(2): 106-108.
8. Jayasankar, P. (2014). Recent advances in freshwater finfish aquaculture: Prospects and Constraints. In: Sinha,V.R.P. and Jayasankar, P. (Eds.), Aquaculture-New possibilities and constraints, Narendra Publishing House, New Delhi, India. 1-12.
9. Nath, T., and Talukdar, A. (2014). Linear Programming Technique in Fish Feed Formulation. International Journal of Engineering Trends and Technology (IJETT), Vol. 17(3): 132-135.
10. Palani R., Kannan, B., Ramar, M., and Balasu bramanian, S. (2019). Development of Linear Encoding Problem to Minimize Fish Feeds. Research Journal of Chemical and Environmental Sciences, Vol. 7(2): 22-26.
11. Zailani, N.A.M., Sufahani, S.F., and Mamat, M. (2019). Mathematical Research on Optimization Technique for diet Planning Problem: Case Research Autism Paralympic Athlete. *International Journal* of Recent Technology and Engineering (IJRTE), Vol. 8(2-3): 387-390.
12. Anonymous (2020). Fisheries Department, Haryana (https:\\harfish.gov.in.)
13. Anonymous (2020). Nutrients Requirement. (www.fao.org.)